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ORIGINAL ARTICLE

Effects of Supplemental Irrigation and Super absorbent polymer on yield and seed quality of Safflower (*Carthamus tinctorius* L.) under Dry-farming conditions

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ABSTRACT

The present investigation studied the effects of supplemental irrigation and application of Super Absorbent Polymer (SAP) on yield and seed quality of safflower. Supplemental irrigation was implemented at 4 levels including dry-farming; supplemental irrigation was implemented at late vegetative, flowering, and filling of seeds phases as main factors. Super absorbent polymer (SAP) at two levels (Control and 200kg/hectares) and 6 safflower varieties were used in winter cultivation in the factorial form as sub-factors. The results of this study showed that supplemental irrigation significantly increased seed yield, seed oil percentage, and total nitrogen content and reduced protein percentage and nitrogen harvest index. Supplemental irrigation increased seed yield 33% in the first year and 25% in the second year. The highest amount of seed oil was obtained from the supplemental irrigation treatment at the flowering stage, and seed filling with an average of 29% compared with dry farming had increased by about 11%. Dry farming had the highest percentages of protein in the first (17.79%) and second years (16.60%), respectively. With the use of supplemental irrigation and improvement in plant growth, particularly at critical growth stages, the share of seed nitrogen from total nitrogen content was reduced. The highest nitrogen harvest indices of the dry farming treatment were attained in the first and second years, averaging 70.54% and 57.80%, respectively. Cultivars showed various reactions to the ***experimentation****. Among the studied cultivars, Sina had the highest seed yield, oil yield, protein and total nitrogen content, but high percentages of oil and protein were obtained from other ones. The use of super absorbent polymer to hold more water, especially with the use of supplemental irrigation, has the positive effect of reducing drought stress and thereby increasing yield and seed quality.*
Key words: Safflower, Super absorbent polymer, Supplemental irrigation, Nitrogen harvest index, Oil content, Protein content.

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INTRODUCTION

Drought stress is a key limiting factor leading to lower crop yields, especially in the late growing season of winter crops because there is not enough precipitation during the spring months. Reddi and Reddi [59] indicated that, in many parts of the world, water is the major factor limiting crop production because water shortage affects several plant physiological processes [61]. Therefore, the availability of water improves most crops' yield [62]. Kar *et al.,* [34] reported that there was a need for irrigation of safflower in addition to winter and spring precipitations. Supplemental irrigation (SI) is defined as the application of a limited amount of water to the crop when rainfall fails to provide sufficient water for plant growth to increase and stabilize yields. The additional amount of water alone is inadequate for crop production [49]. Hence, the essential characteristic of SI is the supplemental nature of rainfall and irrigation. However, SI is usually practiced in the wetter part of the dry areas (300–600 mm annual rainfall). Supplemental irrigation is a temporal intervention, designed to influence when water is made available to augment natural evapotranspiration. It is irrelevant when daily rainfall is often adequate to support crop growth [19, 48]. This is because all field crops response differently in different phonological stages to changing water status of the soil under deficit irrigation, which means that plants are more sensitive to water deficit at one or more stages than at the other stages. For example, these sensitive stages are during flowering and boll formation stages in cotton, during vegetative growth of soybean, flowering and grain filling stages of wheat, vegetative and yielding stages of sunflower and sugar beet [35]. Available limited researches in around the world on safflower production under irrigated conditions revealed that it was a sensitive crop to water [58, 6, 7] and moderately tolerant to salinity. Kar *et al.,* [34] investigated the total water use efficiency of safflower in a study which also included other oil crops such as linseeds and mustard in Eastern India. Similarly, Lovelli *et al.,* [38] investigated yield response to water and water use efficiency of safflower (summer sowing only) under deficit irrigation treatments. Igbadun *et al.,* [28] showed that the crop yield response was very much dependent on the amount of water applied at different crop development stages than the overall seasonal water applied. For an increased crop production in dry-land environments, a greater percentage of the precipitation between crops must be stored in soil and the stored water and growing season precipitation must be used more efficiently. Super absorbent polymer may have great potential in restoration and reclamation of soil and storing water available for plant growth and production. Incorporation of polymer into soil has increased wheat dry weight [32]. Super absorbent polymer can hold 400-1500 g of water per dry gram of hydrogel [66, 9]. Due to the limited water resources in the world, it is essential to save and economize their use. All types of hydrogels when used correctly and in ideal situation will have at least 95% of their stored water available for plant absorption [33]. The super absorbent polymer used under water deficit stress conditions, with improved moisture conditions, increased sink capacity, and provided a longer growing period [64]. Safflower (*Carthamus tinctorius* L.) is a strongly tap rooted annual plant belonging to the Asteraceae family and is native to the Middle East. It is resistant to saline conditions [22], to water stress [8], and can reach the deep-lying water [65]. The deep-root system of safflower enables the plant to capture moisture and nutrients from the soil depths and tolerate heat and dry conditions when established [39]. In addition, the importance of oil seed crops such as safflower has increased in recent years, especially with the growing interest in the production of biofuels [16]. Safflower (*Carthamus tinctorious L.*) is a temperate zone plant grown in arid and semiarid regions of world [41]. Environmental conditions affect oil content and fatty acid compositions of safflower and other oilseed crops [30, 57]. Pasban Eslam [54] indicated that drought stress during seed filling stage in the spring safflower genotypes significantly decreased seed and oil yields in arid and semi-arid regions. Ensiye and Khorshid [20] reported that both oil content and the oil fatty acid composition showed significant differences in relation to the water regime, sowing date and genotype. This research aimed to identify variations occurring in oil, protein, and nitrogen contents in the safflower cultivars receiving supplemental irrigation at several growth stages.

