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Effect of Drought Stress on Flowering and on Seed Yield and its Components in Jojoba (*Simmondsia chinesis* (Link) Schneider) Established in Western Saudi Arabia*

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ABSTRACT. A two year field trial was conducted to assess the effect of drought stress on flowering, seed yield and related traits in a 5 years jojoba plantation (5 to 6 years old) established in Al-Madinah Al-Munawwarah area. Seven irrigation regimes were created by irrigating the crop at 1, 2, 4, 8, 12, 24 and 36 weeks intervals for only one cycle (i.e. 36 weeks). Afterwards, the irrigation schedule was relaxed and the crop was maintained at a limited water supply (187 m^3/ha/month) until the end of the trial. The total amount of water applied in the first 36 weeks of the trial ranged from 35.6 m^3/ha/month for the driest treatment to 223.5 m^3/ha/month for the wettest treatment.

Collected data through the course of the trial revealed no significant differences between the wettest and driest treatments for each of the studied traits. Estimates of seed yield per plant, oil and protein contents of seeds, (100-seed weight), shelling percentage and total number of flowers per season, averaged over treatments, were 569 vs. 784 g, 43 vs. 51%, 17.3 vs. 16.7%, 69 vs. 72% and 38 vs. 49 flowers over the two years for the respective traits and are comparable to those recorded in other parts of the world.

Introduction

Jojoba is an industrial crop that has attracted worldwide attention for several reasons: a) its seed contains a liquid wax which, in addition to several miscellaneous uses, can serve as a replacement of sperm whale oil (a product de-

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rived from an endangered species), b) it is an extensively drought resistant species; c) it can grow in areas of marginal soil fertility, high atmospheric temperatures, high soil salinity , low humidity and low fertilizer requirements (Yermanos, 1982). In all habitats, including inland desert areas, jojoba plants were observed to be physiologically active during the entire year, indicating their capacity in maintaining positive carbon balance even under severe drought at very low (–36 bar) water potential (Al-Ani *et al.,* 1972). Under green house conditions, jojoba was reported to maintain positive growth under stress conditions of up to –70 bars (Al-Ani *et al.,* 1972). A high water use efficiency (0.239 mg CO_2/mg H_2O per mh) for jojoba in comparison to wheat (0.127), sunflower (0.160), and soybean (0.182) was reported in the literature (Rawson *et al.,* 1977).

Yermanos (1982) indicated that annual rainfall of 254-308 mm might be the best as jojoba reaching 5 m in height were observed under these conditions. Average seed yields in the range of 214.3 and 354.7 g/plant were recorded in a 7-year old jojoba population that was respectively non-irrigated or received a total of 336 liters of irrigation water within the indicated period (Azocar and Covarrubias, 1990). Several researchers worked on vegetative growth of jojoba and found that it varied with drought stress (Nerd *et al.,* 1982; Benzioni and Nerd, 1985; Nerd and Benzioni, 1985; Ehrler *et al.,* 1987; Benzioni and Dunstone, 1986, Malende, 1989; Nelson *et al.,* 1993; Nelson, 1996 and Osman and AboHassan, 1998). Others worked on flowering and reached the same conclusion. Flowering (Benzioni *et al.,* 1982; Forti *et al.,* 1985; Benzioni and Dunstone, 1986 and Nerd and Benzioni, 1988). Few researchers tackled aspects of leaves, mineral content and found serious effects for drought stress (El-Tomi *et al.,* 1984). However, seed yields were investigated by several researchers (Ehrler *et al.,* 1987; Benzioni and Nerd, 1985; and Ayerza, 1990) and they reported similar results indicating the significant influence of drought stress on seed yield.

It is known that Jojoba is a perennial shrub and consequently its current year production is dependent upon flower production in the previous year. Therefore, the present study was undertaken to assess the effect of a limited time span (36 weeks) drought stresses on flower production, seed yield and its components in two successive (current and subsequent) years in Western Saudi Arabia.

