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Effects of NPK Fertilization on Flower Production, Seed Yield and Seed Components in Jojoba [*Simmondsia Chinesis* (Link) Schneider] Grown in Western Saudi Arabia*

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ABSTRACT. A two year field trial was initiated to assess the effect of an NPK fertilizer on seed yield and their components in Jojoba plants grown in Al-Madinah Al-Munawwarah area. A randomized block design of eight fertilizer treatments (2^3) comprising two levels (zero and 50 kg ha^{-1}) of each of the three major elements (N, P and K) was used. Data taken on number of flowers per twenty twig of six nodes each in the period extending between Fall 1993 and Summer 1995 (i.e. eight seasons) revealed that the four to five years old Jojoba plants were capable of producing an abundant number of floral buds throughout the year. Production of these buds was adversely affected by the application of P (in two out of eight seasons) and positively with the combined effect of N and P (in one out of eight seasons). Yield per plant ranged from 319 to 488 g and from 292 to 569 g in the respective years and was adversely affected by the addition of P and K in the first year. Wax content among the NPK treatments ranged from 40.1 to 43.4% and from 48 to 54% in the respective years and was significantly affected by the joint application of N and P in the first year. Protein content ranged from 15.2 to 19.9% and was adversely affected by the joint application of N, P and K in the second year. Estimates of 100-seed weight, being in the range of 61.3 to 103.5 g, was negatively affected by the joint application of N and P in the first year. Estimates of shelling percentage ranged from 67.4 to 77.5 and were not affected by fertilizer applications.

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Introduction

Jojoba [*Simmondsia chinesis* (Link) Schneider] is a new industrial crop that is attracting attention in many semi arid parts of the world as its seeds contain appreciable amounts (50%) of a liquid wax that is projected to be a valuable base for various industrial products.

Relatively little is known regarding fertilization requirements of Jojoba. In a previous study Yermanos (1982) indicated that applications of 50 kg N or 50 kg of P as P_20_5 ha^{-1} alone or combined together for three consecutive crops had no significant effect on vegetative growth or seed yield in Jojoba. Similarly, Osman and AboHassan (1998) indicated the NPK fertilization had virtually no significant effects on vegetative growth of Jojoba grown in Western Saudi Arabia.

In contrast to these studies, application of relatively high doses of NPK fertilizers in irrigated fields of Jojoba were reported to induce positive vegetative growth (Benzioni and Nerd, 1985; Benzioni and Dunstone, 1986), induce early flowering and increase the percentage of floral buds that broke dormancy (Nerd and Benzioni, 1988). Lovenstein (1985) estimated that about 58, 11, 22, 4 and 4-kg ha^{-1} of N, P, K, S and Mg are needed for the production of 3 t of seeds ha^{-1} from Jojoba plantations.

Adams *et al* (1977) and Reyes *et al* (1977) indicated that response of Jojoba to fertilizer applications depends on the root type (tap vs. fibrous), soil temperature and season of growth. According to these workers rooted cuttings, having fibrous root system, unlike young seedlings with a tap root system, did not respond to fertilizer applications. The present work was conducted to assess the effect of NPK application on flower production, seed yield, and wax and protein contents of seeds, seed size and shelling percentage of Jojoba plants established under the environment of Western Saudi Arabia.

Materials and Methods

The present work was conducted at a private farm in Al-Yutamah area at a distance of 75 km south of Al-Madinah Al-Munawwarah. The soil at the experimental site is sandy loam, whereas the irrigation water is non saline. Selected meteorological data characterizing the experimental site is shown in Table 1. A seed lot of Jojoba was sown in 1990, in an area of 1.152 ha (18 rows × 4 m × 160 m) under a drip irrigation system. On 20/2/1993, i.e. three years after seeding, the experimental plot was divided into four replications, each of which apart from marginal rows, consisted of 8 rows (8 × 80 m) that were spaced 4 m apart. Plants within each row were spaced 0.5 to 1 m apart. One row (32 m^2) in each replication was randomly allocated to one of the eight NPK fertilizer treatment combinations (2 × 2 × 2) where two levels (0 and 50 kg ha^{-1}) of each of

the three elements were evaluated. In conducting the trial, urea as source of N, super phosphate as source of P_2O_5 and potassium sulphate as source of K_2O were thoroughly mixed and side dressed along the row. Irrigation and weeding were conducted as needed.