MATERIALS AND METHODS

Study location

This experiment was conducted in western Iran during two farming years (2011-13) in a substation at the Lorestan Province Agricultural Studies and Natural Resources Research Center in the city of Khoramabad (longitude: 48°, 21´ E; latitude: 33°, 29´ N; altitude: 1171m). Mean precipitation rate is (440mm), mean annual temperature is 17.19°C, and annual evaporation rate is 1842.52mm (based on meteorological long-run statistics). The region has a semi-arid climate (according to Demarton and Anbrege's climatological coefficients). A control sample was prepared randomly and in zigzag form from 0-20 cm and 20-40 cm soil layers before cultivating the composed sample from farming soil, and its physical and chemical properties were measured (Table 2).

Table.1 : Temperature, relative humidity and precipitation values measured during safflower crop cycle in 2011-12, 2012-13 and long-term data.

Periods	Metrological events	November	December	January	February	March	April	May	June	July
		Months								
Long-term	Temperature (°C)	13.9	8.4	5.6	6.0	9.8	13.4	18.5	24.6	28.8
	Relative humidity (%)	52.1	62.2	64.8	63.1	54.4	55.8	49.6	29.0	23.9
	Precipitation (mm)	57.5	73.7	55.6	66.4	50.8	90.8	33.5	1.8	0
2011-2012	Temperature (°C)	8.1	4.8	3.8	5.6	8.7	15.4	22.5	28.5	30.8
	Relative humidity (%)	66	51	58.1	54.9	43.3	54.5	33.5	18.9	18
	Precipitation (mm)	65.9	0.6	11.4	53.1	13.4	100	11.5	0	0
2012-2013	Temperature (°C)	11.9	6.4	4.7	7.7	12.2	15.9	19.7	27	30.2
	Relative humidity (%)	63.3	67.9	61.1	58	49.3	46.4	49.2	21.6	18.8
	Precipitation (mm)	34.0	77.3	73	29.9	12	33.1	68.4	0	0

Table.2 : Soil chemical and some other important properties of the experimental soils.

years	Soil depth (cm)	Soil tex-ture	pH	$CaCO_3$ (%)	EC ($ds.m^{-1}$)	N (%)	Cu (ppm)	Fe (ppm)	K (ppm)	P (ppm)	Organic matter
2011	0-20	Clay-loam	7.48	3.1	0.65	0.12	1	5.4	300	18	0.9
	20-40		7.63	3.8	0.71	0.14	0.08	4.5	264	14	0.6
2012	0-20	Clay-loam	7.39	3.4	0.62	0.11	1.1	5	338	15	1.0
	20-40		7.76	4.1	0.70	0.12	0.09	3.9	281	11	0.7

Treatments and agronomic operations

The current research was a split-plot factorial test with a fully randomized block design and three repetitions. The main factors were comprised of supplemental irrigation including the control sample without irrigation (T1), supplemental irrigation at late vegetative phase (I2) (175-180 days after cultivation), supplemental irrigation at flowering stage (I3) (195-200 days after cultivation), and supplemental irrigation at seed filling phase (I4) (210-215 days after cultivation). Two subsidiary factors included varieties (Padideh= V1, Goldasht = V2, Varamin 295 = V3, Zarghan 279, = V4, Mec.88 = V5, and Sina = V6), application of SAP at two levels of control group and lack of SAP (S1), and use of 200 kg per hectare SAP (S2). The varieties were well-known cultivars suitable for winter farming in the tested area. The SAP (type: A200) was made by Rahab Resin Ltd. Co. under license from the Iranian Petrochemical and Polymer Institution. The maximum period of retention of this substance is 7 years in the soil, and the rate of its water absorption is about 220g/g in distilled water. SAP was put under seeds (15cm) simultaneously with stripped cultivation so that the plant's rhizomes could absorb more quickly the stored water in the SAP after water absorption and growth of buds. About 180g (30g in each 6m cultivation row) of SAP was consumed for each plot. Few experiments were conducted concerning the use of this substance in cultivating farm plants. This substance was expected to prevent and/or minimize drought stress. The varieties prepared for study were sown inside trial plots on November 14th and 15th of 2011 and 2012, respectively. The dimensions of each experimental plot were 1.5m ×6m with 6 cultivation rows per plot. Cultivation rows were 0.25m wide, and a distance of 0.10m was between the bushes on the cultivation lines. A distance of 2m between major plots and 1m between sub-plots was maintained, and 5m was considered the interval between blocks. Nitrogen and phosphor fertilizers were consumed in amounts of 100kg per hectare pure nitrogen and 100kg per hectare P_2O_5 per year. Nitrogen fertilizer was applied at a rate of one-third at rosette stage, one-third at stemming phase, and one-third before late vegetative stage in all plots. Soil test results showed a sufficient amount of potassium; therefore no more fertilizer was needed. Winter wheat had been growing in the experimental site before the experiment. To compute the irrigation rate at given phases, the sample soil was prepared after measuring the rhizome depth; then water volume was calculated using the following formula:

