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The frequency of spring harvest and row distance affect the seed and forage production of alfalfa (*Medicago sativa* L.) under irrigated Mediterranean conditions

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Abstract

Aim of study: The effect of the number of spring harvests (1 or 2) for forage before letting alfalfa (*Medicago sativa* L.) grow for seed, combined with three different row distances, on seed production was evaluated over a three-year period.

Area of study: Irrigated Mediterranean environment (NE Spain).

Material and methods: Seed yield, forage production and seed weight were evaluated, as well as final plant stands and the economic implications of different decisions.

Main results: The study revealed significant differences ($p < 0.01$) in seed yield between the number of forage harvests prior to letting the crop grow for seed in two of the three years of the study, with an overall average of 500 kg ha^{-1} for one spring harvest and 450 kg ha^{-1} for two spring harvests, but with significant differences associated with row distance in two of the three years. The average annual production of forage was 8.08 Mg of dry matter (DM) ha^{-1} for the case of two spring harvests and 7.57 Mg for one, with significant differences in one of the three years. Row distances of 20, 40 and 60 cm did not significantly affect forage DM production although, on average, higher forage yields were achieved with narrow row distances. From an economic point of view, our results suggest that the 1-harvest treatment before letting alfalfa grow for seed is slightly more profitable than the 2-harvest treatment (higher gross margin of about 54.5 € ha^{-1}).

Research highlights: Under irrigated Mediterranean conditions, alfalfa harvested only once in spring before letting the crop grow for seed production maximizes the gross margin.

Additional key words: seed yield; density; management.

Abbreviations used: a.i. (active ingredient): DM (dry matter); NH1 (crop harvested once and left for seed production); NH2 (crop harvested twice before letting the alfalfa grow for seed); RD1 (20 cm row distance); RD2 (40 cm row distance); RD3 (60 cm row distance).

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Introduction

Alfalfa (*Medicago sativa* L.) is an important forage crop in Mediterranean areas and its seed production has traditionally been regarded as of interest in the final years of the crop, particularly as its forage production decreases from the third year onwards (Delgado, 2020).

Each country tries to produce sufficient alfalfa seeds to satisfy farmers' demand, although often they import and export certain varieties of seed depending on the market, price and yield. As happens in most crops, seed producers modify management practices to improve their yields and economic benefits (Mueller, 2008). However, seed production is quite variable, which is unfortunate given that, in some years, alfalfa seeds can provide a profitable source of farm income (Rincker *et al*., 1988; Hacquet *et al*., 2000; Iannucci *et al*., 2002; Delgado *et al*., 2013; Delgado, 2020).

Depending on the area, and in particular because of climatic conditions, traditions, knowledge, etc., some farmers concentrate mainly on seed production, striving to obtain the highest yields and economic benefits by improving their seed management practices (Husman & Ottman, 2015).

The literature on alfalfa seed production in relation to the optimal number of harvests prior to letting the crop go to seed is scarce and there is little guidance available to farmers for comparison with other crops (Rincker *et al*., 1988; Chloupek & Simon, 1997; Hacquet *et al*., 2000; Mueller, 2007; Delgado *et al*., 2013). In the Mediterranean areas of the Ebro Valley (northeast Spain), where it is a traditional crop, farmers normally produce alfalfa seed during the final years of the crop. This normally means that the crop stays in the field for 4-5 years and that they harvest the regrowth that follows the first or second spring forage harvest(s). However, seed yields tend to be highly variable (Iannucci *et al*., 2002; Delgado *et al*., 2013; Chocarro & Lloveras, 2015).

Alfalfa seed yield is strongly influenced by the environment and by cultural practices (Rincker *et al*., 1988; Simon, 1997; Delgado *et al*., 2013). Yield potential can only be maximised by choosing an optimal environment and management practices that favour the yield components (Marble, 1997). The irrigated Mediterranean areas of the Ebro Valley offer high-yield conditions for producing alfalfa seed due to temperature and rainfall patterns that favour seed setting and ripening (Delgado *et al*., 2013). That is to say, the high levels of solar radiation and low levels of rainfall favour pollination, while there is nonetheless sufficient water due to irrigation.

In the Ebro Valley, seed production is normally of secondary interest to alfalfa growers compared to forage production, with the main objective being to obtain 5-7 harvests per season (Lloveras & Delgado, 2020). However, interest in seed production could possibly rise if the resulting income were sufficient to compensate for any possible losses due to a reduction in the number of spring forage harvests (Delgado *et al*., 2013).