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

	1993/94		1994/95		1995/96	
Season	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

Eight months after the fertilizer application and for eight consecutive seasons (i.e. until 21/9/1995), ten plants were randomly tagged in each experimental plot and were used to determine number of flowers per 20-six node twigs. Two twigs, each five internodes long, were taken from each plant. Seeds were collected from each of the ten plants in the summers of 1993-94 and 1994-95 and were used for determination of seed yield per plant, oil (wax) and protein contents of seeds, 100 seed weight and shelling percentage (i.e. weight of unshelled seeds/weight of shelled seeds × 100). Data was analyzed as suggested by Little and Little (1977).

Results

Number of Flowers and Flowering mode

The number of flowers per twig among seasons ranged from 37.6 to 42.5 flowers with an overall average of 41.5 ± 0.58 flowers for the first year and from 35.8 to 46.7 flowers with an overall average of 42.5 ± 0.58 flowers for the second year (Table 2). Data taken for the individual seasons revealed that seasonal flower production was significantly ($P \leq 0.05$) affected by application of P in the second and sixth seasons, by the joint application of N and K in the first season (F1), and by addition of N, P and K in the third season (SP1) (Tables 2 and 3). It is also evident from table 2 that the jojoba plants in Al-Madinah area continued to flower all over the year. In the first year the average number of flowers produced during the fall was significantly lower than that recorded in other seasons, whereas in the second year the number of flowers recorded in the

TABLE 2. Effect of NPK treatments on flower production of Jojoba after eight consecutive seasons (1993-1995).

NPK treatments	First year					Second year				
	21/12/93	21/3/94	21/6/94	21/9/94	Mean	21/12/94	21/3/94	21/6/94	21/9/95	Mean
	± 3.00d				± 1.52e		± 3.54d			± 1.77e
$N_0P_0K_0$	31.8	43.8	43.0	42.0	40.1	46.5	38.8	47.0	39.3	42.9
$N_0P_0K_1$	47.3	42.5	41.8	41.8	43.3	44.5	37.3	53.5	38.5	43.4
$N_0P_1K_0$	30.3	40.0	47.0	43.0	40.1	45.0	30.5	48.8	40.8	41.3
$N_0P_1K_1$	35.5	39.8	39.0	40.5	38.7	44.3	36.3	42.0	39.6	40.5
$N_1P_0K_0$	38.5	46.3	48.0	40.0	43.2	44.8	37.0	51.5	42.3	43.8
$N_1P_0K_1$	38.0	45.5	44.5	42.0	42.5	40.5	38.3	54.8	41.0	43.6
$N_1P_1K_0$	43.3	42.0	39.5	41.3	41.5	44.5	37.0	50.5	39.5	42.9
$N_1P_1K_1$	36.5	37.8	46.0	39.0	39.8	43.5	31.0	49.8	41.5	41.4
S.E. ± a	3.9	2.7	2.5	2.9		4.3	2.6	4.3	4.0	
S.E. ± b		± 1.25*				± 1.53**				
Mean (Season)	37.6	42.2	43.6	42.5		44.2	35.8	46.7	43.2	
					± 0.58 c					
Mean (Year)		41.1					42.5			

a, b, c, d & e: standard errors for individual seasons, seasons combined over years, combined years, interactions of season × NPK and treatment means averaged over seasons, respectively.

*and ** significant at $P \leq 0.05$ and $P \leq 0.01$, respectively.

TABLE 3. Summary of significance for six yields related traits of Jojoba.