$$V = \frac{(Fc - \theta m) \times \rho a \times A \times ds}{Ea}$$

where *V* denotes irrigation volume, *Fc* is humidity percentage within farm capacity, θm is soil weight moisture percentage, *ρa* is soil bulk density, *A* is plot area, *ds* is approximate root penetration depth in cm at the given phase, and *Ea* is irrigation efficiency (it was considered to be 85%). According to Aforementioned equation, the volume of irrigation water was computed for each of developmental stages (Table 3).

Table 3. Irrigation water quantities applied to safflower at different stages of the experimental years.

Experimental years	Water application	Stage of development			Total stage	precipitation in Growth Season (mm)
		Late vegetative	Flowering	Yield formation		
2011-2012	Application day	178	201	208	246-250	
	Irrigation water (mm)	83	132	147		220
2012-2013	Application day	178	196	204	248-251	
	Irrigation water (mm)	64	118	136		320

Seed Yield

The grains of approximately 0.25 kg per plot were oven-dried to constant weight at 65°C and re-weighed to determine the water content. The grain yields were converted to a standard grain water content of 12%.

Oil, Protein and N Content

Oil content of the seeds was determined with a NMR spectrophotometer and expressed on a percent basis, based on whole seed [31]. Seed protein and Total Nitrogen content were determined by measuring the N content with the Kjeldhal method and multiplying it by 6.25 to express to total protein content [10]. Oil and protein yield were determined by multiplying the oil and protein content by the seed yield.

Nitrogen Harvest Index

Nitrogen harvest index (NHI) was calculated as the seed N content to the total above ground N content at maturity. NHI calculated according to below formula [13]:

1. $$NHI = \frac{G_N}{T_N} \times 100$$

In this formula NHI: Nitrogen harvest index, G_N: Grain nitrogen content (kg.ha^{-1}) and T_N: Total nitrogen content (kg.ha^{-1}).

Statics

Analyses were performed with using the MSTATC software. A split-factorial analysis of variance (ANOVA) was performed for all parameters. In addition the Duncan's Multiple Range Test (DMRT) (P = 0.01) was used to conduct mean comparison of treatments and find significant differences among means. Charts and figures were drawn with Microsoft office Word and Excel software, respectively. Linear regression was conducted to determine the relationship between the amount of water received by plants during the growing season (Rain + Supplemental irrigation) and traits in both experimental years. Pearson correlation analyses across years were done with SPSS.

RESULTS AND DISCUSSION

The findings of this study indicated that supplemental irrigation in various growth phases can affect the seed quality. Moreover, The various varieties showed various reactions to supplemental irrigation that was influenced by the growth duration and collision of growth stages with atmospheric conditions. The weather conditions during the growing season in the years 2011-2012 and 2012-2013 were different. During the 2012-2013 growing season plant's had quite rainfall during the late vegetative stage. In contrast, in 2011-2012 growing season there was lower rainfall during the spring. Therefore, there were differences in the response of the six hybrids to supplemental irrigation and super absorbent polymer during the 2 years of the study, which was probably because of the different weather conditions.

Seed Yield

Test results indicate that all treatments affected seed yield (Table 6). Seed yield was noticeably increased with supplemental irrigation, and it was highly correlated with the amount of water received during the growth season (Fig 1). In the second year of testing, seed yield was improved by additional precipitation and its appropriate dispersion at all levels. In both the first year when precipitation was less and the second year when precipitation was more, supplemental irrigation increased seed yield at the flowering stage. Thus, our findings indicate that the best time for supplemental irrigation is at flowering stage

