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Research Article

Effect of row spacing on seed and forage yield in sainfoin (*Onobrychis viciifolia* Scop.) cultivars

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Abstract: A field experiment including 3 sainfoin cultivars (Makedonka, EG Norm, and the Sokobanja population) was set up in a seed production trial with the aim of determining adequate row spacing for seed and forage yield. The cultivars were sown at 3 different row spacings (20 cm, 50 cm, and 80 cm) and at a within-row spacing of 1 cm. Seed yield was determined over a 3-year period, whereas forage yield and quality were evaluated from the 2nd cut in the 2nd and 3rd years. Crop thinning through the years, distinct competitive ability of sainfoin, and a large impact of weather conditions induced significant differences in seed yield among years. All cultivars gave considerably higher yields at wider row spacings in the 2nd and 3rd years of the experiment. The cultivars responded differently to variable row spacings across years, which was due to differences in seed yield performance under different growing spaces and available moisture conditions. Owing to the low profitability of seed yield, in respect of both seed and forage yield, the use of wider row spacings (about 50 cm) for vigorous cultivars and narrower row spacing (below 50 cm) for less vigorous cultivars for seed yield may become feasible.

Key words: Forage yield and quality, row spacing, sainfoin, seed yield

Introduction

Sainfoin (*Onobrychis viciifolia* Scop.) is a perennial forage legume grown in warm-temperate and dryland areas of Europe, Asia, and western North America (Frame 2005). It is tolerant of high levels of active lime in the soil (DeFalco et al. 2000) as well as of lower phosphorus levels. Although it is characterised by low nitrogen fixation as compared to major perennial legumes, its well-developed root system ensures its good tolerance to soil moisture deficiency (Cash and Ditterline 1996). Sainfoin can also be used for soil organic matter improvement in vineyards and orchards (Porqueddu et al. 2000), as well as for control of wind and water erosion (Xu et al. 2006).

The recent decrease in the acreage of sainfoin and other legumes in Europe has been generally induced by the expansion of forage production in grasslands resulting from the use of more inexpensive mineral fertilisers (Rochon et al. 2004). Borreani et al. (2003) imply that this is due to both structural changes in agricultural ecosystems and a gradual decline in livestock population in Mediterranean upland regions.

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Problems related to the seed production of forage crops in less intensive production regions have not been sufficiently studied. This is due to the fact that attention has mostly focused on resolving problems associated with the cultivation of major profitable crops in developed regions (Porqueddu et al. 2000). Consequently, the obtained amounts of sainfoin seed are far below the demand (Gintzburger et al. 1990; Porqueddu et al. 2000). Perennial legume seed production in arid and semiarid regions is closely related to the amount of evaporation, precipitation, and temperatures during the growing period (Kholak and Gowda 1989; Martinello and Ciola 1994; Martinello 1998). Accordingly, the cultivation of perennial legumes for seed production under arid and semiarid conditions, as reported by Martinello (1998), requires the use of adequate cultural practices to compensate for unfavourable environmental conditions.

The relatively scarce literature on the optimal plant number per unit area in sainfoin seed production is also due to poor persistence of sainfoin, i.e. strongly pronounced stand thinning through the years. Accordingly, Vučković et al. (1997), Ivanovski et al. (1998), and Martinello (1998) recommend narrow row spacing (about 20 cm) and higher seed rates. Conversely, larger growing space facilitates the development of generative organs (Altın and Tuna 1996) by enhancing yield components positively correlated with seed yield (Türk and Çelik 2006a). However, Martinello and Ciola (1994) report that seed yield of sainfoin varieties and ecotypes is more affected by year and available moisture reserves than by plant density.