Appropriate row distance is an important crop management decision for alfalfa seed producers. Wider distances are reported to favour seed production because denser stands attract fewer pollinators and increase the rate of floral abortion (Rincker *et al*., 1988). Recommendations for optimum row distances vary greatly and depend on the growing region.

For example, the optimum row distance ranges from 75-100 cm in medium-textured soils in California and other US states (Rincker *et al.,* 1988; Mueller, 2007) to 20-40 cm in France (Hacquet *et al*., 2000). In irrigated Mediterranean areas, where alfalfa was left for seed after the first harvest, Delgado *et al.* (2013) and Chocarro & Lloveras (2015), in the two studies published in the area, did not observe any significant differences in seed yield when they compared row distances of 20, 40 and 60 cm.

Successful alfalfa seed production is favoured in regions with clear, warm and sunny summer days and with little rainfall, because this promotes flowering and provides an environment conducive to the pollinating activity of bees (Rincker *et al*., 1988). The highest alfalfa seed yields tend to achieve with an irrigation regime that prevents stress and promotes growth throughout the reproductive period, but without excessive vegetative growth (Mueller, 1994).

Despite these general guidelines, little is known about the impact of the number of forage harvests in spring before the alfalfa is left for seed on alfalfa seed yields in intensive production systems with long growing seasons, or on its combination with row distance (Abu-Shakra *et al.*, 1977; Delgado *et al*., 2013). In the Ebro Valley, farmers aim to achieve profitable seed yields without a significant loss of forage production because both the seed and the forage can attract good prices, although these depend on the year and the market situation.

The aim of this study was to evaluate the effect of the number of harvests in spring, one or two, prior to letting the crop grow for seed, combined with row distance, on alfalfa seed and forage production and on the economic return (gross income) in an irrigated Mediterranean environment.

Material and methods

The study was conducted over three consecutive growing seasons (2007-2009) on flood-irrigated plots at the Institut de Recerca i Tecnologia Agroalimentàries (IRTA) research farm, at Gimenells, Spain (41º45′N, 0º30′E). The long-term annual average air temperature was 14.2º C and the average annual rainfall was 341 mm. The mean monthly temperature and rainfall for the 2007-2009 growing seasons at Gimenells are shown in Table 1. The climate is typically Mediterranean, with mild winters and hot, dry summers.

The soil was a Petrocalcic calcixerept, which is representative of many areas in the Ebro valley. Before seeding, an analysis of a composite soil sample (three cores per replication) taken from the experimental site (0-30 cm depth) revealed that the soil plough layer had a loamy texture, with 50% sand, 21% silt, and 29% clay, with 25 g kg^{-1} organic matter, a bulk density of 1.40 (g cm^{-3}), and a pH (water) of 8.0. The average values for initial exchangeable K (K_e) (ammonium acetate method), available P (Olsen method) and Mg (ammonium acetate method) were 161, 37 and 134 mg kg^{-1}, respectively. The soil was tilled with

Table 1. Average temperature (T_m, in °C) and total monthly and annual rainfall (in mm) at Gimenells (Spain) for the period 2007-2009.

Months	Year 1		Year 2		Year 3	
	T_m	Rainfall	T_m	Rainfall	T_m	Rainfall
January	4.4	12.8	5.4	21.8	4.4	21.6
February	8.3	11.4	8.6	12.4	6.8	13.6
March	10.1	12.2	10.2	7.4	9.8	31.0
April	13.9	80.6	13.3	45.2	12.1	90.4
May	17.7	50.2	16.3	119.5	18.9	8.6
June	21.5	18.8	20.6	35.9	22.9	16.4
July	23.8	1.0	23.7	9.0	24.6	31.2
August	22.7	5.0	23.6	9.6	24.9	48.7
September	19.5	8.4	19.1	49.7	20.0	30.1
October	14.6	10.4	14.3	53.6	15.6	33.0
November	6.0	5.4	6.8	23.6	10.4	5.5
December	4.5	10.4	4.4	32.4	5.5	45.5
Mean monthly temperature (°C)/ total annual rainfall (mm)	14.0	227	13.9	420	14.7	376

a disc plough. A rotavator and cultipacker were then used to produce a smooth, firm seedbed. The experimental plots were seeded on 15th March 2006, using a small-plot seeder (Winsterteiger, Ried im Innkreis, Austria).