(Table 6). Reported that the highest damage on grain yield caused in drought stress at blooming (late vegetative stage) [47,29] and flowering stages [47,44,68] in safflower. Ashkani *et al*., [4] showed that supplementary irrigation can be an important tool to increase seed yield of safflower. Sina cultivar produced a higher seed yield than other varieties (Table 6). The decrease in yield and yield components in different safflower genotypes due to water deficiency has also been reported by other researchers [34,38]. The application of SAP in all testing levels, by increasing the soil's water storage potential, caused significant increases in seed yield varying from 200-400kg per hectare. Previous studies revealed that if more SAP is mixed with the soil, the amount of moisture stored in the soil will also increase [27]. FAO presents that good rain fed yields are in the range of 1.0–2.5 ton.ha^{-1}; under irrigation in the range of 2.0–4.0 ton.ha^{-1} from farmers' fields [15]. Safflower yield data in different places under rain fed and irrigated conditions are also available for small experimental plots. For instance: in the Sacramento Valley of California, USA [11]; in the Ariana of Tunisia [25]; in the Pampas region of Argentina [58]; in the south of Italy [38]; in the Orissa of India [34] in the range of 1.0–3.3 ton.ha^{-1}. The yield obtained in this research was higher than the above presented values. Applied irrigation treatment is one of the most important reasons for this. In the present study, seed yield of 1.5-2.0 t ha-1 and seed oil content of 24-29% were similar to those obtained previously in Iran [56] and Turkey [51] but lower than those reported by some other authors. Previous literature reported seed yield of 1.17 to 3.33 t ha-1 [50,37,43,23] and seed oil contents of 23.9-40.3% (Ghamarnia and Sepehri [23] in Iran; and Arslan and Kucuk [3] in Turkey).

Oil Content

Seed oil percentage was significantly increased by supplemental irrigation (Table 5). In both years of the experiment, seed oil percentage of the supplemental irrigation treatment at flowering and seed filling stages increased more than the other two treatments. Percentages for dry farming were 25.64% and 26.55%, respectively, for the first and second years. Supplemental irrigation increased seed oil percentage at flowering stages by almost 13% in the first year and 12% in the second year. The higher oil content in the second year can be explained by better climate factors such as higher precipitations and lower temperatures during stress-sensitive stages of safflower. Oil content was highly correlated with the amount of water received during the growth season (Fig 1). In this experiment, seed oil percentages among different cultivars varied from about 29% for the Goldasht cultivar to 26% for the Padideh cultivar (Table 5). Super absorbent polymer used in supplemental irrigation at the flowering stage caused significant differences in seed oil percentage in all cultivars except Padideh. In dry farming, however, the use of super absorbent polymer did not lead to significant changes in seed oil percentage in any of the cultivars. Our results were consistent with previous work which demonstrated that water deficit reduced oil content and yield of safflower [5,46]. Seed oil percentage was positively and significantly correlated with seed yield (r=0.436**) (Table 4). Results of the correlation between seed oil percentage and seed protein percentage (r=-0.536**) indicated that increasing the seed oil percentage decreased seed protein percentage (Table 4).

Oil Yield

The success of safflower introduction and development in a given country or region largely depends on seed and oil yield [1,6,40]. Treatments had significant effects on oil yield (Table 5). But this effects were caused more by the treatments' effects on seed yield and not by their effects on seed oil percentage. This indicates that the oil yield impressibility of seed yield was more than the seed oil percentage. Irrigation in heading and flowering stages in the first year (525.1 kg.ha-1) and in flowering and seed filling stages in the second year (768 kg.ha^{-1}) had maximum and without irrigation was minimum (327.6 and 519.3 kg ha-1 in the first and second year, respectively) oil yield, and no significant differences were observed between these stages of each year (Table 5). According to the reducing of yield in non-irrigated conditions in addition as oil yield is depended to the seed yield, we observed reduction oil yield by the seed yield reduction, thus sufficient irrigation is useful to increase the seed and oil yield [60]. These results are also confirmed with founding's by Naderi *et al.,* [46]. Between the genotypes there were significantly differences on oil yield (Table 5). Sina genotype had maximum (634.1 and 1099 kg.ha^{-1} in the first and second year, respectively) and Padideh in first year (418.1 kg.ha^{-1}) and mec.88 in second year (569.3 kg.ha^{-1}) had minimum oil yield (Table 5). Naderi *et al.,* [46] also reported the existing differences between genotypes.

Protein Content

In both experiment years, the lowest percentage of protein was obtained from supplemental irrigation at the flowering stage, and dry farming had the highest percentage of protein (Table 5). Generally, the treatments which had the highest and lowest seed oil yields had the lowest and highest seed protein percentages, respectively. The negative and significant correlation between them (r=-0.536**) also expresses this issue (Table 4). It seems that drought stress reduces the seed filling period, and because seed protein accumulation occurs sooner than seed oil accumulation, the percentage of protein is not reduced, but the oil percentage is decreased. Also, protein content was highly correlated with the amount of water received during the growth season (Fig 1). Of course, the protein percentage increase under dry farming conditions where the yield is decreased because of water deficit and drought stress was negligible. Overall, the whole amount of produced protein (protein yield) under dry farming conditions and water deficit was reduced. Mirshekari et al., [42] stated that maximum protein contents in safflower was recorded for ceasing irrigation at heading and flowering stages, respectively. Seed protein percentage in the tested cultivar varied each year (Table 5). In the first year, the Padideh cultivar with 17.86% and in the second year, the Varamin295 cultivar with 16.78% had the highest seed protein percentages. Super absorbent polymer usage in both testing years had a significant effect on seed protein percentage by decreasing it (Table 5). Overall, the seed protein percentage was higher the first year than the second year. These results could be due to improved rainfall in the second year, and consequently other seed proportions than seed protein increased.