One of the reasons for the low acreage of sainfoin is lack of profitability of seed production, i.e. relatively low seed yields. Gintzburger et al. (1990) report average seed yields of 0.5 t ha^{-1} in Provence (France). Apart from this, sufficiently high amounts of seeds (pods) are required for good establishment of sainfoin. Accordingly, an analysis should be conducted not only for seed yields at different row spacings, i.e. seed rates per unit area but also for biomass yield obtained from subsequent growth (combined seed and forage production). The objective of this study was to determine approximate row spacings to be employed to achieve the most satisfactory performance in terms of seed and forage yield.

Materials and methods

Soil properties: A field experiment was set up at a trial field of the 'Serbia' Agricultural Research Institute, Agricultural and Technological Research Centre Zaječar (located at 43°53′219′N; 22°17′352′E and 159 m a.s.l.) in 2002-2004. The trial was established on vertisol that contained 0.98% $CaCO_3$, 2.8% organic matter, and 6.3 mg and 16.2 mg P and K 100 g^{-1} soil, respectively. The preceding crop was winter wheat. In autumn 2001, 45 kg ha^{-1} N, 45 kg ha^{-1} P_2O_5, and 45 kg ha^{-1} K_2O were incorporated into the soil by primary tillage. During seedbed preparation, the EPTC (Bescort) herbicide was incorporated at a rate of 5 L ha^{-1}.

Weather conditions: Data on mean monthly temperatures and rainfall were recorded throughout the experiment by a weather station located within the Institute. As compared to the long-term average (1967-2001), the mean annual temperature was 1.2, 0.5, and 0.4 °C higher in 2002, 2003, and 2004, respectively. Monthly rainfall (Figure) showed large variations across experimental years, particularly during the growing season (April-September).

Experimental design: Three sainfoin cultivars, namely Makedonka, EG Norm, and the Sokobanja

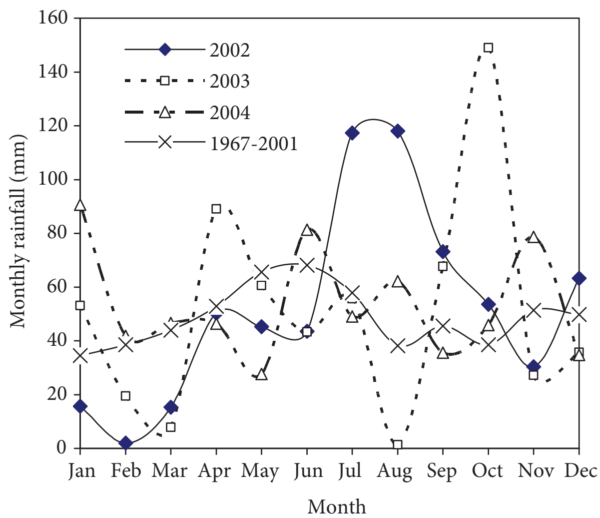

Figure. Monthly rainfall distribution for experimental years and 35-year (1967-2001) average.

population (originating from eastern Serbia), were used in the trial. Being of the so-called giant type, all of the cultivars flowered during the stand establishment year (Delgado et al. 2008a; 2008b). The experiment was a split-block arrangement in a randomised complete block design with 3 blocks. Row spacings formed the main plot treatments, while 3 cultivars the subplot treatments, randomly distributed within blocks in 4 replications.

The cultivars were sown at 3 row spacings: 20 cm (5 rows per plot 5 × 1 m in size), 50 cm (4 rows per plot 5 × 2 m in size), and 80 cm (4 rows per plot 5 × 3.2 m in size). Seeds were spaced 1 cm apart within the row, at a depth of 2 cm, with seed rate ha^{-1} being dependent upon row spacing and 1000-kernel weight of the cultivars used. Seeds were sown by hand on 17 April 2002. In order to avoid the "border effect", seeds of border cultivars were sown in 2 rows around each whole-plot at an identical row spacing. In the 2nd and 3rd years, before the onset of the growing season, the herbicide metribuzin (Sencor) was applied at a rate of 0.75 kg ha^{-1} for weed control. During the growing season, weeds were removed manually. Topdressing treatments (45 kg ha^{-1} P_2O_5 and 45 kg ha^{-1} K_2O) were applied in autumn of the first 2 years. The plots were not irrigated during the experiment.