The experimental plots were fertilized with 100 kg ha^{-1} K and 87 kg ha^{-1} P as a topdressing. This was applied annually before the end of January. Herbicide was applied prior to seeding at a rate of 1.15 kg ha^{-1} active ingredient (a.i.) benfluralin (10 mL L^{-1}). Weeds were also controlled, when required, by applying 1 kg ha^{-1} a.i. hexazinone (90 mL L^{-1}). Alfalfa weevil (*Hyperia postica*) was controlled in the first spring regrowth, some time before the first forage harvest, by spraying once with 0.1 kg ha^{-1} a.i. fenvalerate (15 mL L^{-1}), but only if necessary. This insecticide treatment did not affect pollination because alfalfa does not flower, in our conditions, in the first spring harvest.

The plots were flood irrigated every 15-20 days, from April to September, following the usual irrigation schedule of the irrigation channel, with a total application of ≈900 mm of water in each growing season. The same irrigation strategy was maintained after the second harvest, when the crop was left for seed production, to ensure adequate irrigation during pollination.

Two harvest management schemes for forage were applied in spring: the crop was harvested once and left for seed production (NH1); and the crop was harvested twice before letting the alfalfa grow for seed (NH2) (Table 2), and then harvested again (regrowth after seed collection) in mid-October. In the first harvest, the date of cutting was based on elongation of the basal shoots, whereas in the second harvest, harvesting was done when alfalfa was at first flower.

These harvest treatments were combined with three different row distances: 20 cm (RD1) (which is the normal distance in the region for forage production) (Lloveras *et al.*, 2020), 40 cm (RD2), and 60 cm (RD3). Two different cultivars of alfalfa were used for each combination of harvest treatment × row distance. The cultivars used were 'Aragon' and 'Ampurdan' (fall dormancy rating 8) with quite similar flowering times. 'Aragon' is the most common cultivar grown in Spain, and 'Ampurdan' is a traditional variety which is widely used in the test area (Chocarro & Lloveras, 2015). The crop was sown at a rate of 23 kg ha^{-1} of pure live seed, which is considered appropriate for combined forage and seed production, without inoculation (Lloveras *et al.*, 2008). In our conditions, 1 kg of seed contains approximately 403,000 'Aragon' seeds and about 500,000 'Ampurdan' seeds. In a field plant density study, it was found that 10 kg ha^{-1} of seed produced about 340 plants m^{-2} (Lloveras *et al.*, 2008).

The plants were pollinated naturally by the region's native pollinators. The experimental plot size was 2 × 7 m, making a total field size of about 1800 m^2, alleys included. The experiment was arranged in a complete randomized factorial design, with four blocks, and was analysed annually as a split-split-split plot (Steel & Torrie, 1980). Harvest management was the primary factor, row distance the secondary factor and cultivar the third factor. The results were processed by analysis of variance (ANOVA), using the General Linear Model procedure in the Statistic Analysis System (SAS Inst., 2000) with number of harvests, row distance and cultivar, as the class variables. We also calculated correlations coefficients between annual grain and forage production. Forage production was determined

Table 2. Seed and forage production and alfalfa seed weight under the different treatments

NH	RD	C	Seed yield (kg ha^{-1})				Forage dry matter (kg ha^{-1})				Seed weight (g/1000 seeds)			
			Yr-1	**Yr-2**	**Yr-3**	**Av**	**Yr-1**	**Yr-2**	**Yr-3**	**Av**	**Yr-1**	**Yr-2**	**Yr-3**	**Av**
1	20	Aragon	456	426	436	439	8455	6503	7443	7467	1.719	1.715	1.797	1.543
		Ampurdan	654	285	725	555	9559	7111	9121	8597	1.770	1.696	1.772	1.746
	40	Aragon	475	400	374	417	8838	5352	6758	6986	1.874	1.638	1.942	1.818
		Ampurdan	518	444	788	584	9487	5854	8441	7944	1.823	1.714	1.729	1.755
	60	Aragon	451	325	521	432	8075	5877	7215	7056	1.740	1.886	1.763	1.796
		Ampurdan	559	470	736	588	8667	5579	7836	7361	1.682	1.662	1.844	1.789
2	20	Aragon	465	313	530	436	8838	7581	7798	8072	2.015	2.124	1.797	1.867
		Ampurdan	424	366	551	447	9847	8328	9464	9213	1.979	2.017	1.772	1.922
	40	Aragon	362	382	668	470	8197	7476	8190	7954	2.040	2.139	1.942	2.040
		Ampurdan	337	456	602	465	8526	7539	9420	8495	1.870	1.945	1.729	1.848
	60	Aragon	333	415	444	397	8271	5431	6652	6785	2.005	2.205	1.763	1.991
		Ampurdan	351	489	624	488	8435	6989	8438	7954	2.044	1.976	1.844	1.953
	Average		448	397	583	**476**	8766	6635	8069	**7823**	1.864	1.843	1.811	**1.839**
		ANOVA												
		Rep	**	**	**		**	**	**		**	**	**	
		NH	**	**	ns		**	ns	ns		**	ns	ns	
		RD	**	*	ns		ns	ns	ns		*	ns	ns	
		RD*NH	**	ns	ns		**	**	ns		**	**	ns	
		C	ns	ns	ns		ns	**	**		ns	**	*	
		C*NH	*	*	*		ns	ns	ns		ns	ns	ns	
		C*RD	ns	ns	ns		ns	ns	ns		ns	ns	ns	
		C*RD*NH	ns	ns	ns	ns	ns	ns	ns		ns	ns	ns	