Protein Yield

All treatments had a significant effect on seed protein yield . As with the oil yield, these effects were caused more by the treatments' effects on seed yield rather than their effects on seed protein percentage. With the negative correlation between seed yield and seed protein percentage (r=-0.451**), however, seed yield and seed protein yield have a very strong and positive correlation (r=0.984**), one that is much greater than the correlation between seed protein percentage and protein yield (r=0.357**) (Table 4). The Sina cultivar received super absorbent polymer in all supplemental irrigation treatments (Table 5). In these treatments and even in dry farming, this cultivar produced the highest protein yield. This is due to the cultivar's high yield toward the mentioned treatments. Protein yield increased when super absorbent polymers were used because of the impact of water availability, and thus yield increased. Haddadi *et al*., [24] stated that stressful levels of environmental factors such as temperature and water directly affect oil, protein, and fatty acids contents. Alahdadi *et al*., [2] reported that drought stress decreased oil and increased protein content of sunflower seed

Total Nitrogen Content

In this experiment, all simple and alternate effects of treatments on total nitrogen content were significant. Supplemental irrigation increased total nitrogen content (Table 6). This increase was greater with irrigation at the flowering stage in the first year, and irrigation at the flowering and seed filling stages in the second year. Also, total nitrogen content was highly correlated with the amount of water received during the growth season (Fig 1). In both years of testing, the Sina cultivar with very many difference had the highest total nitrogen content (Table 6). Moreover, super absorbent polymers have positive effects on improving humidity conditions and plant growth; thus, their usage increases total nitrogen content (Table 6). Dordas and Siolas [17] studied the allocation and transfer of nitrogen in safflower and observed that in low rainfall years, plant nitrogen absorption reduced and total nitrogen absorption under water stress was lowered. These results are consistent with the results of the present study. Total nitrogen content after seed yield had a strong and significant positive correlation with seed oil percentage (r=0.570**) and a significant negative correlation with seed protein percentage (r=-0.504**) (Table 4). There are several factors which can affect N loss, such as N levels of the plant, water stress, and genotype. N loss from plants can happen in various ways, such as volatilization of ammonia (after senescence of photosynthetic tissues), leaching of soluble organic nitrogen, and natural abscission of plant organs [26,53,55]. Many plant species lose N during the period from anthesis to maturity, and the losses in this study are similar to those found in other studies with different plant species. This indicates that it is a universal phenomenon and the magnitude of the N losses can depend on the N content, environmental factors and genotype [52,12,14,63]. Since N is taken up with water, the total amount of N taken up is lower under water stress; this is confirmed by others who found that in high temperature and low rainfall conditions there is a reduction in N uptake by safflower [36].

Nitrogen Harvest Index

The nitrogen harvest index is a ratio of shoot nitrogen that allocates to seed. Growing conditions, such as incidence of drought, can reduce the NHI because of the lower N uptake and hence lower N remobilization to the seed [67]. In the current experiment, plant growth conditions were improved with the application of supplemental irrigation and super absorbent polymers. Thus, the share of seed nitrogen of **shoot** nitrogen decreased, and consequently dry farming and the non-use of super absorbent polymers increased this proportion (Table 6). Nitrogen harvest index was highly correlated with the amount of water received during the growth season (Fig 1). The lowest nitrogen harvest indices were achieved in the first year from irrigation at flowering stage (58.27%) and in the second year from irrigation at flowering and seed filling stages (51.49% and 50.71%, respectively). The relative flow and remobilization of N to the grain during the grain filling period depends on genotype, environment, planting date, population density, nutrients, and water stress: all of these factors are critical for determining the final seed yield [16]. Information on N accumulation and its partitioning into the plant's various parts is important for understanding the mechanisms of plant growth and development; this in turn can help us analyze and interpret our experimental results, and also lead to better understanding of processes and resource manipulation for optimum crop production [21]. Genotype can affect the NHI as has been found in other studies [52,36]. The strong negative correlation between the nitrogen harvest index and seed yield (r=-0.962) shows that through the improvement of plant growth with supplemental irrigation and seed yield increase, the plants' needs for shoot nitrogen stores decreased.