Measurements: Sainfoin seed yield was evaluated from the 1st cutting in the 1st, 2nd and 3rd years, due to the ability of sainfoin to make good use of winter moisture reserves, i.e. due to its high moisture requirements for the 1st growth (Bolger and Matches 1990). The sainfoin seeds were harvested on 28 July, 20 June, and 18 June in the 1st, 2nd, and 3rd years, respectively. The cultivars did not produce regrowth in the 1st year due to the poor regeneration capacity of sainfoin. The 2nd cutting intended for forage was harvested at the beginning of the flowering stage on 17 August and 20 August in the 2nd and 3rd years, respectively.

Stem number m^{-2} was determined before harvest by counting the number of stems in m^{-1} of middle row length of the plot in 4 replications. The crop was desiccated with the herbicide Reglone Forte (3 L ha^{-1}) at a stage when 70%-80% of the pods turned brown. Ten days later, the crop was manually cut and the seeds were threshed under laboratory conditions. The seed samples obtained from each plot were used to determine 1000-kernel weight (by measuring the 1000-seed weight in 4 replications), germination rate, germination energy, and proportion of hard kernels in an average sample of 50 g by germinating seeds on filter paper at 20 °C in 4 replications of 100 seeds.

Forage dry matter yield and quality were evaluated from the regrowth of the crop intended for seed production in the 2nd and 3rd years. Dry matter yield was calculated using data on green forage yield and dry matter percentage (by drying at 60 °C). The proportion of leaves (%) was estimated from a sample of 30 middle-row stems in 4 replications, by removing the leaves from the stems and weighing them. The proportion of dry matter (%) was estimated from a sample of 30 stems in 4 replications following drying to constant weight in an oven at 105 °C. Dry matter was analysed for total nitrogen by the Kjeldahl method (InKjel 450M), crude protein (CP) using the formula $N_{(\%)} \times 6.25$, crude fibre (CF) by the Scharner-Kurschner method, crude fats (CFs) by the Soxhlet method (KEX 100F Soxlet, Behr), and ash (A) by ignition at 550 °C to constant weight. The minerals found in the dried sample included P and Ca, which were determined by spectrophotometry (SPEKORD 50, Analytik Jena) and atomic absorption (A Analyst 400 AA Spectrophotometer, PerkinElmer), respectively.

The obtained results were subjected to a 3-factor analysis of variance, mixed model (year random, cultivars and row spacings fixed effects) using SPSS (SPSS 1995). Differences between means were tested by LSD test.

Results

Seed yield

Stem number m^{-2} declined significantly over the years regardless of cultivar and row spacing (Table 1). This decline was proportional in all cultivars, with cvs. Makedonka and EG Norm producing a significantly higher stem number m^{-2} than the Sokobanja population. Stem number declined significantly with increasing row spacing proportionally for all cultivars. The significance of the year × row spacing interaction suggests that differences across years were not consistent at all row spacings: stem number at 80 cm row spacing in the 1st year was significantly lower than that in the 2nd year.

Table 1. Stem number (stems m^{-2}), seed yield (kg ha^{-1}), germination rate (%) and 1000- kernel weight (g) of sainfoin cultivars at different row spacings over the 3-year period.

