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EFFECT OF ROW SPACING AND SOWING RATE ON SEED YIELD OF ALFALFA (*Medicago sativa* L.) UNDER MEDITERRANEAN CONDITIONS

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ABSTRACT

The effects of row spacing (25, 50, 75 and 100 cm) and sowing rate (4, 8 and 12 kg ha^{-1}) on alfalfa (*Medicago sativa* L.) seed yield and its components were investigated under Mediterranean conditions throughout the years of 2008-2011. In the study cultivar Nimet was used and it was evaluated for number of pods per raceme, number of seeds per pod, biomass yield, harvest index, thousand seed weight and seed yield.
The results of the study indicated that row spacing and sowing rate significantly affected biomass yield and harvest index but no significant differences were found in pod number and thousand seed weight. Seed yield was significantly affected by sowing rate. The highest and the lowest seed yield were recorded in the first and third years of the experiment, respectively. The highest seed yield averaged over three years was obtained from 25 cm row spacing with 4 kg ha^{-1} seed rate while the lowest one was obtained from 75 cm row spacing with combining 4 kg ha^{-1} seed rate. Results of this study suggest that among the various row spacing and seeding rates, narrower row spacings (25 cm or 50 cm) with the lowest seeding rate (4 kg ha^{-1}) were found to be better treatments for alfalfa seed production under Cukurova ecological conditions.

Key words: Alfalfa, row spacing, sowing rates, seed yield components

INTRODUCTION

Seed yield of alfalfa (*Medicago sativa* L.) is important in determining the effective distribution of new cultivars to farmers (Bolanos-Aguilar et al., 2002). Many genetic and environmental factors affect seed yield. Successful alfalfa seed production is favored in regions that are characterized by clear, sunny, warm summer days in combination with little or no rainfall. These climatic conditions promote good flowering of alfalfa and provide an environment conductive to the pollinating activity of bees. In addition to a favorable climate, there are other variables that will influence the yield and quality of alfalfa seed. Stand density is known to be an important factor in seed production because competition between and within plants affects a plant's ability to produce vegetative and reproductive material. The flowering period should be timed to coincide with the period of least competition from other pollen sources and greatest pollinator activity. The best period of flowering is not the same for every location because seed is grown over a wide range of climatic conditions where different pollinators predominate. Irrigation requirement for alfalfa seed production is dependent upon soil texture, natural precipitation, temperature, and length of growing season. Highest seed yield could be obtained when irrigation practices prevent severe plant stress and promote slow, continuous growth through entire production period without excessive stimulation of vegetative growth.

According to Rincker et al. (1988), seed yield is a complex trait and it depends on the number of seeds per unit area and individual seed weight. Seeds are produced in pods and the yield components include number of seeds per pod, number of pods per raceme, number of stems per plant and number of plants per unit area. They also stated that alfalfa seed yields range from 0 (crop failures) to a verified yield of 2110 kg ha^{-1} of clean seed. Thin, uncrowded stands are recognized capable of producing higher seed yield than dense stands in solid planted fields. Low seed production from dense stands can be explained in part by low nectar production, unattractiveness to pollinators, and increased floral abortion. Proper row spacing for alfalfa depends on soil depth and texture, total water availability, length of growing season, cultivar and possibly other factors.

In the previous researches, carried out in different countries, (Askarian et al., 1995; Mermer and Serin, 2007;

Abadouz et al., 2010) various and often not consistent suggestions were stated about appropriate row spacing and seeding rate to achieve the highest seed yield of alfalfa. According to Askarian (1993), recommendations for optimum row spacing and sowing rate for alfalfa seed production vary in the literature, and several studies have reported conflicting results. He also stated that in New Zealand, alfalfa seed has commonly been produced in rows 9 or 18 cm apart at sowing rates of 6-12 kg ha^{-1}. Along with that in the United States, row spacings from 60 to 150 cm apart and seed rates from 0.5 up to 2 kg ha^{-1} were reported (Abu Shakra et al. 1969).

The increase in the production of alfalfa seed yield should help to provide sufficient supply of local alfalfa seed, which would decrease the dependence on imported seed. Objectives of this study were to determine the optimum row spacing and seeding rate for alfalfa cultivar Nimet and its seed production potential under Cukurova climatic conditions.

