Effect of Irrigation on Jojoba Production Under Arid Chaco Conditions: II—Seed Yields and Wax Quality

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In the phytogeographic region of the Arid Chaco, in Las Oscuras, Province of Cordoba, Argentina, the production of jojoba seed under four levels of irrigation was evaluated during two years. The plants used were established by direct sowing with seeds from the Tucson Mountains, outside Tucson, Arizona, four years before the test started. The plants were not irrigated until the test began. The treatments were: T1 = 0; T2 = 300; T3 = 600; and T4 = 900 mm/ha/year, in twelve equal irrigations, applied every 30 d. The experimental design used was randomized complete blocks with two replications (30 plants in each replication). Each of the variables was compared by analysis of variance, and means were subjected to Duncan's New Multiple Range Test. For the conditions of this test, the results obtained suggest that: (i) seed production of jojoba plants increased significantly with high levels of water applied monthly (treatments T3 = 600 mm and T4 = 900 mm); (ii) The most efficient irrigation treatment was T3; (iii) Jojoba plants respond to high levels of irrigation (T4 = 900 mm) and produce the heaviest seeds under these conditions; (iv) an increase in water does not produce significant differences in fatty acid content, but it may change from year to year; and (v) increased jojoba yields can be achieved on dry-farm plantations by applying irrigation.

KEY WORDS: Irrigation, seed yield, *Simmondsia chinensis* L., wax quality.

Jojoba [*Simmondsia chinensis* (Link) Schneider] is a new industrial crop that is attracting attention in the United States and many semi-arid parts of the world (1). Its great resistance to drought allows this shrub to produce seed with significantly less water than is necessary for traditional crops (2).

Approximately 50% by weight of jojoba seed is made up of a practically odorless, colorless liquid wax. The wax is composed mainly of a straight-chain monoester of C20 and C22 alcohols and acids, with two double bonds, one on each side of the ester bond. The nearly complete absence of glycerin indicates that jojoba differs radically from most other known oils (3).

For a raw natural extract, jojoba wax is remarkable because of its molecular uniformity—it is composed of 97% linear wax esters. It also has an amazing internal homogeneity, as more than 87% of the esters present are combinations of acids and alcohols, with chainlengths of 20 or 22 carbon atoms. By contrast, common vegetable oils have fatty acids with carbon chainlengths of mostly 16 or 18 atoms (4,5).

Jojoba is a plant native to the Sonoran Desert, which is located in the northwest of Mexico and the southwest of the United States. It covers approximately 120,000 square miles, a huge area that includes southwestern Arizona, southeastern California, most of the peninsula of Baja, California (including the islands in the Gulf of California) and the state of Sonora, Mexico. It is one of the four deserts on the North American continent: The Sonoran, the Great Basin, the Mojave and the Chihuahuan.

Jojoba is an evergreen shrub and is considered a drought-resistant plant (6–8). It grows naturally in a large area that extends over 16 million hectares, through 12° latitude and between 119 and 117° longitude west of Greenwich (9).

Over this area, jojoba shows a discontinuous distribution due to edaphic, geographic and microclimate factors (10). It is possible to find wild jojoba populations in areas with annual rainfall as low as 65 mm (Vizcaino) and 94 mm (Matancitas) in Baja California Sur; 105 mm (El Desemboque) in Sonora; or 109 mm (Joshua Tree National Monument) in California; and as high as 433 mm (Superior) or 394 mm (Globe) in Arizona (11). The highest density of jojoba plants is found in areas with the highest rainfall (9).

In South America, the first extensive research programs were started in 1976 in Brazil and in 1977 in Argentina. Although most Latin American countries have planted jojoba research plots, not all of them have been successful. Some that have succeeded are located in Argentina, Bolivia, Chile and Peru (6,9).

Argentina has 4,000 hectares under commercial cultivation, 2,000 hectares in the Monte Desert and the Arid Chaco and 2,000 hectares in the Semi-Arid Chaco. Commercial production started in 1989–1990 with 9,000 kg. In 1990–1991, more than 100,000 kg were harvested, and in 1991–1992 about 80,000 kg were realized. Argentina is fourth in commercial jojoba production in the world, very close behind Israel (12).