		Number of flowers (a)								Yield		Wax (%)		Protein (%)		100-seed wt		Shelling (%)	
Parameter	d.f.	F_1	W_1	SP_1	S_1	F_2	W_2	SP_2	S_1	Y_1	Y_2	Y_1	Y_2	Y_1	Y_2	Y_1	Y_2	Y_1	Y_2
N	1	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
P	1	ns	*	ns	ns	ns	*	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
N × P	1	*	ns	ns	ns	ns	ns	ns	ns	ns	ns	*	ns	ns	ns	*	ns	ns	ns
K	1	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
N × K	1	*	ns	ns	ns	ns	ns	ns	ns	ns	ns	n.s	ns	ns	ns	ns	ns	ns	ns
P × K	1	ns	ns	ns	ns	ns	ns	ns	*	ns	*	n.s	ns	ns	ns	ns	ns	ns	ns
N × P × K	1	ns	ns	*	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	*	ns	ns	ns	ns

*and ns = indicate respectively significant at ($P \leq 0.05$) and no significant differences.
a = F, W, SP and S indicate Fall, Winter, Spring and Summer of the first year (Y_1) and second year (Y_2), respectively.

winter was significantly higher ($P \leq 0.1$). Average number of flowers recorded in the first year and second year (41.1 vs. 42.5) were statistically similar (Tables 2 and 3).

Seed Yield

Seed yield per plant among the eight NPK combinations ranged from 319 to 488 g with an overall average of 386 ± 73.8 g for the first year and from 291 to 569 g with an overall average of 454 ± 73.8 g for the second year (Table 4). Within the second year, seed yield was significantly affected by the joint application of P and K (Tables 3 and 4).

Wax (Oil) Content

Wax content in the seeds ranged from 40.1 to 43.4% with an overall average of 41.4 ± 0.56% and from 48 to 54% with an overall average of 51.0 ± 0.56% in the respective years (Table 4). Oil content was significantly affected by the joint application of N and P only in the first year, whereas in second year effects of NPK applications on oil content were non-significant (Tables 3 and 4).

Protein Content

Estimates of protein content in the seeds ranged from 15.2 to 17.5% with an average of 16.4 ± 0.36% and from 16.8 to 19.9% with an average of 18.6 ± 0.36% for the respective years (Table 4). Applications of N, P or K alone or in combination with one another had no significant effects on protein content in the first year; whereas the joint effects of N, P and K were significant ($P \leq 0.05$) in the second year (Tables 3 and 4).

100-Seed Weight

100-seed weight ranged from 84.8 g to 103.5 g with an overall average of 92.3 ± 1.9 g and from 61.3 to 86.3 g with an overall average of 70.0 ± 1.9 g in the respective years (Table 4). Data in Tables 3 and 4 revealed that 100-seed weight was significantly ($P \leq 0.05$) affected by the joint application of N and P in the first year and not in the second.

Shelling Percentage

Shelling percentage among the eight NPK combinations ranged from 67.4% to 77.5% with an overall average of 71.5 ± 1.5 g in the first year and from 70.1 g to 74.7 g with an overall average of 71.4 ± 1.5 g for the second year (Table 4). Data in Tables 3 and 4 revealed that shelling percentage was not significantly affected by application of N, P or K alone or in combination with one another.

TABLE 4. Effect of N, P and K treatments on seed yield and seed components of Jojoba plants grown in Al-Madinah area (1993/94-1994/95).