		Stem number	Seed yield	Germination rate	1000- kernel weight
	2002	367.0 a	179.9 b	87.8 a	22.3 ab
Year	2003	296.9 b	592.0 a	85.1 b	21.4 b
	2004	203.6 c	579.3 a	89.9 a	23.3 a
	Makedonka	306.2 a	488.8 a	87.7	22.3 b
Cultivar	EG Norm	311.0 a	486.1 a	87.4	26.6 a
	Sokobanja	250.2 b	376.3 b	87.8	18.1 c
	20 cm	518.7 a	368.4 c	81.6 c	20.1 c
Row spacing	50 cm	226.3 b	499.1 a	88.8 b	22.1 b
	80 cm	122.4 c	482.0 b	92.6 a	24.8 a
	Makedonka	380.4	200.7 d	88.1	23.1
2002	EG Norm	384.7	191.0 d	87.0	25.9
	Sokobanja	336.0	148.0 e	88.3	17.9
	Makedonka	312.6	635.0 a	84.7	21.3
2003	EG Norm	328.7	625.0 a	85.0	25.6
	Sokobanja	249.3	516.0 b	85.6	17.3
	Makedonka	225.8	630.7 a	90.3	22.5
2004	EG Norm	219.6	642.5 a	90.4	28.4
	Sokobanja	165.3	465.0 c	89.3	19.2
	20 cm	681.3 a	151.3 f	82.3	19.9
2002	50 cm	299.6 d	192.3 e	88.7	22.1
	80 cm	120.0 g	196.0 e	92.6	24.8
	20 cm	516.7 b	460.7 d	79.8	19.3
2003	50 cm	227.2 e	669.3 a	86.7	21.2
	80 cm	147.0 f	646.0 ab	89.1	23.6
	20 cm	358.1 c	493.3 d	83.0	21.0
2004	50 cm	152.4 f	640.7 b	91.2	23.1
	80 cm	100.3 g	604.0 c	96.0	26.0
	20 cm	548.0	392.0 c	81.8	19.3
Makedonka	50 cm	242.4	527.3 a	88.6	22.1
	80 cm	128.3	547.0 a	92.7	25.5
	20 cm	553.7	378.0 cd	81.3	24.6
EG Norm	50 cm	241.5	547.7 a	88.6	26.2
	80 cm	138.0	532.7 a	92.4	29.1
	20 cm	454.3	335.3 e	81.7	16.4
Sokobanja	50 cm	195.3	427.3 b	89.0	18.1
	80 cm	101.1	366.3 d	92.7	19.8
Year (A)		**	**	**	**
Cultivar (B)		**	**	ns	**
Row spacing (C)		**	**	**	**
A × B		ns	**	ns	ns
A × C		**	**	ns	ns
B × C		ns	**	ns	ns
A × B × C		ns	**	ns	ns

Values followed by different letters within columns are significantly different ($P < 0.05$) according to the LSD test
**F test significant at $P \leq 0.01$; ns – non-significant

Seed yield during the 2nd and 3rd years was significantly higher than that in the 1st year, irrespective of cultivar and row spacing (Table 1). Although stem number in the 3rd year was significantly lower, seed yield in the 3rd year was comparable to that obtained in the 2nd year. Cultivars Makedonka and EG Norm gave higher seed yields than the Sokobanja population regardless of row spacing or year. Notwithstanding year and cultivar, the seed yields were highest at 50 cm row spacing, significantly lower at 80 cm, and lowest at 20 cm row spacing. The significance of the year × cultivar interaction indicates that differences in seed yield of cultivars across years were not in agreement with differences in average yields, which was the result of a more pronounced yield decline in the Sokobanja population than in cvs. Makedonka and EG Norm in the 3rd year. The analysis of the year × row spacing interaction reveals no significant differences between seed yields at row spacings of 50 and 80 cm during the 1st and 2nd years, which was inconsistent with differences in average seed yields at different row spacings. The presence of the cultivar × row spacing interaction resulted from the absence of differences between cvs. Makedonka and EG Norm at 50 cm and 80 cm row spacings.

The significance of the year × cultivar × row spacing interactions suggests different seed yield performance of cultivars as dependent upon weather conditions and row spacing (Table 2). During the 1st year, cvs. Makedonka and EG Norm gave significantly higher yields at wider row spacings (Makedonka at 80 cm, and EG Norm at 50 cm and 80 cm), whereas seed yield in the Sokobanja population showed non-significant variations. During the 2nd and 3rd years, seed yields in cvs. Makedonka and EG Norm were significantly higher at 50 cm and 80 cm row spacings. The highest yield of the Sokobanja population was obtained at 50 cm; however, seed yield declined significantly with decreasing/increasing row spacing.