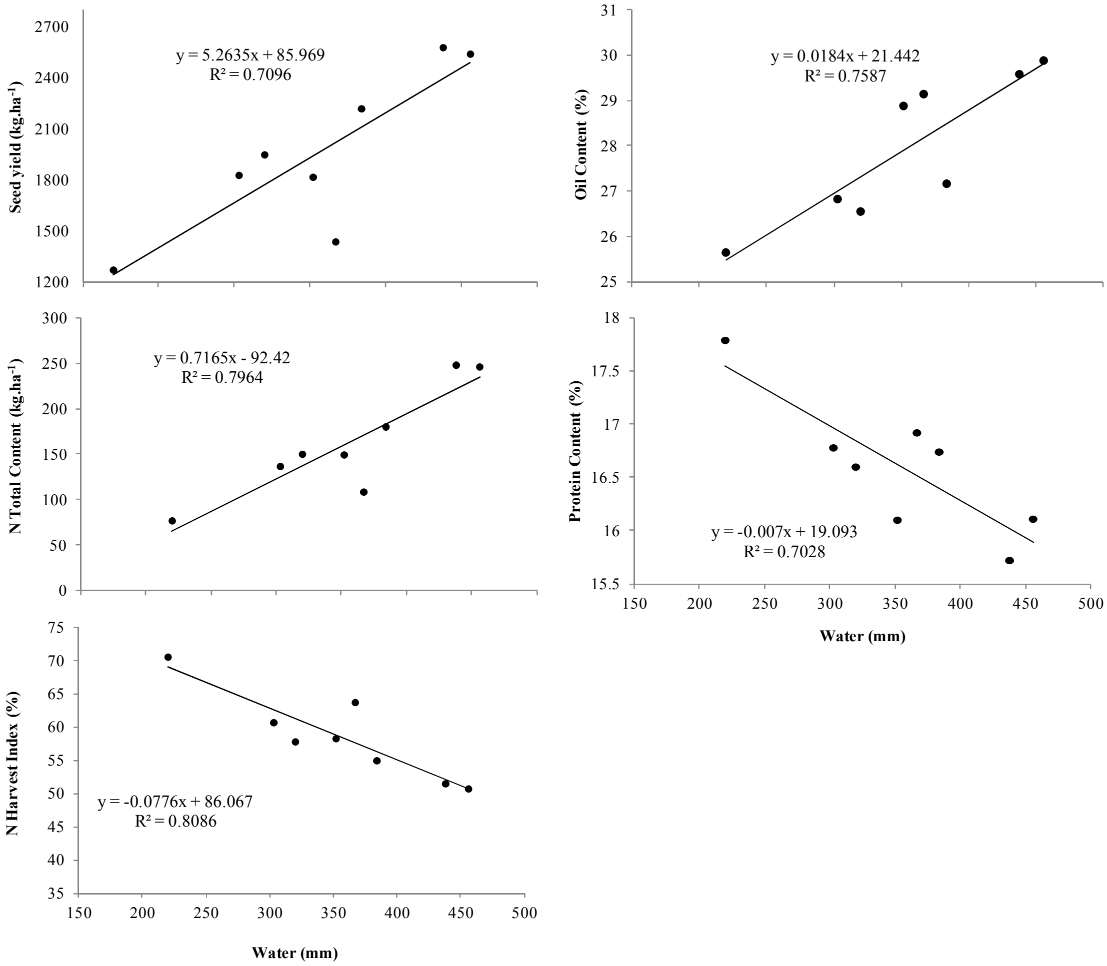

Fig 1. Relationship between the amount of water received by plants during the growing season (Rain + Supplemental irrigation) and seed yield, total nitrogen content and nitrogen harvest index in both experimental years.

Table 4. Pearson correlation coefficients among some of the characteristics that were measured in this study in two years

	Seed Yield	Oil Percent	Oil Yield	Protein Percent	Protein Yield	N Total Content	HIN
Seed	-	.436**	.986**	-.451**	.984**	.985**	-
Oil		-	.574**	-.536**	.357**	.570**	-
Oil Yield			-	-.504**	.957**	.998**	-
Protein				-	-.295**	-.504**	.536**
Protein					-	.956**	-
N Total						-	-
Nitrogen							-

**. Correlation is Significant at the 0.01 Level

Table 5. Effects of supplemental irrigation (SI) and superabsorbent polymer (SP) treatments on oil and protein content of Six safflower varieties (VA) in 2012 and 2013.