MATERIALS AND METHODS

Non-dormant (Fall dormancy rating 8) synthetic cultivar Nimet was used as plant material for field experiment at the East Mediterranean Agricultural Research Institute, Adana, Turkey (36° 51.675 N, 035° 20.662 E, altitude 14 m above sea level) under irrigated management conditions during 2008-2011. The soil type was silty-clay; with organic matter content 2.51%, pH level 7.62, and P_2O_5 level 87.0 kg ha^{-1} and rich in lime. The southern region of Turkey has long growing season and moderate climatic conditions during winter. Summers are hot and humid with many days above 30°C. Meteorological data of location is presented in Table 1. The mean long-term annual temperature is 18.8 °C, the lowest and highest average temperatures occur in January and August, respectively. During the experiment years annual average temperatures were 19.1, 20.7 and 18.8, respectively. Annual average temperature was lower in 2011 comparison to 2009 and 2010.

Table 1. Some meteorological data of Adana province

	Average temperature (°C)				Total precipitation (mm)				Relative humudity (%)			
Months	**2009**	**2010**	**2011**	**LYA**	**2009**	**2010**	**2011**	**LYA**	**2009**	**2010**	**2011**	**LYA**
Jauary	10.0	11.0	9.9	9.3	146	148	79	109	63.1	68.6	64.1	65.6
February	11.0	12.0	11.2	10.0	131	80	113	84	73.6	63.4	62.5	63.7
March	13.0	14.8	13.2	13.0	135	0	83	60	66.5	62.0	66.5	65.1
April	18.0	17.5	16.5	17.3	34	40	117	48	63.5	62.9	68.5	67.1
May	22.0	21.1	20.2	21.5	29	0	30	44	58.5	66.2	69.3	66.0
June	27.0	25.0	24.5	25.3	0	1.4	0	21	59.8	64.9	72.1	67.0
July	28.0	27.8	27.9	27.8	23	0.7	0	10	66.1	67.4	72.7	70.7
August	29.0	30.2	28.8	28.3	0	0	0	8	59.2	64.0	67.6	70.8
September	25.0	27.2	26.9	26.0	33	1.7	0	15	60.7	66.6	63.4	64.4
October	24.0	21.6	20.8	21.3	16	17	6	52	57.9	63.4	49.4	60.8
November	15.0	19.1	12.6	14.7	130	0	35	85	69.3	53.3	54.5	64.0
December	12.0	13.3	10.0	10.6	131	212	225	120	72.1	71.5	65.5	66.7
Mean/Total	19.1	20.7	18.8	18.8	808	501	661	655	64.2	64.5	65.5	66.0

+) LYA: Long years average

Long-term averaged annual precipitation of the Province Adana is 655 mm, most of rain falls in winter months so distribution unbalanced and leading to long and short-term droughts in summer months, while relative humidity of the province is 66.0%. Throughout the research years of 2009, 2010 and 2011, total annual precipitation amounts were calculated as 808, 501 and 661mm respectively. In the third year of the experiment monthly average relative humidity, especially for June, was calculated to be relatively higher than those in 2009 and 2010 (Anonymous, 2009-2011).

The seedbed was prepared by ploughing and then firming with a field cultivator and harrow. The experiment was arranged in a split-plot design with four replications. Main plots were row spacings and the sub-plots were sowing rates. The area of each sub-plot was 3 m x 5 m= 15 m^2. The row spacings were 25, 50, 75 and 100 cm, and the sowing rates were 4, 8 and 12 kg ha^{-1}. Plots were fertilized with 120 kg ha^{-1} of P_2O_5 and 50 kg ha^{-1} of N prior to sowing. The plots were sown on 20 March 2008. The first year of study (2008) was considered as establishment year and plots were harvested several times for hay production. In the second, third and fourth years of study, first harvests were done at the first week of May when plants reached to the early flowering stage (10% bloom). Second harvests were made for seed production. Normally in the Cukurova basin (deep-medium or heavy-textured soils) winter and early spring rains could satisfy requirements of alfalfa for second-crop seed production unless rainy season is not drought. However enough moisture must be supplied in the spring and especially summer months to maintain growth and overcome the detrimental effects of moisture stress. Therefore flood irrigation was applied when it was needed. The weather in March, April and May of 2010 had lower precipitation (0.0, 40.0 and 0.0 mm) in comparison to the same months of 2009 and 2011 (135, 34, 29 and 83,117, 30 mm respectively), (Table 1). For that reason, one irrigation was made after first cutting for hay production only in the spring of 2010. Two irrigations in August and in September after seed harvest were done in all three years.