This paper seeks to determine the influence of irrigation on yield, individual seed weight and wax quality in a jojoba plantation located in the Argentine Dry Chaco.

MATERIALS AND METHODS

The research was conducted on the slopes of the Pocho Mountains, located 31° 25′ south latitude and 65° 26′ west longitude, in Las Oscuras, Province of Cordoba, Argentina. Phytogeographically, the site is located in the Arid Chaco.

The phytogeographic similarities between this region and the Sonoran Desert have been discussed (13). The texture of the soil is light, well drained, with low alkaline reaction, and rather poor in organic matter and total nitrogen. The soil has good calcium, potassium and phosphorus levels. Climatic data for the two years in which measurements were made are given in Table 1.

The experimental design used was a randomized block with two levels of replications (30 plants in each replication). Each of the variables was compared by analysis of variance, and the means were subjected to Duncan's New Multiple Range Test (DNMRT).

The seeds came from the Tucson Mountains (Tucson, Arizona). They were sown in October 1981, in parallel rows, with 4 m between rows and 1 m between plants within the row. There were equal numbers of male and female plants, and the plants were not irrigated until the test started in January 1986.

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TABLE 1

Climatic Data for the Location of the Research Plots

Year	Jan.	Feb.	March	April	May	June	July	Aug.	Sept.	Oct.	Nov.	Dec.	Annual
	Maximum temperatures (°C)												
1986	39	38	38	32	30	28	29	31	34	45	42	39	45
1987	47	45	35	37	37	24	26	30	39	38	47	47	47
	Minimum temperatures (°C)												
1986	10	16	14	10	−2	−4	2	3	3	6	11	14	−4
1987	13	17	10	5	−1	2	3	−3	4	9	7	11	−3
	Rainfall (mm)												
1986	135	168	0	0	0	0	29	0	27	32	9	62	462
1987	197	106	63	6	0	0	0	0	48	2	20	212	654
	Days with rain												
1986	4	8	0	0	0	0	1	0	1	2	2	3	21
1987	6	2	9	1	0	0	0	0	3	2	1	8	32

Four irrigation treatments were evaluated: T1 = 0 mm; T2 = 300 mm; T3 = 600 mm; and T4 = 900 mm. The water was applied in twelve equal applications every 30 d beginning in the last week of January 1986. The water applied was measured by the volume method (14). The flow volume is determined from the time required for the flow to fill a container of a fixed capacity.

The mature seeds were harvested by hand for two years, beginning when the plants were five-years-old. They were cleaned and dried in the shade and weighed after drying. The seeds were stored until 1988 when the content of oleic acid, eicosanoic acid and docosanoic acid were determined by gas–liquid chromatography.

The effects of irrigation were determined on the basis of the average production, individual plant production, number of seeds per kilogram and acid content.

RESULTS AND DISCUSSION

Seed yield. Table 2 shows the average seed production from the plots. Both years show the same trend, with seed production increasing with an increase in irrigation. DNMRT, however, shows no statistically significant differences between treatments T1 and T2; nor between T3 and T4. The results show that the T3 treatment is the most efficient because a further increase in water did not significantly increase production. The differences in production between years is assumed to be due to genetic variability, which gives rise to differences in production following frost. The plants that produced best in the second year were those that were more frost-resistant.

Table 3 shows the average production per plant. As with total production, individual plant production increased with irrigation. The DNMRT shows significant differences between treatments T1 and T2 and between T3 and T4. Again, treatment T3 was the most efficient.

Frost damage caused a high percentage of the plants not to produce seeds in the second year. The percentage of productive plants for each treatment were: T1, 48.3%; T2, 33.3%; T3, 35%; and T4, 45.8%. Under these test conditions, the plants that were irrigated during the winter did not show any differences from those that were put under water stress during the cold weather.

TABLE 2

Total Seed Production (kg)[a]

Treatment	T1	T2	T3	T4
1986	6.5a	8.4a	11.4b	11.9b
1987	3.9a	4.0a	5.8b	6.2b

[a]Within a row, means followed by the same letter are not statistically different at the 0.05 probability level according to Duncan's New Multiple Range Test.

TABLE 3

Production per Plant (g)[a]

Treatment	T1	T2	T3	T4
1986	107a	139a	194b	199b
1987	136a	161a	232b	241b

[a]Within a row, means followed by the same letter are not statistically different at the 0.05 probability level according to Duncan's New Multiple Range Test.