Total seed germination rate was significantly higher in all cultivars in the 1st and 3rd years regardless of row spacing (Table 1). In all years and cultivars, germination rate was highest in seeds from the sparsest stand, significantly lower in those from the 50 cm stand and lowest at 20 cm row spacing. Thousand-seed weight was found to be significantly higher in seeds from the 3rd year than from the 2nd year, with differences in this quality indicator being consistent across cultivars and row spacings. Significant differences were also observed among cultivars: 1000-seed weight was highest in cv. EG Norm, followed by Makedonka and the Sokobanja population. Decreasing row spacing induced a significant decline in 1000-seed weight viz. the highest 1000-seed weight in all years and cultivars was obtained with seeds from the sparsest stand, followed by those from 50 cm and 20 cm row spacings.

Yield and quality of second-cut forage

During the stand establishment year, due to late seed harvest, only leaf rosettes developed before the onset of the 1st frost. Accordingly, forage yield and quality were evaluated from the 2nd growth of sainfoin in the 2nd and 3rd years. As in the 1st sainfoin cut, stem number was significantly lower in the 3rd year than in the 2nd, regardless of cultivar and row spacing. Makedonka and EG Norm produced a significantly higher stem number than the Sokobanja population in both years notwithstanding row spacing. As row spacing increased, stem number declined significantly irrespective of year and cultivar. The significance of the year × row spacing and cultivar × row spacing interactions shows that the decline

Table 2. Seed yield (kg ha^{-1}) of sainfoin cultivars at different row spacings during 2002-2004.

	Makedonka			EG Norm			Sokobanja		
	2002	2003	2004	2002	2003	2004	2002	2003	2004
20 cm	168 ij	496 de	512 cd	139 j	463 ef	532 cd	147 j	423 fg	436 fg
50 cm	198 hi	697 a	687 a	236 h	715 a	692 a	143 j	596 b	543 c
80 cm	235 h	712 a	693 a	198 hi	697 a	703 a	154 j	529 cd	416 g

Values followed by different letters are significantly different (P < 0.05) according to the LSD test was not proportional to years or across cultivars. There was no variation in leaf proportion in sainfoin forage across years (Table 3). Leaf proportion was significantly higher in the Sokobanja population than in cvs. Makedonka and EG Norm at all row spacings in both years. Row spacing had a significant effect on forage leaf proportion in all cultivars in both years, being highest in the forage harvested from stands grown at 20 cm, then at 50 cm and 80 cm. Dry matter yields of sainfoin regrowth did not show significant

Table 3. Stem number (stems m^{-2}), leaf proportion (%), dry matter yield (t ha^{-1}) and crude protein (CP) yield (t ha^{-1}) in the 2nd growth of sainfoin cultivars at different row spacings in 2003 and 2004.