NH: number of harvests. RD: row distance. C: cultivar. Av: average. **,*: significant at 0.01 and 0.05, respectively. ns: not significant

once or twice before the crop was left for seed production and then again (regrowth after seed collection) in mid-October.

In the study environment, the alfalfa growing season normally commences in February-March each year and finishes in October depending on the season's conditions. Harvest dates for NH1 were 7 May, 1 March and 16 April in years 1, 2 and 3, respectively. The first harvest dates for NH2 were the same as for NH1 in each year, while the second harvest dates for NH2 were 6 June, 29 May and 28 May in years 1, 2 and 3, respectively. Seed was harvested on 10 September, 16 September and 14 September in years 1, 2 and 3 respectively. The regrowth of the alfalfa cut for seed was harvested for forage on 11, 20 and 20 October in years 1, 2 and 3, respectively, and their production was added to the previous harvests to calculate the annual forage production of each treatment.

Forage yields were determined automatically by harvesting a 1.5 m-wide central strip with a Haldrup small-plot sickle bar forage harvester (Haldrup, Løgstor, Denmark), with a cutting height of 5 cm. Herbage was also automatically removed, and a 300 g sample of green herbage was collected from each plot and then dried at 70ºC, for 48 hours, to determine the dry matter (DM) content.

The seed was harvested at mid-September 7-10 days after the application of paraquat (1,1'-dimethyl-4,4'-bipyridinium) at a rate of 1.5 L ha^{-1} a.i. to dry the plants and thereby facilitate seed harvesting. Paraquat was applied when nearly all pods were ripe. Grain yield was determined by harvesting a 1.5 m-wide central strip with a small-plot combine for grain (Winsterteiger, Ried im Innkreis, Austria), with each plot being individually harvested. To calculate the clean seed production of each plot, a gross sample of about 50 to 100 g from the combine was cleaned. The proportion of clean sample divided by the gross sample was used to calculate the production of clean seed per plot.

Stand densities (plants m^{-2}) were evaluated at the end of the trail. Plants from one of the central rows of each plot were dug up and the number of tap roots found in two

0.5 m-long rows on each plot were counted. Seed weight (1000 grain weight) was determined on the basis of 50 g of dried and cleaned grain taken from each plot.

The economic evaluation of differences between harvest treatments was made considering two aspects of the crop: forage and seed production. The gross income differences in forage production were determined by multiplying differences in DM production (kg ha^{-1}) by the value (€) of the unit of forage (kg). Differences in seed value were calculated by multiplying differences in seed production (kg ha^{-1}) by the cost of each kilogram of seed (€). The present prices (April 2022) paid to seed or forage producers are 3.5-4 € kg^{-1} for alfalfa seed and 250-270 € Mg^{-1} of alfalfa forage DM. The prices were provided by the dehydration company Aldahra Europe.

Results

Environmental conditions and seed harvest time

Both average temperature and rainfall differed little from year to year during the growing season (particularly, in the months of June, July and August) (Table 1). Over the course of these three months, the most important for seed production because of pollination, fruit setting and fruit growing, the average temperature of these three months was 22.66 °C, 22.63 °C and 24.13 °C, for years 1, 2 and 3, respectively, and total precipitation 24.8 mm., 54.5 mm and 96.3 mm. So, for the three months analysed, year 3 was a little warmer and rainier than years 1 and 2. The long-term averages for temperature and rainfall during June, July and August were, respectively, 21.9 °C and 25.4 mm, 23.9 °C and 25.1 mm, and 23.2 °C and 192 mm, making a three-month average temperature of 23.7 °C and total precipitation of 242.5 mm (Servei Meteorologic de Catalunya).