Materials and Methods

A two-year field trial was conducted at Al-Yutamah area, 75 km south of Al-Madinah Al-Munawwarah, to assess seed yield and related traits in a 5 to 6 year old jojoba population established in 1989. Relevant meteorological data recorded at the experimental site are shown in Table 1. Rows making up the

population, were spaced 4 m apart; whereas plants within each row were spaced ½ to 1 m apart. An area of 1.024 ha (16 rows × 4 m × 160 m), placed under a drip irrigation system, was divided into four replications and used for conducting the trial. Each of the four replications, apart from marginal rows, consisted of 7 experimental rows, each one of which was randomly allocated, in a randomized block design, for one of the seven irrigation regimes that were imposed, starting 1/2/1993, through irrigating the crop at 1, 2, 4, 8, 12, 24 and 36 weeks intervals. On the 37th week, (i.e. after one complete cycle of the imposed regimes), the irrigation schedule was relaxed and the crop was maintained under a limited water supply (187 m^3/ha/month/treatment) until the end of the trial. Starting 21/12/1993, ten plants were randomly tagged in each experimental plot and were used for determining the number of flowers produced per twenty 6-nodes twigs per season for eight consecutive seasons. In the summer of each of the two years of the study, harvested seeds from the ten plants were weighed and used for determining seed yield $plant^{-1}$, seed size (100 seed wt) wax and protein contents of seeds. Shelling percentage or the ratio of seed weight to fruit weight × 100, was estimated from a 100-fruit lot. In addition to these parameters, total amounts of irrigation water applied during the first 36 weeks of the trial were recorded through flow meters connected to each of the 28 experimental plots. The data was analyzed as suggested by Little and Little (1977) for a randomized block design.

TABLE 1. Absolute seasonal ranges of temperature and relative humidity at the experimental site in the period 21/6/93 to 20/12/96.

Season	1993/94		1994/95		1995/96	
	Temp. (ºC)	R.H. (%)	Temp. (ºC)	R.H. (%)	Temp. (ºC)	R.H. (%)
Winter (W)	–	13-98	4-34	20-100	6-36	9-100
Spring (Sp)	–	14-96	7-44	6-95	12-45	19-100
Summer (S)	20-45	13-95	16-48	9-100	17-47	22-100
Fall (F)	9-42	6-98	8-40	20-100	11-42	13-98

Results

Number of Flowers

Number of flowers among seasons ranged from 41 to 44.9 flowers in the first year and from 37.6 to 49.4 flowers in the second year with the overall averages of 42.4 ± 0.69 and 42.2 ± 0.69 flowers in the respective years (Table 2). The data revealed high significant difference ($P \leq 0.01$) among seasons in the second

TABLE 2. Means of number of flowers for the irrigation treatments (flowers/20-6-nodes twigs) in a jojoba plantation established in Al-Madinah area.

Irrigations treatments	First Year					Second Year				
	21/12/93	21/3/94	21/6/94	21/9/93	Mean	21/12/93	21/3/94	21/6/94	21/9/93	Mean
	± 3.55a				± 1.77b		± 3.74a			± 1.87b
1	44.3	46.0	40.5	42.0	43.2	36.0	37.3	53.8	42.5	42.4
2	38.8	45.0	41.5	45.0	42.7	35.8	33.5	49.5	42.5	40.3
3	40.0	49.0	41.0	46.8	44.2	40.8	38.5	52.5	45.8	44.4
4	40.8	41.5	38.0	42.8	40.8	35.5	34.3	47.3	43.3	40.1
5	46.0	42.5	39.3	43.3	42.8	41.0	42.8	44.8	40.3	42.2
6	41.3	42.3	45.3	38.8	41.8	38.0	40.3	55.8	40.0	43.5
7	42.0	42.0	41.3	41.5	41.7	36.5	40.8	42.0	49.8	42.3
S.E. ± c	4.4	3.6	7.5	3.3		1.6	2.9	4.8	4.3	
			± 1.27d				± 1.27d**			
Mean (Season)	44.9	44.0	41.0	42.9		37.6	38.2	49.4	43.4	
					0.69e					
Mean (Year)		42.4a					42.2a			

a: treatment 1 to 7 indicate irrigation at 1, 2, 4, 8, 12, 24 and 36 weeks intervals. Amounts of water received (m^3 ha^{-1}) for respective treatments = 223.5, 133.2, 83.6, 61.9, 58.1, 43.1 and 35.6 m^3 ha^{-1} $month^{-1}$.