		Stem number	Leaf proportion	Dry matter yield	CP yield
Year	2003	278.2 a	50.1	1.59	0.30
	2004	216.7 b	51.1	1.70	0.32
Cultivar	Makedonka	276.2 a	48.4 b	1.73 a	0.33 a
	EG Norm	266.2 a	47.6 b	1.78 a	0.33 a
	Sokobanja	200.0 b	55.7 a	1.43 b	0.28 b
Row spacing	20 cm	390.2 a	52.4 a	2.21 a	0.43 a
	50 cm	198.6 b	51.1 b	1.74 b	0.33 b
	80 cm	153.5 c	48.3 c	0.99 c	0.18 c
2003	Makedonka	309.7	48.0	1.66	0.31
	EG Norm	303.3	47.3	1.73	0.32
	Sokobanja	221.7	54.9	1.37	0.27
2004	Makedonka	242.7	48.7	1.80	0.34
	EG Norm	229.0	47.9	1.83	0.34
	Sokobanja	178.3	56.6	1.48	0.30
2003	20 cm	432.0 a	51.8	2.14	0.41
	50 cm	231.0 c	50.5	1.70	0.32
	80 cm	171.7 d	47.9	0.93	0.17
2004	20 cm	348.3 b	52.9	2.28	0.44
	50 cm	166.3 d	51.7	1.78	0.34
	80 cm	135.3 e	48.6	1.05	0.20
Makedonka	20 cm	420.3 a	49.9	2.34	0.45
	50 cm	231.6 c	49.1	1.82	0.34
	80 cm	176.5 d	46.0	1.04	0.19
EG Norm	20 cm	425.2 a	49.2	2.36	0.45
	50 cm	214.4 c	47.7	1.86	0.35
	80 cm	158.6 d	45.8	1.11	0.20
Sokobanja	20 cm	324.3 b	57.9	1.93	0.39
	50 cm	150.0 de	51.1	1.53	0.30
	80 cm	125.5 e	48.3	0.83	0.16
Year (A)		**	ns	ns	ns
Cultivar (B)		**	**	**	*
Row spacing (C)		**	**	**	**
A × B		ns	ns	ns	ns
A × C		**	ns	ns	ns
B × C		**	ns	ns	ns
A × B × C		ns	ns	ns	ns

Values followed by different letters within columns are significantly different (P < 0.05) according to the LSD test
*F test significant at P ≤ 0.05; **F test significant at P ≤ 0.01; ns – non-significant

differences in the 2nd and 3rd years (Table 3). Makedonka and EG Norm had significantly higher dry matter yields than the Sokobanja population in both years and at all row spacings. Dry matter yield decreased significantly with increasing row spacing in all cultivars in both years. Protein yield was in agreement with dry matter yield across years, cultivars, and row spacings (Table 3). Crude protein content in dry matter of the Sokobanja population in both years and at all row spacings was significantly higher than protein content in cvs. Makedonka and EG Norm (Table 4). There were significant differences in crude protein content between stands grown at 20 cm and those grown at 80 cm in all cultivars and in both years. The Sokobanja population had a significantly lower crude fibre content in both years at all row spacings (Table 4). Crude fibre content increased significantly with increasing row spacing in all cultivars in both years. Crude fats and ash contents were significantly higher in the Sokobanja population in both years at all row spacings (Table 4). Moreover, ash content was significantly lower in the sparsest stand in all cultivars in both years as compared to the other stands. The Ca/P ratio in all cultivars, in both years, and at all row spacings showed non-significant variations (Table 4).

Discussion

Seed production of perennial legumes in arid and semiarid environments is largely dependent upon climatic factors, primarily rainfall, temperature, and evaporation during the growing season (Kholak and Gowda 1989; Martinello and Ciola 1994; Martinello 1998). Haddad et al. (2002) and Xu et al. (2006) evaluated rainfall as a major environmental factor affecting total biomass production. In reference to this, O'Connor et al. (2001) stressed the importance of rainfall distribution during growing season over total annual rainfall. The unproportionally lower number of stems in the 1st year at 80 cm row spacing, which caused the year × row spacing interaction, was most likely due to poorer plant growth resulting from the extremely dry period in the 1st part of the growing season. The strong decline in stem number during the 3rd year at all row spacings can also be attributed to pronounced moisture deficiency in the previous growing season that might have caused sudden death

Table 4. Content of crude proteins (%), crude fibre (%), crude fats (%), ash (%), and Ca/P ratio in dry matter of the 2nd growth of sainfoin cultivars at different row spacings in 2003 and 2004.