The number of days between forage harvest and seed harvest was 126, 183, and 151 for years 1, 2 and 3, respectively, for the NH1 treatment, and 96, 110 and 109 days for the NH2 treatment. The number of days was less in year 1 as it was the seeding year of the crop (seeded on March 15). Furthermore, the seed harvest date also depended on the weather forecast, because in year 1 the seed was harvested earlier (about 7-10 days) to avoid the possible danger of hail at harvest time.

Seed production

The three-year average seed yield was 476 kg ha^{-1}, with a moderate annual variation. Seed yield was 448 kg ha^{-1} in year 1, 397 kg ha^{-1} in year 2 and 583 kg ha^{-1} in year 3 (Table 2). On average, the alfalfa harvested only once for forage yielded 500 kg ha^{-1} of seed, whereas the two-forage harvest strategy yielded 450 kg ha^{-1}, with significant differences in two of the three years. However, in year 2, NH2 yielded higher seed production than NH1 (Table 2). The three-year average values ranged from 466 kg ha^{-1}, for the 20 cm distance, 483 kg ha^{-1}, for the 40 cm distance, and 476 kg ha^{-1}, for the 60 cm distance, with significant differences in years 1 and 2 when 60 cm row distances gave the highest seed yields. Row distance affected seed yield significantly in two of the three years, with RD3 giving the highest seed yields. The three-year average seed yields were 469 kg ha^{-1} for RD1, 458 kg ha^{-1} for RD2 and 522 kg ha^{-1} for RD3.

The ‘Ampurdan’ cultivar produced three-year average seed yields of 520 kg ha^{-1}, compared with 432 kg ha^{-1} for ‘Aragon’. However, there were no statistically significant differences in any year, although ‘Ampurdan’ always had higher yield values. There were significant interactions between cultivar and number of harvests in the three years, because in two of the three years, the number of harvest (NH2) of ‘Ampurdan’ yielded proportionally higher than ‘Aragon’, except in one year that in NH2 produced more seed that ‘Ampurdan’.

As commented above, the number of spring harvests and the annual growing season, which can be confused with the stand age of the crop, seem to affect seed production. Temperature and rainfall differed to some degree year to year during the growing season (particularly in the months of June, July and August). Seed set and possibly pollination, therefore, could have been affected by the weather conditions in year 3, despite irrigation.

Forage yields

The overall three-year average forage DM yield was 7,823 kg ha^{-1}. The corresponding values for NH1 and NH2 were 7,567 kg ha^{-1} and 8,078 kg ha^{-1}, respectively. In year 1, the NH1 treatment gave statistically higher values than the NH2 treatment. In years 2 and 3, the NH2 treatment gave higher values than the NH1 treatment, but without statistical significance (Table 2).

The effect of row distance on forage production was not statistically significant in any year, although, on average, narrow rows (20 cm) showed higher DM yields (8,337 kg ha^{-1} compared to 7,844 kg ha^{-1} for 40 cm and 7,288 kg ha^{-1} for 60 cm). There was also a significant *Number of harvests * Row distance* interaction. Although average RD1 values were higher than RD2 in any year, the yield decrease slope differed when going from RD1 to RD2 compared to from RD2 to RD3.

Cultivar significantly affected forage yield in years 1 and 2, in which ‘Ampurdan’ outperformed ‘Aragon’, whereas there were no significant differences in year 3. On average, ‘Ampurdan’ yielded 8,260 kg ha^{-1} and ‘Aragon’ 7,386 kg ha^{-1}.

The correlations coefficients between annual grain and forage production and also with the whole data of the three years, were significant only in year 3.

Seed size

On average, NH2 produced heavier seeds than NH1 (1.937 g per 1,000 seeds *vs.* 1.741 g per 1000 seeds), although the difference was only statistically significant in year 1 (Table 2).

Row distance did not significantly affect seed size in any year (Table 2), although an interaction between number of harvests and row distance was detected in years 1 and 2. The average three-year values were 1.769 g per 1,000 seeds for the 20 cm row distance, 1.865 g per 1,000 seeds for the 40 cm rows and 1.882 g per 1000 seeds for the 60 cm rows.