**significant at $P \leq 0.01$.

a, b, c, d and e: stand for S.E. (standard errors) for interactions of seasons × treatments (a), treatment means over seasons (b), treatments mean within each seasons (c), seasonal means (d) and annual means (e), respectively.

N.B: LSD at P 0.05 or P 0.01 = S.E. ×2 * T value at error d.f. or 18.

year where the highest number of flowers (49.4) was recorded during the spring. Differences among the irrigation treatment in each of the eight seasons as well between the annual means and interactions of treatments with seasons in each of the two years were all non-significant (Table 2).

Seed Yield

Seed yield among irrigation treatments ranged from 458 to 699 and from 680 to 930 g plant^{-1} with the overall averages of 569 ± 35 and 784 ± 35 g plant^{-1} in the respective years (Table 3). The data revealed high significant difference ($P \leq 0.01$) between years but no significant differences among the irrigation treatments were found (Table 3).

Wax (Oil) Content

Estimates of oil content in the seeds ranged from 42.4 to 43.9% with an overall average of 43.0 ± 0.4% in the first year and from 50.0 to 54.0% with an overall average of 51.1 ± 0.40% in the second. The data revealed high significant difference ($P \leq 0.01$) between years but not among treatments in each of the two years (Table 3)

Protein Content

Protein content in jojoba seeds ranged from 16.5 to 17.9% with an overall average of 17.3 ± 6.2% in the first year and from 14.8% to 17.7% with an overall average of 16.7 ± 0.2% in the second year. The data revealed that protein content at the driest treatment (14.8%) was significantly similar to those recorded at the 1-week (15.7%) and the two-weeks (16.6%) irrigation intervals but it was significantly different ($P \leq 0.05$) from the other four irrigation treatments (Table 3).

100-seed Weight

Estimates of 100-seed weight ranged from 84.9 to 95.3 g with an overall average of 89.6 ± 1.25 g in the first year and from 61.5 to 74.5 g with an overall average of 68.7 ± 1.25 in the second (Table 3). The data revealed high significant difference ($P \leq 0.01$) between years but not among the irrigation treatments in both years (Table 3).

Shelling Percentage

Shelling percentage ranged 63.3 to 75.1% and from 70.1 to 73.0% with overall averages of 69.4 ± 1.9 and 71.7 ± 1.9 for the respective years (Table 3). The data revealed no significant differences between years or among irrigation treatments in each of the two years (Table 3).

TABLE 3. Treatment means for seed yield and its component in a jojoba population established in Al-Madinah area.

Irrigation treatment	Seed yield (g plant $^{-1}$)		100-seed wt. (g)		Shelling percentage (%)		Oil content (%)		Protein content (%)	
	1st year	2nd year	1st year	2nd year	1st year	2nd year	1st year	2nd year	1st year	2nd year
1	537	860	84.9	71.0	66.1	70.1	42.4	50.0	17.9	15.7
2	519	930	91.5	70.5	75.1	71.0	43.7	54.0	17.3	16.6
3	614	750	94.3	70.8	73.6	72.0	42.7	50.0	16.6	17.7
4	458	680	89.7	67.3	63.3	73.0	42.7	50.0	17.7	17.7
5	621	890	95.3	61.5	71.4	71.4	43.0	50.0	16.9	17.3
6	699	690	87.0	65.3	65.4	72.0	42.4	52.0	18.2	17.3
7	534	680	84.9	74.5	70.1	72.3	43.9	52.0	16.5	14.8
S.E. ±	105	106	5.9	6.5	31	6.6	0.70	0.60	0.50	0.42*
Mean (year)	569b	784a	89.6a	68.7b	69.4a	71.7a	43.0b	51.1a	17.3a	16.7a

*significant among treatment means at $P \leq 0.05$.
a,b: Figures followed by the letter (bottom line) for a particular trait are not significantly different from one another according to Duncan's multiple range test.
N.B.: LSD at P or P 0.01 = S.E. × 2 × T value at error d.f.