Weeds were controlled with hand hoeing as needed throughout the growing seasons. Pollination during the seed production years was provided primarily by leaf cutter bees (*Megachile rotundata*) naturally found in the region (Avci et al. 2010b), and other pollinators such as honey bees (*Apis mellifera* L.) and bumble bees (*Bombus spp*.). Although honey bees were in high populations, their tripping activities were lower than those of leaf cutter bees. To determine the number of pods per raceme and the number of seeds per pod 20 racemes were chosen randomly in each plot (Dordas, 2006). After counting the pods on a one raceme, they were grinded by hand and the average number of seeds per pod was calculated. Forage dry biomass, harvest index and seed yields were estimated by harvesting the center of each plot (8, 4, 3 and 2 rows with a 4 m length for 25, 50, 75 and 100 cm row spacings, respectively). Plots were harvested when the most of the pods were reached to black-browned color (Askarian et al. 1995) during the second week of July. All harvested plant material from each plot was air dried for each year and weighed to determine alfalfa dry biomass.

The harvest index was calculated as the ratio between seed yield and total alfalfa dry biomass (seed + seed pods + all vegetative parts). To obtain clean seed, naturally dried plant material from each plot was threshed and cleaned by experimental sieves and blower. Seed yield was determined weighing harvested seed from each plot.

Analysis of variance was performed using the MSTAT-C statistical analysis programmer, and differences were compared using Duncan's multiple range test (Steel and Torrie, 1960).

RESULTS AND DISCUSSION

Pod number

Results of the variance analysis showed that the number of pods per raceme was not significantly influenced by row spacing and sowing rate in 2009, 2011 and three years average (Table 2).

Table 2. Averaged values for the number of pods per raceme under three sowing rates and four row-spacings in the years of 2009, 2010 and 2011

Row spacing (cm)	Sowing rate (kg ha^{-1})	Years			
		2009	**2010**	**2011**	**Average**
25	4	18.1	14.0	11.7	14.6
	8	17.2	13.8	11.4	14.1
	12	17.6	13.7	11.6	14.3
Mean		17.6	**13.8 B+**	11.5	14.3
50	4	17.5	14.5	11.8	14.6
	8	18.3	14.9	12.3	15.2
	12	17.0	14.9	12.0	14.7
Mean		17.6	**14.8 A**	12.0	14.8
75	4	16.9	13.2	11.4	13.8
	8	17.0	14.3	11.9	14.4
	12	17.1	14.1	11.7	14.3
Mean		17.0	**13.9 B**	11.7	14.2
100	4	18.2	14.8	11.5	14.8
	8	18.6	14.9	11.9	15.1
	12	17.5	14.1	11.4	14.3
Mean		18.1	**14.6 AB**	11.6	14.8
Grand Mean		**17.6 A***	**14.3 B**	**11.7 C**	**14.5**

Means with the same capital letter in the same column are not statically significant different according to Duncan test at P ≤ 0.05 probability level.
* Means with the same letter in the same line are not statically significant different according to Duncan test at P ≤ 0.05 probability level.