Cultivar affected seed size significantly in years 2 and 3, with heavier 'Aragon' seeds. The three-year average seed size was 1.843 g per 1,000 seeds for 'Aragon' and 1.836 g per 1000 seeds for 'Ampurdan'.

Stand density

The results obtained reveal statistically significant differences in stand density due to number of harvests at trial end after three years of treatment. The number of plants was 78 plants m^{-2} for NH1, compared to 129 plants m^{-2} for NH2. However, row distance and cultivar had no effect on final stand density.

Management economics

The seed and forage yields of the harvest treatments were calculated, and their gross income compared. The differences in average seed and forage production of the harvest treatments (seed + forage) were (Table 2): 1 Harvest - 2 Harvests = (500 kg ha^{-1} of seed + 7,567 kg ha^{-1} of forage DM) - (450 kg ha^{-1} of seed + 8,078 kg ha^{-1} of forage DM) = 50 kg ha^{-1} of seed – 511 kg ha^{-1} of forage DM. Therefore, the average differences in gross income between the two harvest treatments (seed + forage) were: 50 kg ha^{-1} × (3.5 – 4.0 € kg^{-1}) – 511 kg ha^{-1} × (250 – 270 € Mg^{-1}) = (175 to 200) – (128 to 138) € ha^{-1}. Taking the means of the price intervals, the difference in gross income is: 187.5 € ha^{-1} – 133 € ha^{-1} = 54.5 € ha^{-1}. Gross income is considered to be a more reliable indicator of the success of the crop grown for seed (Pajic & Markovic, 2016). However, when comparing the average economic income of the six possible NH+RD combinations, NH1 + RD1 and NH2 + RD1 gave the best results (3,931 € ha^{-1} and 3,903 € ha^{-1}, respectively) while the NH1 + RD3 combination gave the lowest income (3,494 € ha^{-1}).

Overall, although the differences between NH1 and NH2 were small, it seems that (using the lowest or highest prices currently paid to farmers of both seed and forage) one harvest prior to letting the alfalfa grow for seed is better than two harvests in terms of economic benefit (gross income).

Discussion

The main aspect of the paper is a comparison of alfalfa seed production between two spring harvest treatments: one vs. two harvests for forage before letting the crop grow for seed. This aspect has been controversial for seed producers in Mediterranean areas, and there is very little published research about it (Delgado, 2020). It has been reported in other areas of the world that seed yields tend to decrease with delays in harvesting date (Derscheid & Walstrom, 1981). Another aspect of the paper is the economic quantification of the comparison.

Seed production

As earlier described, alfalfa harvested only once for forage yielded on average 500 kg ha^{-1} of seed, whereas the two-forage harvest strategy yielded 450 kg ha^{-1}, with significant differences between treatments in only two of the three years. Average seed yields were 448 kg ha^{-1}, 397 kg ha^{-1} and 584 kg ha^{-1} for years 1, 2 and 3, respectively.

Over the study period, temperatures and rainfall in the growing season (mainly in June, July, and August) differed little from year to year (Table 1), and it does not appear that these factors affected the differences in seed set and seed production, except perhaps in year 3. It is known that the development rate is accelerated by increasing temperature (Fick *et al.,* 1988). In year 3, with the highest seed yields, the three months analyzed seem more favorable and were a little warmer and rainier. In year 1, the number of days between forage harvest and seed harvest was 126. This period was shorter than in the other two years because year 1 was the seeding year and because the seed harvest was advanced to avoid hailstorms that had been forecast. This shorter time may have affected seed production. Possible reasons for the average lower seed yields in year 2 include excessive plant stand, growth, and some lodging, as normally happens in that year.

Agronomic precautions may be taken and the quality of the pollination may vary, but some losses of pollinated flowers and pods will always take place due to the competition between seed and vegetative growth. Depending on whether agroclimatic conditions are favorable to vegetative growth, ovule and embryo abortion can range between 30% and 90% of pollinated flowers (Hacquet *et al.,* 2000).

Environmental influences on alfalfa seed yield have also been reported under many other growing conditions, including in France (Bolaños-Aguilar *et al.*, 2002), Australia (Downes, 2002), the Czech Republic (Simon, 1997), China (Zhang *et al.*, 2008), Italy (Iannucci *et al.*, 2002) and Spain (Delgado *et al.*, 2013).