Discussion

The total amount of water applied to the crop during the first 36 weeks of the trial ranged from 35.6 m^3 ha^{-1} for the driest treatment to 223.5 m^3 ha^{-1} for the wettest treatment with an overall average of 91.4 ± 28.6 m^3 ha^{-1} $month^{-1}$ (Table 2). Data taken in the course of this study revealed that none of the traits evaluated, except for seed protein content in the seeds (2nd year), was significantly affected by drought stress. Protein content recorded at the driest treatment (14.8%) was statistically similar to those recorded at the one - (15.79%) and two - (16.6%) weeks irrigation interval, indicating that both excess and limited water supply tended to have had an adverse effect on seed protein content.

Relatively little is known regarding the effects of drought stress on seed yield and its components in jojoba. Ehler *et al.* (1987) indicated that application of 435 and 876 mm/ha resulted in yields of 8 and 23 g/tree; whereas Mann and Muthana (1985) revealed that seasonal rains of 250-450 in winter and spring were adequate for seed production in jojoba. An average seed yield of 2500 kg/ha was achieved in a 4-year jojoba field irrigated at a rate of 4000 to 4500 liters/tree/year (Benzioni and Nerd, 1985). Ayerza (1990) indicated that irrigating jojoba at rate zero, 30, 600, 900 mm/year, at one month interval, resulted in average yields of 107, 139, 194 and 198 g/plant for the respective treatments. According to Azocar and Covarrubias (1990), yields of a six-year old jojoba plant that received a total of 120 and 216 liters/year (in the fifth or previous year), were 10.3 and 24.5 g/plant for the respective treatments.

In the present, study yields in range of 534 to 537 g/plant and from 680 to 860 g/plant were obtained respectively at the driest (35.6 m^3 ha^{-1} $month^{-1}$) and the wettest (223.5 m^3 ha^{-1} month) treatments over the two years.

Studies on flowering in jojoba revealed that in temperature climates anthesis and fruiting occur in mid to late winter until early summer; whereas in tropical areas, flowering is associated with the wet season and flowering usually coincides with the number of rainfall events throughout the year. Consequently, spasmodic flowering and extending flower seasons characterized these regions (Benzioni and Dunstone, 1986). Under the environmental conditions of Al-Madinah area (Table 1) where the present work was conducted, irrigated jojoba plants were continuously producing an abundant number of flowers throughout the year. In drought years (Gentry, 1958 and Nerd and Benzioni, 1988), as well as under 109 mm of annual rain (Benzioni *et al.,* 1982), jojoba plants failed to flower. Ranges of 73 to 88% flower induction, were associated with 154 and 309 mm of annual rainfall, respectively. Under irrigated conditions 81% of the floral buds flowered on plants irrigated with 0.5 m^3 of water $plant^{-1}$ $season^{-1}$, whereas a higher proportion flowered when 2 m^3 was applied (Benzioni *et al.,*

1982). A large increase in flowering in plants irrigated in winter after an extended period of drought was also recorded by Benzioni and Dunstone (1986).

Seed size or 100-seed weight among the irrigation treatments ranged from 85 to 95 g and from 62 to 75 g in the respective years and was not adversely affected by drought stress. Similarly, fruit growth and consequently the final seed weight were not affected by drought stress as they had a high resistance to water loss and they were capable of retaining relatively high amounts of water during the filling stage (Nerd and Benzioni, 1986 and 1988).

Seed oil content ranged from 42 to 44% and from 50 to 54% among the irrigation treatments in the respective years and it was not significantly affected by drought stress. Estimates in ranges of 44 to 58% were reported in the literature and they observed to be highly stable under a wide range of temperatures (Yermanos, 1982).