		Crude proteins	Crude fibre	Crude fats	Ash	Ca / P
Year	2003	18.99	27.63	4.16	7.02	3.00
	2004	19.15	27.46	4.17	7.12	2.99
Cultivar	Makedonka	18.74 b	27.62 b	4.15 b	6.87 b	2.99
	EG Norm	18.54 b	28.30 a	4.10 b	6.56 c	3.02
	Sokobanja	19.94 a	26.72 c	4.24 a	7.80 a	2.98
Row spacing	20 cm	19.43 a	26.64 c	4.20	7.14 a	2.98
	50 cm	19.14 ab	27.21 b	4.16	7.11 a	3.00
	80 cm	18.64 b	28.79 a	4.13	6.98 b	3.01
Year (A)		ns	ns	ns	**	ns
Cultivar (B)		**	**	**	**	ns
Row spacing (C)		*	**	ns	**	ns
A × B		ns	ns	ns	ns	ns
A × C		ns	ns	ns	ns	ns
B × C		ns	ns	ns	ns	ns
A × B × C		ns	ns	ns	ns	ns

Values followed by different letters within columns are significantly different (P < 0.05) according to the LSD test
*F test significant at P ≤ 0.05; **F test significant at P ≤ 0.01; ns – non-significant

of plants (Bolger and Matches 1990; Martinello 1998). A significant decline in plant number over years is associated with poor persistence of sainfoin as a result of crown and stem disease (Morril et al. 1998; Peel et al. 2004), stress susceptibility (Kallenbach et al. 1996; DeFalco et al. 2000; Liu et al. 2008a) or sainfoin competitive ability that is most pronounced in dense stands (Ćupina and Erić 1999; Türk and Çelik 2006a). Declining seed yields of all cultivars regardless of row spacing in the 1st year were induced by low rainfall amounts in the 1st part of the growing season as well as by failure of some plants to develop inflorescences (Delgado et al. 2008a; 2008b). The significantly higher yields of cvs. Makedonka and EG Norm were attributable not only to the significantly higher stem number, but also to their higher seed yield potential as compared to the Sokobanja population. The higher yields of more vigorous cvs. Makedonka and EG Norm in stands grown at higher row spacings in the 1st year can also be accounted for by better utilisation of available assimilates and moisture. The significantly higher seed yields of cvs. Makedonka and EG Norm, as compared to Sokobanja, in the 2nd and 3rd years at 50 cm and 80 cm row spacings were primarily due to their higher yield potential. Apart from the significant decline in stem number in the 3rd year, the seed yield of cvs. Makedonka and EG Norm that was comparable to that of the 2nd year at all row spacings can be related to the highly favourable rainfall distribution during the 1st part of the growing season when plants underwent generative organ development. Porqueddu et al. (2000) proposed solutions to problems related to seed production, focusing on improving the effectiveness of the plant reproductive system, i.e. facilitating the maximum exploitation of the seed yield potential rather than seeking to increase it. Being less vigorous, the Sokobanja population reached its maximum seed yield potential in the 2nd and 3rd years at the row spacing of 50 cm. Significantly lower seed yields of all cultivars in the 2nd and 3rd years in the densest stand can be partly ascribed to the high competitive ability of plants for available assimilates and moisture. Altın and Tuna (1996) also indicated advantages of larger growing space per plant in seed production trials under low moisture supply. However, Martinello and Ciola (1994) suggested that the seed yield and yield components of tested cultivars and ecotypes were more affected by environmental factors, primarily rainfall during the year, than by seed density; moreover, higher seed density had a positive effect on seed yield under non-irrigated conditions. According to Lorenzetti (1981) and Martinello (1998), under non-irrigated conditions, depending on the stage of generative organ development, moisture deficiency leads to a single yield component consuming assimilates more than the other components do, without restoring the plant reserves, thus causing depletion of carbohydrate reserves in the root and crown. Under optimal moisture supply, yield components complement one another, thus making better overall use of available resources, and active photosynthesis and related physiological processes are maintained, resulting in positive long-term effects on both seed yield and subsequent growth.