IR	VA	SP	Oil Percent (%) 2012	Oil Percent (%) 2013	Oil Yield (kg.ha-1) 2012	Oil Yield (kg.ha-1) 2013	Protein Percent (%) 2012	Protein Percent (%) 2013	Protein Yield (kg.ha-1) 2012	Protein Yield (kg.ha-1) 2013
I1			25.64c	26.55c	327.6c	519.3c	17.79a	16.60ab	225.0b	323.5c
I2			26.82b	27.16b	492.7a	603.9b	16.78b	16.74a	303.8a	370.6b
I3			28.88a	29.58a	525.1a	768.0a	16.10c	15.72c	291.9a	409.2ab
I4			29.14a	29.88a	419.3b	761.3a	16.92b	16.11bc	242.2b	407.4a
	V1		26.23e	27.33d	418.1c	609.0b	17.86a	16.45bc	282.2b	358.6b
	V2		28.99a	29.49a	501.7b	544.3cd	15.99e	15.80d	275.0b	289.9d
	V3		27.64c	28.15c	359.7d	538.3d	16.95c	16.87a	220.2d	318.5c
	V4		27.10d	27.65d	364.2d	619.2b	16.95c	15.81d	226.1cd	349.6b
	V5		27.58c	28.06c	369.2d	569.3c	17.48b	16.23c	230.4c	326.1c
	V6		28.20b	29.06b	634.1a	1099a	16.14d	16.59ab	360.3a	623.3a
I1	V1		24.78k	25.73l	313.8j	416.6mn	19.45a	17.23bc	245.8fg	277.7h
	V2		26.53gh	27.69gh	370.4ghi	436.0m	16.72fgh	16.37defg	233.3ghi	256.1i
	V3		25.67ij	26.58jk	268.6k	384.1n	17.13def	17.23bc	179.2k	248.5i
	V4		25.13jk	25.75l	303.3j	479.5l	18.15bc	15.73ghi	218.7ij	291.7gh
	V5		24.90k	26.37kl	249.6l	492.9kl	18.43b	16.18efgh	184.6k	304.1fgh
	V6		26.85g	27.16hij	459.7e	906.7c	16.85fg	16.85cde	288.2cd	562.6b
I2	V1		25.30jk	25.77l	520.5d	547.1ij	17.38de	17.94a	356.9b	379.5c
	V2		27.52f	28.19fg	601.6c	565.4ghi	15.85k	15.28ij	345.6b	306.7efg
	V3		26.07hi	27.01hij	388.4g	501.3jk	17.65cd	17.75ab	263.8ef	328.9de
	V4		26.17hi	27.43hi	349.1i	549hi	16.27ij	15.63ghi	216.6ij	311.1ef
	V5		27.50f	26.82ijk	385.7g	483.5kl	17.93bc	17.15bc	250.9fg	308.6efg
	V6		28.37e	27.63gh	711.0b	978.0c	15.58l	16.67cdef	389.0b	588.6b
I3	V1		26.95g	28.55def	447.7ef	750.7d	16.27ij	14.82j	270.1de	388.5c
	V2		31.50a	31.65a	594.3c	599.0gh	15.25m	15.42hij	287.2cd	290.9fgh
	V3		29.00d	28.54def	423.1f	597.4fg	16.05jk	15.67ghi	234.3gh	326.9de
	V4		28.07e	28.35efg	422.0f	716.3de	16.38hij	15.82ghi	245.6fg	394.0c
	V5		29.50cd	29.40c	468.7e	586.1ghi	16.53ghi	15.52hij	262.6ef	306.5efg
	V6		28.28e	30.99ab	794.7a	1359a	16.08jk	17.08bcd	451.7a	748.5a
I4	V1		27.88ef	29.25cd	390.5g	721.6de	18.33b	15.82ghi	256.2ef	388.6c
	V2		30.40b	30.43b	440.5ef	576.9ghi	16.13ijk	16.13efgh	233.8gh	305.7efg
	V3		29.83c	30.37b	358.5hi	670.6ef	16.98efg	16.83cde	203.6j	369.6cd
	V4		29.03d	29.08cde	382.5gh	733.0de	17.02ef	16.07fghi	223.6hi	401.6c
	V5		28.40e	29.65c	372.9gh	714.8de	17.03ef	16.05fghi	223.6hi	385.4c
	V6		29.30cd	30.47b	571.0cd	1151b	16.05jk	15.75ghi	312.3c	593.5b
I1		S1	25.52f	26.33f	292.2f	440.8f	17.89a	16.69a	203.2f	278.3e
		S2	25.77f	26.77e	363.0e	597.8d	17.69a	16.51ab	246.7d	368.6c
I2		S1	26.41e	26.80e	435.2d	526.1e	16.92b	16.89a	276.9c	330.9d
		S2	27.23d	27.51d	550.2b	681.6b	16.64c	16.59ab	330.7a	410.3b
I3		S1	28.34c	28.75c	491.0c	664.9c	16.12d	15.87cd	287.7c	368.1d
		S2	29.43a	30.42a	559.1a	871.2a	16.07d	15.57d	305.1b	450.3a
I4		S1	28.89b	29.42b	369.1e	637.3bc	16.97b	16.26bc	216.4e	350.8cd
		S2	29.46a	30.33a	469.6c	885.4a	16.88b	15.96cd	268.0c	464.0a

Means within columns not followed by the same letter are significantly different at the p<0.01 level by Duncan's multiple range test.

Table 6. Effects of supplemental irrigation (SI) and superabsorbent polymer (SP) treatments on seed yield, nitrogen harvest index and total nitrogen content of Six safflower varieties (VA) in 2012 and 2013.