Although no significant differences were found among treatments, the highest mean number of pods (18.1) per raceme was found in 100-cm row spacing in the first year of experiment (2009). In contrast, the averaged values in 2010 were influenced by row spacing. The number of pods per raceme tended to increase as row spacing increased from 25 cm to 50 cm and it was significantly higher at the 50 cm than those at 25 cm and 75 cm. Significant differences were observed among years for number of pods per raceme. Averaged pod number per raceme (17.6) in 2009 was significantly higher than those in 2010 and 2011 (Table 2). Although the effect of row spacing on the number of pods per raceme was significant in 2010, no consistent trend was detected among the three years averaged values of pod number per raceme. Alfalfa has a highly specialized flower with a unique tripping mechanism that limits the types of insects providing pollination. The percentage of flowers setting pods in a highly self-sterile plant may vary considerably, depending partly upon the environment. Plant density and plant vigor usually decline with increasing stand age (Sheaffer et al. 1988; Avci et al. 2010a; Cinar and Hatipoglu, 2015). Decreasing the number of pods per raceme as years advanced can be attributed to the reductions in plant vigor and for this reason to reductions in biomass production, flowers and number of pods per raceme. In the previous researches, Askarian et al. (1995), Zhang et al. (2008), Rashidi et al. (2009) and Abadouz et al. (2010) found similar results to our findings that sowing rate and row spacing had not significant effect on pod number per raceme.

Seed number

Row spacing and sowing rate did not significantly affect seed number per pod during the experimental years (Table 3). However, the highest (5.48) and the lowest (4.63) number of seeds per pod were determined with the combination of 25-cm row spacing and 8 kg ha^{-1} sowing rate, and with that of 100 cm row spacing and 4 kg/ha sowing rate, respectively, in 2009, whereas the highest seed numbers per pod were recorded with 75 cm row spacing and 12 kg ha sowing rate in 2010 and 2011.

Table 3. Averaged values for seed number per pod under three sowing rates and four row-spacings in the years of 2009, 2010 and 2011

Row spacing (cm)	**Sowing rate (kg ha^{-1})**	**Years**			
		2009	**2010**	**2011**	**Average**
	4	4.80	4.87	4.85	4.84
25	8	5.48	4.50	4.28	4.75
	12	5.03	4.05	4.03	4.37
Mean		**5.01**	**4.47**	**4.39**	**4.65**
	4	4.85	4.69	4.45	4.66
50	8	5.13	5.02	4.76	4.97
	12	5.32	4.64	4.38	4.78
Mean		**5.10**	**4.78**	**4.53**	**4.80**
	4	4.91	4.71	4.56	4.69
75	8	4.86	4.89	4.63	4.79
	12	5.19	5.28	5.01	5.16
Mean		**4.99**	**4.96**	**4.70**	**4.88**
	4	4.63	4.85	4.65	4.71
100	8	5.14	4.90	4.70	4.91
	12	5.34	5.05	4.77	5.05
Mean		**5.04**	**4.93**	**4.70**	**4.89**
Grand Mean		**5.07 A***	**4.79 B**	**4.85 C**	**4.81**

* Means with the same capital letter in the same line are not statically significant different according to Duncan test at $P \leq 0.05$ probability level.

The year effect (environmental conditions during growing season) was significant for seed number per pod. The mean number of seeds per pod in the first experimental year was significantly higher than those in the second and third years, and it was significantly higher in the second year than that in the third year (Table 3). The high percentage of flower abortion occurs in lucerne and seed number per pod is closely related with the amount of the production and storage of photosynthetic materials (Gender et al., 1997).

The poor performance of mean seed number per pod, like pod number per raceme, in 2010 and 2011 can be attributed to competition among plants for nutrients, senescence, disease and other pest's damages. Based on average of three years, the seed number per pod changed between 4.37 and 5.16, but no statistically significant differences were found among them. According to Wang et al. (2011) an alfalfa flower has 7-13 ovules, but only a small proportion usually develop into seed. They also stated that the numbers of ovules per ovary, fertile ovules per floret and the number of seeds per pod among the alfalfa varieties varied. Few-to-many ovules can be sterile and unavailable for fertilization (Rosellini et al. 1998). A low seed/ovule ratio is a general characteristic of outcrossing species. In general, no more than 5 ovules per pod could become seed (Lorenzetti, 1993). In the previous researches, Rashidi et al. (2009) reported the number of seed per pod as 5.5-5.7, Gender et al. (1997) as 3.36-4.62, Iannucci et al. (2002) as 1.04-7.41, Abdouz et al. (2010) as 4.1-4.8 and Dordas (2006) as 1.85-9.16. According to the results of this study, the number of seeds per pod wasa unimportant yield component at different plant densities. This results agree with those of Askarian et al., (1995) and Zhang et al. (2008), who reported that there were no change in the number of seeds per pod when plants were grown at different row spacings.