Annual variations recorded for seed yield, seed size and wax content in the course of this study revealed that these traits, unlike protein content and shelling percentages, were less tolerable to climatic changes. In this respect, Benzioni and Nerd (1988) indicated that the overall performance of jojoba plants in arid and semi-arid environments might be directly associated with the overall environmental changes. A negative correlation was recorded between soil temperature and transpiration and consequently lower growth rates at soil low temperatures ranges under these environments. In reality, interrelationships between reproductive growth and water needs are more complex than this. Recent reports (Brown and Palzkill, 1990) emphasized the importance of availability of irrigation water or rain at 'critical stages' in the plant life for obtaining commercial yields. These critical times may vary with the location and region of planting. For example, Gentry (1958) in Arizona believes that "winter and spring are natural pristine growing and flowering times of jojoba. Water should be provided to them: never in summer, as it interferes with harvesting and desynchronizes the jojoba cycle." According to Yermanos (1982), a mid summer irrigation in winter-forest-free areas in excessively dry years might be needed to ensure good flower production.

Since jojoba is a perennial plant and its seed production in the current year is dependent upon flower production in the previous year, critical times, according to Brown and Palzkill (1990), for a particular crop of seed might stretch over two years. Hence water must be available during the previous year to allow new growth and flower bud production to occur. For the current crop, water must be available during anthesis and fruit filling stages. Consequently, for achieving high yields of jojoba in Madinah area, flowering must be synchronized and occur at a time when the critical environmental factors are satisfactory for high

seed set. In these areas, early flowering could be minimized by withholding water and nutrients in autumns. A late winter irrigation and application of fertilizer will then stimulate abundant flowering in early spring. Breeding for "low dormancy" genotypes (i.e. genotypes having low chilling requirements) may prove to be a better practice in these areas as suggested by Benzioni and Dunstone (1986).

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أثر الإجهاد الرطوبي على التزهير ووزن المحصول ومكوناته لشجيرة الهوهوبا المستزرعة بالمنطقة الغربية بالمملكة العربية السعودية *

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المستخلص . أجريت تجربة حقلية لمدة عامين لتقييم أثر الاجهاد الرطوبي على التزهير ووزن المحصول والصفات المرتبطة به لشجيرات الهوهوبا ذات الخمس والست سنوات المستزرعة بمنطقة المدينة المنورة . اشتملت التجربة على سبعة مقننات مائية تمثلت في الري مرة واحدة كل ١، ٢، ٤، ٨، ١٢، ٢٤، ٣٦ أسبوعًا (لدورة واحدة - أي ٣٦ أسبوعًا) ومن ثم روي المحصول بمعدل ثابت (١٨٧م^3 / هـ / شهر) حتى نهاية التجربة . تراوح إجمالي الماء الذي روي به المحصول خلال الستة والثلاثون أسبوعًا الأولى من عمر التجربة ما بين ٦ , ٣٥م^3 / هـ / شهر للمعاملة الجافة و٥ , ٢٢٣م^3 / هـ / شهر للمعاملة الرطبة . أوضحت البيانات عدم وجود فروقات معنوية بين المعاملة الجافة والمعاملة الرطبة في جميع الصفات التي شملتها الدراسة خلال العامين . كانت تقديرات انتاجية البذور ، محتويات الزيت والبروتين بالبذرة ، وزن المائة بذرة ، نسبة الدارس والعدد الكلي للأزهار في الموسم ٧٨٤ و ٥٦٩ جرام، ٤٣ و ٥١٪ ، ٣, ١٧ و ٧, ١٦٪ ، ٦٩ و ٧٢٪ ، ٣٨ و ٤٩ للصفات المذكورة على التوالي مما يشير إلى تطابقها مع تلك التي سجلت في أنحاء أخرى من العالم .

* أجرى هذا البحث بدعم من مدينة الملك عبد العزيز للعلوم والتقنية بالمنحة رقم أ ت/ ١٣/ ٢٣ .