TABLE 4

Number of Seeds per kg[a]

Treatment	T1	T2	T3	T4
Number of seeds/kg	1372a	1366a	1287a	1160b
Weight/seeds (g)	0.73a	0.73a	0.78a	0.86b

[a]Within a row, means followed by the same letter are not statistically different at the 0.05 probability level according to Duncan's New Multiple Range Test.

Weight of seeds. Table 4 shows a decrease in the number of seeds per kg, and an increase in the individual weight of the seeds, with increasing quantity of water used. DNMRT shows a significant difference between treatment T4 and the other three treatments.

Jojoba fruits are spherical or cylindrical in shape and have the potential to produce three seeds per fruit. In

TABLE 5

Weight of Oval-Shaped and Flat-Shaped Seeds[a]

Treatment	T1	T2	T3	T4
Oval-shaped seed	0.81a	0.82a	0.85a	0.92b
Flat-shaped seed	0.56a	0.50a	0.53a	0.54a
Significance	**[b]	**[b]	**[b]	**[b]

[a]Within a row, means followed by the same letter are not statistically different at the 0.05 probability level according to Duncan's New Multiple Range Test.
[b]Within each column, means are statistically different at the 0.01 level.

TABLE 6

Percentage of Oil Attributed to Oleic, Eicosenoic and Docosenoic Acids

Treatment	T1	T2	T3	T4
1986	56.374	56.323	55.328	55.264
1987	50.485	49.870	49.795	40.095

TABLE 7

Percentage of Oleic Acid Found in the Oil

Item	T1	T2	T3	T4
1986	6.1	5.3	5.1	5.5
1987	5.7	4.4	5.5	5.8

TABLE 8

Percentage of Eicosenoic Acid Plus Docosenoic Acid Found in the Oil

Item	T1	T2	T3	T4
1986	51.2	50.9	50.1	50.1
1987	45.0	45.4	45.4	45.2

some cases, two of the three seeds abort at an early stage of development, and only a single oval seed per fruit reaches maturity. When only one seed aborts, two mature seeds per fruit develop which, together, have approximately the size and shape of a single mature seed per fruit (9,15).

Table 5 shows an increase in the oval-shaped seed weight, according to the quantity of water used. DNMRT shows a significant difference between treatment T4 and the other three treatments. Table 5 also shows a decrease in the flat-shaped seed weight with an increase in the quantity of water used. DNMRT shows no significant difference between treatments. Significant difference ($P < 0.01$) was observed between the oval-shaped and flat-shaped seed weight in every treatment.

Oil quality. Table 6 shows that an increase in irrigation decreased the total amount of oleic, eicosenoic and docosenoic acids, although this trend can not be detected by DNMRT. A significant difference ($P < 0.1$) in the total amount of the three fatty acids was detected between years for each treatment, however.

Tables 7 and 8 show that, in both years, there were no significant differences between treatments in the percentage of oleic and the eicosenoic and docosenoic acids. However, highly significant differences ($P < 0.01$) in all the treatments were found between years for the eicosenoic and docosenoic acids.

The lack of stability in wax composition from year to year could be a problem in marketing and utilization of jojoba wax. Whether this difference was due to irrigation or plant genetic differences alone was not determined.

An important variability in the wax composition of jojoba seeds due to genetic factors was determined elsewhere (10). In the first year, 240 plants produced seeds in this experiment. In the second, only 97 of the previous 240 plants produced seeds. The genetic dispersion decreased and was concentrated in the frost-resistant genotypes. Therefore, the variation could be related to different genotypes.

For the conditions of this test, the results obtained suggest that: The production of jojoba plants increases significantly with high levels of water, when applied monthly (treatments T3 = 600 mm and T4 = 900 mm). The most efficient irrigation treatment was found to be T3. Jojoba plants respond to high levels of irrigation (T4 = 900 mm) and produce the heaviest seeds under these conditions. An increase in water does not produce significant differences in fatty acid content; however, contents may change from year to year. Increased jojoba yields can be achieved over dry-farming plantations by applying irrigation. Others have found this to be so in Israel (16), Mexico (17) and Chile (18).

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