Biomass yield

The statistical results of the study indicated that biomass yield (dry weights of shoots and seeds) was significantly ($P \leq 0.05$) influenced by the row spacing in 2009 and both row spacing and sowing rates in the averaged values of three years (Table 4).

Table 4. Averaged values (kg ha^{-1}) for biomass yield under three sowing rates and four row-spacings in the years of 2009 2010 and 2011

Row spacing (cm)	Sowing rate (kg ha^{-1})	Years			
		2009	**2010**	**2011**	**Average**
	4	6158	4263	4240	4887
25	8	6200	4345	3995	4846
	12	6270	4583	4318	5057
Mean		**6209 A+**	**4397**	**4184**	**4930 A+**
	4	5228	4250	4065	4514
50	8	5118	4025	3765	4303
	12	5283	4225	3870	4459
Mean		**5209 B**	**4167**	**3900**	**4425 AB**
	4	4718	3712	3530	3987
75	8	5000	3810	3673	4161
	12	5040	4320	4155	4505
Mean		**4919 B**	**3948**	**3786**	**4218 B**
	4	4423	3240	3478	3713
100	8	4847	3598	3760	4065
	12	4733	3568	3915	4072
Mean		**4664 B**	**3468**	**3718**	**3950 B**
	4	5131	3866	3828	4275 B+
A.V.S.R	8	5289	3944	3798	4344 B
	12	5331	4174	4064	4523 A
Grand Mean		**5250 A***	**3995 B**	**3897 B**	**4381**

+) Means with the same capital letter in the same column are not statically significant different according to Duncan test at $P \leq 0.05$ probability level.
* Means with the same capital letter in the same line are not statically significant different according to Duncan test at $P \leq 0.05$ probability level.
A.V.S.R: Average Values for Sowing Rates

There were also significant year effect and year x sowing rate interactions on biomass production. Sowing rates did not have statistically significant effect on dry biomass production in the all years.

In the first year of the research, the narrowest (25 cm) row spacing produced statistically significant higher biomass yield than the other row spacings tested. Increasing row spacing resulted in decreasing the biomass yield, but the biomass yields at wider row spacing than 25 cm were not statistically different from each other. In the second and third years of the research, the biomass yield was not statistically significant influenced by the row spacing. According to the averaged values over three years, row spacing of 25 cm resulted in statistically significant higher biomass yield than the row spacings of 75 and 100 cm. The row spacing of 50 cm gave statistically smilar biomass yield with all other row spacings. On the other hand, increasing sowing rate increased the biomass yiled and the biomass yield at 12 kg ha^{-1} was significantly higher than those at the sowing rates of 4 and 8 kg ha^{-1}. Plants were smaller and less vigorous in 2010 and 2011 as compared in the second year of establishment (2009). Therefore averaged biomass yield (5250 kg ha^{-1}) in the second year of establishment was higher than those (3995 and 3897 kg ha^{-1}, respectively) in the other years. The climatic conditions, especially during the vegetative growth, were quite variable. The year 2009 with higher and steadily rainfall up to the June was the best year for alfalfa biomass production when compared with 2010 and 2011. Lower rainfall during the vegetative growth period could explain the lower dry biomass yield obtained in 2010. During the vegetative growth period in 2011, the amount of the precipitation was higher than in the year of 2010, but increasing the stand age and declining the plant vigor resulted in significant biomass yield decrease. Bolanos-Aguilar et al. (2002) reported that seed yield of alfalfa cultivars was highly correlated with aboveground biomass at harvest (r = 0.94). In another study (Gender et al. 1997) stated that seed production of lucerne is very low (250- 400 kg ha^{-1} seed) compared to its high vegetative biomass (8000 kg ha^{-1}).