Season / NPK treatments	Seed yield (g/plant)		Wax content (%)		Protein content (%)		100-seed wt. (g)		Shelling percentage (%)	
	1st Year	2nd Year	1st Year	2nd Year	1st Year	2nd Year	1st Year	2nd Year	1st Year	2nd Year
$N_0P_0K_0$	429	569	41.5	54.0	15.6	19.9	87.3	68.8	68.8	70.1
$N_0P_0K_1$	435	391	41.8	50.0	17.5	18.6	103.5	68.8	74.9	70.7
$N_0P_1K_0$	319	292	40.6	52.0	16.9	18.2	87.5	67.5	69.5	73.2
$N_0P_1K_1$	337	518	41.4	48.0	17.2	18.3	94.1	77.5	68.0	74.7
$N_1P_0K_0$	324	499	41.5	48.0	15.4	18.1	94.8	61.3	77.5	70.6
$N_1P_0K_1$	356	429	40.1	50.0	17.0	18.7	94.4	65.0	73.8	70.2
$N_1P_1K_0$	488	399	43.4	54.0	16.4	18.4	93.2	65.0	72.4	70.6
$N_1P_1K_1$	400	534	41.0	52.0	15.2	16.8	84.8	86.3	67.4	71.0
S.E ± a	87.4	85.8	0.83	0.84	0.85	0.24*	4.4	7.19	2.9	2.51
S.E. ± b	± 73.8		± 0.56**		± 0.36*		± 1.9*		± 1.5	
Mean	385.9	454.0	41.4	51.0	16.4	18.6	92.3a	70.0	71.5	71.4

a & b: standard errors for individual years and combined data for two years, respectively.
*and **significant at $P \leq 0.05$ and $P \leq 0.01$, respectively.

Discussion

Data collected in this study revealed that Jojoba plants grown in Al-Madinah area are capable of maintaining a relatively high number of floral buds throughout the year (Table 2). In previous studies, Yermanos (1982) indicated that Jojoba plants established in tropical and subtropical areas are capable of maintaining a relatively high vegetative growth and consequently a positive reproductive growth (floral bud production) throughout the year. Similar results were observed by Osman *et al.* (1997) and Osman and Abo Hassan (2000) in a Jojoba population that was previously established in Al-Madinah area in Saudi Arabia.

Thus it is evident that continuous production of flowers throughout the year as observed in this study is not a desirable trait (Table 2). For a Jojoba plant to produce high yield of seed that matures over a short period of time, flowering must be synchronized and must occur at a time when critical environmental factors are satisfactory for high seed set Benzioni and Dunstone (1986). Early flowering, according to Benzioni and Dunstone (1986) and Benzioni *et al* (1982) can be minimized by withholding water and nutrients in the autumn. A late winter irrigation and application of fertilizer will then, according to these workers, stimulate abundant flowering in early spring. Breeding for low dormancy genotypes for tropical regions may prove to be a more advantageous practice (Benzioni and Dunstone, 1986; Brown and Palzkill, 1990).

Effects of NPK applications on number of flowers, seed yield and seed yield related traits evaluated in this study are very much limited. In this respect, number of flowers were adversely affected by application of P in the second (W1) and the sixth (W2) seasons (Table 2). In contrast to this, the joint application of N and K (N_0K_0 = 31.8 vs. N_1P_1 = 43.3 flowers) in first (F1) season had positively affected total number of flowers produced (Table 2).

Seed yield per plant, on the other hand, was adversely affected by the joint application of P and K (P_0K_0 = 429 g vs. P_1K_1 = 337 g) in first year but not in the second (P_0K_0 = 569 g vs. K_1P_1 = 518 g) (Table 4). In previous studies, Yermanos (1982) indicated that the addition of N alone or P alone or in combination with one another at a rate of 50 kg per ha had no significant effect on seed yield. In contrast to this, Benzioni and Nerd (1985) and Nerd and Benzioni (1988) indicated that fertilizer application in adequately irrigated fields had favorably affected both vegetative growth and seed yield.

Studies on effects of NPK applications on wax and contents of the seeds, seed size and shelling percentage are very scarce in the literature. Wax content of the seeds at Al-Madinah planting site ranged from 44.01 to 43.40% in the first year and from 48 to 54% in the second year. In previous studies, a range of

44-58% wax content was reported for Jojoba natural plantations in Southern California (Yermanos, 1982) and in Saudi Arabia (Osman and Abo Hassan, 1997and Osman and Abo Hassan, 2000). Under Al-Madinah conditions, apparently joint application of N and P in the first year (N_0P_0 = 41.5% and N_1P_1 = 43.4%) elevated the oil content of the seeds.