Germination rate and 1000-kernel weight as basic seed quality indicators were highest in the 1st and 3rd years, being due to good moisture supply during the seed development. In addition, as a result of good assimilate and moisture supply, germination rate and 1000-kernel weight in all cultivars and years were highest in seeds obtained from the sparsest stand; their values decreased significantly with decreasing row spacing. The significantly higher 1000-kernel weight in cvs. Makedonka and EG Norm that exhibited higher seed yield potential was consistent with the results obtained by Turk and Celik (2006b), who identified positive correlation between 1000-kernel weight and seed yield. The decline in stem number in the 3rd year in the 2nd cut intended for forage production was also due to poor persistence, stress susceptibility (exceedingly dry period at the end of the growing season of the 2nd year) and competitive ability of sainfoin (most pronounced in the densest stand). Nevertheless, dry matter yield of all cultivars at all row spacings did not differ significantly in the 2nd and 3rd years due to the favourable distribution of rainfall in the 2nd part of the growing season in the 3rd year. The results of the present study are consistent with those obtained by Martinello (1998) and Delgado et al. (2008a), who reported that good moisture supply contributes to a significant increase in dry matter yield. The higher forage yield potential of cvs. Makedonka and EG Norm as compared to the Sokobanja population was evident in both years at all row spacings. Martinello (1998) also reported differences among cultivars with respect to increases in dry matter yield under irrigated conditions. The significant decline in dry matter yield along with the decline in the leaf proportion of sainfoin forage at increasing row spacings resulted from the significant decline in stem number m^{-2}. The results herewith obtained are in agreement with those of Glover and Melton (1991), Cash et al. (1993) and Türk and Çelik (2006a). Agreement in dry matter yield and protein yield across years and row spacings was due to slight variations in protein content of DM, which was consistent with the results obtained by Ćupina and Erić (1999). However, Convertini et al. (1997) and Iwaasa et al. (2006) suggested that the crude protein content of dry matter can vary significantly between years, being brought about by the amount of rainfall. The significantly higher protein content in the Sokobanja population than in cvs. Makedonka and EG Norm, being directly associated with its significantly higher leaf proportion in the forage (DeFalco et al. 2000; Liu et al. 2008a, 2008b), did not reflect in a significant increase in crude protein yield. The low fibre content and high ash content of dry matter of the Sokobanja population serve as confirmation of reports by DeFalco et al. (2000), Iwaasa et al. (2006), and Liu et al. (2008a, 2008b) on negative correlation between dry matter yield and quality. The slight variations in the ash and crude fibre content and Ca/P ratio across years, cultivars, and row spacings show these to be characteristics of sainfoin as a plant species (Kidambi et al. 1990; Ćupina and Erić 1999; Vučković et al. 2006).

The narrow range of Ca/P values observed across years, cultivars, and row spacings confirms the results obtained by Kidambi et al. (1990) suggesting that Ca and P levels can change depending on soil moisture, with their ratio in the forage remaining unchanged.

The distinct competitive ability of sainfoin and its high moisture requirements, particularly in the 1st growth, provide sufficient reasons for favouring larger growing space in seed production under arid and semi-arid conditions. Better moisture and assimilate supplies of plants in sparse stands facilitate the effectiveness of the reproductive system, i.e. maximum exploitation of the seed yield potential. The different degree of realisation of seed yield potential depending on biological properties of cultivars, environmental conditions, and growing space (year × cultivar × row spacing interaction) suggests the need to determine the most adequate row spacing for each cultivar grown under particular climatic conditions. Owing to the low profitability of seed production, in respect of both seed and forage yield, the use of wider row spacings (about 50 cm) for vigorous cultivars (Makedonka and EG Norm) and narrower (below 50 cm) for less vigorous cultivars in seed production may become feasible. In view of the poor persistence of this species, the within-row spacing of 1 cm may ensure adequate plant numbers during exploitation of this seed crop.

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