Harvest index

Results of the variance analysis showed that the harvest index of alfalfa was significantly influenced by row spacing and sowing rate and their interactions (AXB) in the first year (Table 5). But it was influenced by only row spacing in the second and third years of the experiment. Based on averaged values over three years, row spacing, sowing rate, and year significantly affected the harvest index. On the other hand, significant interactions were determined between row spacing and years (AxC), and among the row spacing, sowing rates and years (AxBxC)

Table 5. Averaged values (%) for harvest index under three sowing rates and four row-spacings in the years of 2009, 2010 and 2011

Row spacing (cm)	Sowing rate (kg ha^{-1})	Years			
		2009	2010	2011	Average
25	4	14.6 bc[1]	14.2	7.53	12.1
	8	10.6 f-h	14.6	7.65	10.9
	12	9.6 h	13.6	7.85	10.4
Mean		**11.6 B+**	**14.1 B+**	**7.68B+**	**11.1B+**
50	4	13.3c-e	16.1	9.05	12.8
	8	14.1b-d	15.6	8.30	12.7
	12	10.4 gh	16.1	10.6	12.4
Mean		**12.6 B**	**15.9 AB**	**9.33AB**	**12.6A**
75	4	12.4d-f	16.2	11.4	13.3
	8	12.7c-e	17.6	10.9	13.7
	12	11.6e-g	17.0	9.78	12.8
Mean		**12.2B**	**16.9 A**	**10.7A**	**13.3A**
100	4	16.9a	17.7	9.08	14.5
	8	14.2b-d	16.0	8.70	12.9
	12	15.7ab	16.1	8.48	13.4
Mean		**15.6 A**	**16.6 A**	**8.75 B**	**13.6 A**
A.V.S.R	4	14.3 a[1]	16.1	9.3	13.2 A+
	8	12.9 b	16.0	8.9	12.6 B
	12	11.8 c	15.7	9.2	12.2 B
Grand Mean		**13.0B***	**15.9 A**	**9.11 C**	**12.7**

[1] Means with the same letter in the same column are not statically significant different according to Duncan test at $P \leq 0.05$ probability level.
+) Means with the same capital letter in the same column are not significantly different according to Duncan test at $P \leq 0.05$ probability level.
* Means with the same capital letter in the same line are not statically significant different according to Duncan test at $P \leq 0.05$ probability level.
A.V.S.R: Average Values for Sowing Rates

In the first year of the experiment, the highest harvest index values were recorded at 100 cm row spacing and 4 kg ha^{-1} sowing rates while the lowest ones were found in the narrowest row spacing with 12 kg ha^{-1} sowing rate. The lower harvest index from the combination of 25 cm row spacing and 12 kg ha sowing rate suggesting that the thicker plant density produced much more biomass but it could not compensate seed and pod development. High density of bushes on rows has undesirable effect on production seed rate (Abadouz, 2010). In the second and third years of the experiment, increasing the row spacing up to 75 cm increased harvest index and this row spacing resulted in statistically significant higher harvest index than that at the row spacing of 25 cm. Increasing the row spacing more than 75 cm did not increase the harvest index as compared with that at 75 cm row spacing. Based on averaged values over three years, the row spacing of 50 cm gave statistically significant higher harvest index than the row spacing of 25 cm but it was statistically similar with the row spacings of 75 and 100 cm. Harvest index is an important indicator of how vegetative mass is allocated to seed at crop maturity (Iannucci, 2002; Dordas, 2006).

According to the three year averaged values, the sowing rate of 4 kg ha^{-1} gave statistically significant higher harvest index than the other sowing rates, and increasing sowing rate decreased the harvest index (Table 5).

Averaged harvest index (15.9 %) in the second year was significantly higher than those of the first and third years (13.0 and 9.11 %). Alfalfa is a primarily cross-pollinated species, and a flower must be tripped before fertilization, so it must be visited at least once by an insect for seed setting. During the flowering and pollination periods in the third year of experiment, average relative humidity of June (72.1%) was significantly higher than those of the first and second years (Table 1). Higher humidity during the flowering period under hot temperature conditions of Cukurova basin had a negatively impact on pollination activity of the pollinator bees, and this could be reason of the lower harvest index in the year of 2011.