The Ebro Valley climate, with its warm, sunny summer days and scant rainfall in summer (rainfall may affect pollination by insects), favours alfalfa seed production, with our experiment conducted under flood irrigation conditions. However, our seed yields were much lower than the 1200-2110 kg ha^{-1} reported in California and Washington state (Rincker *et al*., 1988; Mueller, 2007). The reasons for the large differences between our seed production conditions and those reported in the USA potentially include their longer growing seasons and use of pollinators. We did not analyse the number of pollinators because commercial fields are relatively small in our region and are normally surrounded by fruit trees (almond, apple, peach, etc.), which host many pollinating insects. According to Hacquet *et al*. (2000), the best way to promote pollination is to conserve local fauna, although pollinating insects have been deliberately incorporated in other countries (Palmer & Donovan, 1980; Rincker *et al*., 1988; Mueller, 2007). Such diverse strategies and management conditions could explain the variations in seed yields seen in our Mediterranean environment and the USA.

As row distance affected seed production in two of the three years in our study, it seems appropriate to use, in our conditions, wide rows (60 cm) for seed production, although this would tend to lead in particular to lower biomass yields. Similar results were reported by Delgado *et al*. (2013) in the Ebro valley, with an average four-year seed yield of 429 kg ha^{-1}. Our average seed yield of 476 kg ha^{-1} was higher than the 367 kg ha^{-1} reported in a previous study comparing the row distance effect on seed production in quite similar conditions, but with only one harvest date in spring (Chocarro & Lloveras, 2015). The main difference between the latter study and the present one was use of a sprinkler as opposed to flooded irrigation. It is known that sprinkler irrigation sometimes can interfere with pollination when plants are at the blooming stage (Rincker *et al.,* 1988).

The row distance recommended for alfalfa seed production varies greatly between and in different countries, probably due to climatic conditions, irrigation practices, different varieties, and previous field experience. A distance of at least 35 cm is recommended by the French Association of Seed Producers (Hacquet *et al*., 2000), whereas 76-102 cm is commonly used for commercial seed production in California (Mueller, 2007), and 50 cm is considered the most appropriate distance in Lebanon (Abu-Shakra *et al*., 1977).

In our studies, the ‘Ampurdan’ cultivar produced a three-year average seed yield of 520 kg ha^{-1} compared with 432 kg ha^{-1} for the ‘Aragon’ cultivar. However, there were no statistically significant differences in any year, although ‘Ampurdan’ yield was always higher.

Seed production is cultivar dependent (Abu-Shakra *et al*., 1977; Rincker *et al*., 1988; Bolaños *et al*., 2000). In our experiments, ‘Ampurdan’ produced yields that were significantly higher than those with ‘Aragon’. These differences were, however, smaller than those obtained in previous experiments involving only one spring harvest: 437 kg ha^{-1}, for ‘Ampurdan’ and 298 kg ha^{-1} for ‘Aragon’ (Chocarro & Lloveras, 2015).

Our seed yields were normal by European standards: 210-570 kg ha^{-1} in France (Hacquet *et al*., 2000), 440 kg ha^{-1} in Italy (Iannucci *et al*., 2002), 150-220 kg ha^{-1} in the Czech Republic and 155-299 kg ha^{-1} in Hungary (Bócsa & Pummer, 1997). The differences in yield within Europe probably reflect both climatic and varietal diversity.

Forage yields

The three-year average forage DM yield was 7,823 kg ha^{-1}, with the NH1 treatment yielding an annual average of 7,567 kg ha^{-1} and the NH2 treatment 8,078 kg ha^{-1}. A statistically significant difference was observed in year 1 when the NH1 treatment had a higher forage DM yield than the NH2 treatment, but not in years 2 and 3 when the NH2 presented higher values than NH1 (Table 2).

The forage DM yields of NH1 and NH2 were very similar, although a little higher for NH2, possible because one more harvest (and more growing time) was given for forage. As a trade-off, the plants used for seed in NH1 had, on average, 153 days to produce seed (from forage harvest to seed harvest), whereas in the NH2 treatment only 105 days elapsed from the second harvest to seed harvest. As previously mentioned, the alfalfa of the NH1 treatment yielded on average 500 kg ha^{-1} of seed, whereas the NH2 yielded 450 kg ha^{-1}, with significant differences between treatments only in two of the three years.

There was also a significant interaction between *Number of harvests * Row distance*. Although average forage yield values for RD1 were higher, RD2 outperformed RD1 in the NH1 treatment.