Seed weight (100-seed weight) under Al-Madinah conditions ranged from 61.3 to 103.5 g, and it was apparently increased by the joint application of NP in the first year (N_0P_0 = 87.3 g and N_1P_1= 93.2 g).

Thus, it is evident from the present findings that favorable effects of NPK applications on seed yield and its components in Jojoba, established under the conditions of Al-Madinah area, are very much limited.

Thus it is evident from this study that jojoba plants grown in Al-Madinah area are capable of maintaining a high number of flowers throughout the year. The plants are also capable of producing a relative high number of large seeds containing relatively adequate amounts of wax and protein comparable to those reported elsewhere (Yermanos,1982 and Osman and Abo Hassan, 2001). Apparently many interrelated factors, including the heterogeneous nature of the Jojoba population evaluated in this study (Nerd and Benzioni, 1988) might have contributed to the lack of a definite positive response of Jojoba to NPK applications. Evaluation of colonal populations under relatively controlled conditions might result in a better understanding on the response of Jojoba to NPK applications.

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أثر التسميد بالآزوت والفوسفور والبوتاسيوم على التزهير ووزن المحصول ومكونات البذور بشجيرة الهوهوبا المستزرعة بالمنطقة الغربية بالمملكة العربية السعودية

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المستخلص . أجريت تجربة حقلية لمدة عامين لدراسة أثر التسميد بالعناصر الكبرى (NPK) على إنتاج البذور ومكوناتها بشجيرة الهوهوبا ذات الأربع والخمس أعوام والمستزرعة بمنطقة المدينة المنورة . نفذت التجربة باستعمال تصميم القطع كاملة العشوائية حيث اشتملت على ثمانية معاملات (٣٢) سمادية بمعدل مستويين (صفر و٥٠ كجم/ هـ) لكل عنصر من العناصر الكبرى (N, P, K). أوضحت النتائج التي سجلت خلال الفترة من خريف ١٩٩٣م وحتى صيف ١٩٩٥م (أي لمدة ثمان فصول متتالية) أن شجيرة الهوهوبا لها القدرة على إنتاج كمية عالية من البراعم الزهرية على مدار العام ، إلا أن إنتاج هذه البراعم قد تأثر سلباً بالتسميد بعنصر الفوسفور (P) في موسمين ، وإيجابيا بالتسميد المشترك بعنصري الآزوت والفوسفور (NP) في موسم واحد من الثمانية مواسم التي شملتها الدراسة . أما وزن البذور للشجيرة الواحدة فقد تراوح ما بين ٣١٩ إلى ٤٨٨ جم ، ومن ٢٩٢ إلى ٥٦٩ جم للعامين الأول والثاني على التوالي ، وقد تأثر سلبا بالتسميد المشترك بعنصري الفوسفور والبوتاسيوم (PK) خلال العام الأول . أما محتوى الشمع في البذور فقد تراوح ما بين ٤٠,١ و ٤٣,٤ ومن ٤٨ إلى ٥٤٪ ، خلال العامين وقد تأثر بالتسميد المشترك بعنصري الآزوت والفوسفور (NP) خلال العام الأول . أما محتوى البذور من البروتين فقد تراوح ما بين ١٥,٢ و ١٩,٩ خلال العامين ، وقد تأثر سلباً بالتسميد المشترك بالعناصر الثلاث (NPK) خلال العام الثاني . أما وزن المائة بذرة والذي تراوح بين ٦١,٣ و ١٠٣,٥

خلال العامين فقد تأثر إيجابيا بالتسميد المشترك بعنصري الآزوت والفوسفور (NP) في العام الأول . أما نسبة الدراس فقد تراوحت ما بين ٤ , ٦٧ و ٥ , ٧٧٪ ولم تتأثر بإضافة الأسمدة .*