The results on the harvest index from this study are in agreement with those of Iannucci et al. (2002), who stated that the weather conditions affected the harvest index and seed yield. They also stated that wide range of harvest index values (4.2 to 24.2) had been determined in alfalfa however no consistent relationship was found between treatments and cultivars in that character over the 3-year period.

Harvest index values determined in the present study were higher than those reported by Askarian (1993); Mermer and Serin (2007), while they are similar with those reported by Bolanos-Aguilar et al. (2002).

1000-seed weight

The 1000-seed weight was not statistically significan influenced by the varying row spacing and sowing rate in 2009, 2010, and 2011 and in the averaged values over three years. Averaged value of 1000-seed weight was statistically significant higher in the first year than those in the second and third years of experiment (Table 6).

Table 6. Averaged values (g) for 1000 seed weight under three sowing rates and four row-spacings in the years of 2009, 2010 and 2011

Row spacing (cm)	**Sowing rate (kg ha^{-1})**	**Years**			
		2009	**2010**	**2011**	**Average**
25	4	2.08	1.90	1.84	1.94
	8	2.07	1.84	1.82	1.91
	12	2.06	1.90	1.85	1.94
Mean		2.07	1.88	1.84	1.93
50	4	2.10	1.88	1.84	1.94
	8	2.11	1.87	1.86	1.94
	12	2.07	1.89	1.84	1.93
Mean		2.09	1.88	1.85	1.94
75	4	2.05	1.84	1.80	1.89
	8	2.05	1.92	1.83	1.93
	12	2.06	1.93	1.82	1.93
Mean		2.05	1.90	1.82	1.92
100	4	2.15	1.93	1.87	1.98
	8	2.04	1.87	1.82	1.91
	12	2.06	1.89	1.83	1.92
Mean		2.08	1.90	1.84	1.94
Grand Mean		**2.07 A***	**1.89 B**	**1.83 C**	**1.93**

* Means with the same letter in the same line are not statically significant different according to Duncan test at $P \leq 0.05$ probability level.

According to the averaged values over three years, the lowest sowing rate (4 kg ha^{-1}) with the widest row spacing (100 cm) produced the highest 1000-seed weight (1.98 g), while the lowest 1000-seed weight (1.89 g) was determined at the 4 kg ha^{-1} sowing rate and 75 cm row spacing. However no statistically significant differences found among them.

These results supported the finding of Zhang et al. (2008) who reported that seed size was influenced primarily by years but no significant differences between-row spacing treatments over the years. Rashidi et al. (2009) also stated that seeding rates did not significantly affect the 1000- seed weight. In the previous researches, 1000- seed weight of alfalfa was found by Askarian (1993) as 1.53-1.82 g; by Mermer and Serin (2007) as 1.86-1.95 g; by Wang et al. (2011) as 1.63-2.07 g; Iannucci et al. (2002) as 1.92-2.32 g; by Dordas (2006) as 1.74-2.39 g; by Rashidi et al. (2009) as 2.24-2.29 g. The values related to 1000 seed weight recorded in this study were lower than those reported by Rashidi et al. (2009) and higher than those Askarian et al. (1995) while 1000 seed weight values determined by Mermer and Serin (2007) were similar with those of this study. These results indicate that environmental conditions and cultivar differences (Rincker et al. 1988; Iannucci et al. 2002; Zhang et al. 2008) have greatly effect on 1000-seed weight.

Seed yield

Results of the variance analysis showed that the seed yield of alfalfa was significantly influenced by sowing rates in the first and second years. In addition to these, row spacing x sowing rate (AxB) interactions in the first and second years and in the averaged values over three years were found highly significant. Seed yield did not significantly change depending on the row spacing during the years of the experiment.

Based on combined analyses of the data from three years, row spacing x sowing rate (AXB), year (C), row spacing x year (AxC), and sowing rate x year (BxC) interactions significantly affected the seed yield (Table 7).