Cultivar significantly affected forage yield in years 1 and 2, when ‘Ampurdan’ performed better than ‘Aragon’, but there were no significant differences in year 3. On average, ‘Ampurdan’ yielded 8,260 kg ha^{-1} and ‘Aragon’ 7,388 kg ha^{-1}.

The annual average forage DM yields of 7,823 kg ha^{-1} observed in our trial for seed production, with 2-3 forage harvests per year, were much lower than the 15-20 Mg DM ha^{-1} yields produced when alfalfa was harvested 6-7 times per year, only for forage, under normal conditions (Lloveras *et al*., 2012).

Our study sought to maximize alfalfa seed yields while penalising forage production as little as possible. In our case, the plots that received two forage harvests before the crop was left for seed production yielded 511 kg ha^{-1} DM of forage more per year than plots that had only one harvest (6.7 %), whereas the corresponding alfalfa seed yields fell by 50 kg ha^{-1} per year (10%). The correlations coefficients between annual grain and forage production, show that only in one year there were significant correlations between seed and forage production.

Many forage breeders expect a negative correlation between dry matter production and seed yield. In alfalfa, a significant positive phenotypic correlation between seed and forage yield was observed by Melton (1969), while Heinrichs (1965) and Bolaños-Aguilar *et al.* (2000) found no relationship between seed yield and dry matter yield.

Seed size

On average, the NH2 treatment produced heavier seeds than NH1 (1.937 g *vs.* 1.741 g per 1000 seeds). However, the difference between number of harvests was only statistically significant in year 1, possibly because the seed components (number of pods and seeds per pod) were lower and reduced competition. Our seed size generally fell within the normal range reported in the literature. In Italy, Iannucci *et al*. (2002) recorded a seed weight of 1.74-2.27 mg compared to our 1.741-1.937 mg. In the Lebanon, Abu-Shakra *et al*. (1977) recorded a seed weight of 2.0 mg and, in France, Bolaños-Aguilar *et al*. (2000) reported a weight of 1.87-2.14 mg, which was slightly higher than our mean value of 1.86 mg. The variation in yield components (in our case the P1000) reported in the literature probably reflects the responses of different cultivars to different irrigation and harvest management practices (Abu-Shakra *et al.,* 1977; Martinello & Emilio, 1997).

Stand density

Plant mortality over time is a normal behavior of alfalfa due to root and crown competition, disease conditions, etc. As stated by Volenec *et al.* (1987), the density of the plant stands declined with time with loss of plants being greatest in stands established using high rates of seeding. Similar results were obtained by Lloveras *et al.* (2008) in irrigated Mediterranean conditions. In their field seed rate studies, 10 kg ha^{-1} of seed produced about 340 plants m^{-2}. In the present study about 600-800 plants m^{-2} emerged, and only 78 and 129 plants m^{-2} were left after the three years of the study period for the NH1 and NH2 treatments, respectively.

Gross income

At present, alfalfa seed has a price of about 3.5-4.0 € kg^{-1}, whereas the price of forage depends on its quality and may be around 250-270 € Mg^{-1} (Jaume Areny, Aldahra Europe, *pers. commun.).* Considering these values and comparing the costs and revenues of the two harvest treatments (seed + forage), the increases in revenue to be obtained from selling either the extra seed or forage were 175-200 € ha^{-1} for the 50 kg ha^{-1} of extra seed in the NH1 treatment *vs.* 147-158 € ha^{-1} for the 511 kg ha^{-1} of extra forage for the NH2 treatment. This gives a difference in gross income in favour of NH1 of about 54.5 € ha^{-1}.

Although the differences in economic benefit (gross income) between the NH1 and NH2 treatments are relatively small, on the basis of current prices it seems be better to have only one harvest prior to letting the alfalfa grow for seed and that maximising seed yield maximizes gross income. However, this will always depend on variations in price as well as the quality of the seed and forage.

Conclusions

There is a slight advantage, in terms of seed yield or forage production, in harvesting alfalfa only once in spring as opposed to obtaining two harvests of forage before letting it grow for seed. While an advantage was observed in terms of seed yield if the rows are spaced 60 cm apart, it seems that forage production was a little higher with narrower rows.

Our findings suggest that, from an economic point of view, the single harvest treatment is more profitable than the two-harvest treatment to the extent of approximately 54.5 € ha^{-1}. Under our conditions, alfalfa should therefore only be harvested once before letting the crop grow for seed production and seeded in narrow rows to maximize gross income.

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