SR	VA	SP	Seed Yield kg.ha-1 2012	Seed Yield kg.ha-1 2013	Nitrogen Harvest Index % 2012	Nitrogen Harvest Index % 2013	N Total Content kg.ha-1 2012	N Total Content kg.ha-1 2013
I1			1271c	1949c	70.54a	57.80a	76.65d	150.1c
I2			1827a	2218b	60.68c	54.96b	136.6b	180.1b
I3			1817a	2578a	58.27d	51.49c	149.3a	248.1a
I4			1437b	2540a	63.70b	50.71c	108.4c	246.2a
	V1		1595c	2207b	63.54b	54.62bc	108.0c	184.4b
	V2		1727b	1839d	59.46c	55.52ab	139.0b	159.7c
	V3		1300d	1895cd	67.98a	56.04a	86.76d	157.5d
	V4		1338d	2217b	67.65a	53.88c	88.18d	189.6b
	V5		1325d	2012c	66.93a	55.41ab	91.15d	168.4c
	V6		2241a	3756a	54.23d	46.97d	193.2a	377.2a
I1	V1		1265mn	1619j	70.80c	61.40a	71.14j	108.9l

	V2		1395jkl	1571j	66.92def	60.08ab	89.82ghi	116.6l
	V3		1047o	1442k	76.25a	61.37a	56.74k	100.5m
	V4		1206n	1853i	73.15b	58.03bc	67.05j	137.0k
	V5		1002o	1868ghi	75.82a	57.49cd	52.80k	139.8jk
	V6		1712e	3338b	60.32gh	48.44k	122.4e	298.0c
I2	V1		2055cd	2119d	57.40i	56.11de	145.7d	158.3hi
	V2		2181c	2006de	54.93j	54.67ef	177.0c	165.2fgh
	V3		1493ghi	1853fghi	65.18f	57.35cd	95.62g	139.2ij
	V4		1333klm	1995def	68.78cd	55.05ef	81.82i	159.8gh
	V5		1399jkl	1800hi	65.77ef	58.56bc	95.79g	132.3jk
	V6		2501b	3535b	52.00k	48.01k	223.4b	325.9c
I3	V1		1660ef	2624c	61.03gh	50.37j	117.9ef	239.9d
	V2		1885d	1884fghi	55.15j	54.34efg	173.1c	181.0fg
	V3		1460hij	2088d	62.45g	53.26fgh	108.7f	180.8f
	V4		1500gh	2510c	62.52g	51.15hij	109.0f	227.2de
	V5		1587fg	1981efg	59.67h	54.73ef	126.1e	175.8fgh
	V6		2808a	4382a	48.82l	45.08m	261.0a	483.9a
I4	V1		1400ijk	2465c	64.93f	50.61j	97.28g	230.4de
	V2		1448hij	1896efgh	60.85gh	53.00fghi	116.2ef	176.1f
	V3		1200n	2199d	68.05de	52.17ghij	85.96hi	209.6e
	V4		1315lm	2508c	66.15ef	51.27ij	94.88gh	234.5de
	V5		1313klm	2400c	66.45ef	50.87j	89.91gh	225.7de
	V6		1946d	3770b	55.78ij	46.37l	166.3c	400.8b
I1		S1	1140f	1667e	73.01a	60.60a	65.62f	122.0f
		S2	1402d	2231c	68.08b	55.00c	87.69e	178.3d
I2		S1	1645bc	1959d	63.11c	56.96b	113.8d	150.0e
		S2	2009a	2477b	58.25e	52.95d	159.3b	210.2b
I3		S1	1732b	2294c	59.84d	54.01d	135.8c	206.0c
		S2	1901a	2862a	56.71f	48.96e	162.8a	290.3a
I4		S1	1280e	2164c	67.11b	52.72d	89.67e	197.5bc
		S2	1593c	2916a	60.29d	48.71e	127.2c	294.9a

Means within columns not followed by the same letter are significantly different at the p<0.01 level by Duncan's multiple range test.

CONCLUSION

The application of supplemental irrigation under dry-farming conditions, especially in regions where there is the possibility of this type of irrigation, could remove the stress conditions from the plant and improve seed yield. One of the important points in this method is the plant's stage of growth in which supplemental irrigation is implemented. In both years of the current study, given that the two testing years differed from each other in terms of rate and dispersion of precipitation, supplemental irrigation resulted in increased seed yield at the flowering stage more than other treatments. Of course, if precipitation conditions are adverse (i.e. raining stops before the late vegetative stage), supplemental irrigation may be utilized in the late vegetative stage and under appropriate rain conditions (until end of late vegetative phase) at the seed filling stage in order to reduce losses caused by drought stress and to increase seed yield. Consuming SAP, especially when combined with the implementation of supplemental irrigation, provided more moisture for the plant and caused the given plant to be less exposed to stress conditions. Employing supplemental irrigation during the plants' critical need phases, applying SAP to increase the impact of supplemental irrigation, and using plant varieties that have appropriate characteristics for exposure to water shortage and stress conditions are valuable strategies for increasing seed yield under dry-farming conditions.

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