In the first year of experiment the highest seed yield (834 kg ha^{-1}) was obtained from the narrowest row spacing at the 4 kg ha^{-1} seed rate, while the lowest yield (582 kg ha^{-1}) was obtained from 50 cm row spacing at the rate of 12 kg ha^{-1} seed (Table 7) . In this year, increasing the sowing rate decreased the mean seed yield, and the lowest sowing rate (4 kg ha^{-1}) produced statistically significant higher seed yield (754 versus 707 and 667 kg ha^{-1}) than two higher sowing rates. On the other hand, mean seed yield at the sowing rate of 8 kg ha^{-1} was statistically significant higher than that at the sowing rate of 12 kg ha^{-1}. However the highest sowing rate (12 kg ha^{-1}) produced statistically significant higher mean seed yield than the other sowing rates in the the second year. In the third year, increasing the sowing rate tended to increase the mean seed yield, but these increases were not statistically significant. (Table (7). In the first year higher sowing rates probably create greater interplant competition, resulting in a negative effect on seed yield. In the next two years, the lowest seed yields were consistently obtained from the lower seed rates probably that with the thinner or spaced plant density could no longer compensate for declining seed yield.

Table 7 Averaged values (kg ha^{-1}) for seed yield under three sowing rates and four row-spacings s in 2009, 2010 and 2011

Row spacing (cm)	Sowing rate (kg ha^{-1})	Years			
		2009	**2010**	**2011**	**Average**
25	4	834 a[1]	610 a-c[1]	335	593 a[1]
	8	676 b-e	619 a-c	354	550 a-d
	12	672 b-e	631 a-c	400	568 a-d
Mean		**727**	**620**	**363**	**570**
50	4	738 a-d	645 ab	386	590 ab
	8	694 b-d	563 cd	352	536 b-d
	12	582 e	653 a	409	548 a-d
Mean		671	620	382	558
75	4	666 c-e	524 d	351	514 d
	8	754 a-d	591 a-d	388	577 a-c
	12	646 de	649 ab	403	566 a-d
Mean		689	588	381	552
100	4	779ab	533d	311	541 a-d
	8	703b-d	570cd	318	530 cd
	12	769a-c	579b-d	329	559 a-d
Mean		750	561	319	543
A.V.S.R	4	754 a[1]	578b[1]	346	560
	8	707b	586b	353	548
	12	667c	628a	385	560
Grand Mean		**709 A***	**597 B**	**361 C**	**556**

* Means shown with the same letter in the same column are not statically significant different according to Duncan test at P ≤ 0.05 probability level.
** Means shown with the same capital letter in the same line are not statically significant different according to Duncan test at P ≤ 0.05 probability level.
A.V.S.R: Average Values for Sowing Rates

This results probably indicate that wide row spacing promotes more branches, flowers per plant, higher percentage seed set, and higher seed yield per plant (Kowithayakorn and Hill, 1982). However, the combination of narrower row spacing with higher sowing rates consistently had higher seed yield as year advanced.

The highest and the lowest seed yields were determined in the first and third years respectively. The poor performance of alfalfa in 2010 and 2011 can be attributed to stand decline with competition among plants, senescence, diseases and other pest damages. Because plant population and yield (herbage and seed yield) usually decline with increasing stand age (Sheaffer et al. 1988). Avci et al. (2007) also found that alfalfa cultivars produced the highest seed yield in the second years of establishment. Reductions in plant vigorous result in decreasing biomass production, flowers and number of pods per racemes. In the previous researches, seed yield of alfalfa was found by Askarian et al. (1993) as 102-209 kg ha^{-1} ; by Iannucci et al. (2002) as 130-660 kg ha^{-1} ; by Rashidi et al. (2009) as 606-805 kg ha^{-1}; by Avci et al. (2007) as 537-634 kg ha^{-1} . The mean values related to seed yields recorded in this study (543-570 kg ha^{-1}) were lower than those reported by Rashidi et al. (2009), higher than those Askarian et al. (1995), while similar Avci et al. (2007). Variation among the yields may be due to differences in location, climatic conditions and management techniques under researches were conducted.

CONCLUSIONS

Results of this study suggest that among the various row spacing and seeding rates, narrower row spacings (25 cm or 50 cm) with the lowest seeding rate (4 kg ha^{-1}) were found to be better treatments for alfalfa seed production under Cukurova ecological conditions.

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