Establishment and production of common sainfoin (*Onobrychis viciifolia* Scop.) in the UK. 2. Effects of direct sowing and undersowing in spring barley on sainfoin and sainfoin-grass mixtures

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Summary

The dry matter (DM) yield and herbage quality of swards of sainfoin (*Onobrychis viciifolia*), meadow fescue (*Festuca pratensis,*) and tetraploid perennial ryegrass (*Lolium perenne*) grown in monocultures and in four sainfoin:grass mixtures (0·33 sainfoin:0·66 meadow fescue, 0·66 sainfoin:0·33 meadow fescue, 0·33 sainfoin:0·66 perennial ryegrass and 0·66 sainfoin:0·33 perennial ryegrass), established by direct sowing or undersowing in spring barley, were investigated over 3 years in a field experiment in the UK. Direct sowing produced a mean yield across all species and mixtures of 1·8 t DM ha^{-1} in the establishment year, whereas undersowing produced no measurable yield except for that of the spring barley. Undersowing reduced the yields of sainfoin and sainfoin-grass mixtures in the first full-harvest year but not in the second. The annual yield of a monoculture of sainfoin was 7·53 t DM ha^{-1} and that of sainfoin-grass mixtures was 8·33 t DM ha^{-1} averaged over 3 years. Both sainfoin and the sainfoin-grass mixtures had higher annual DM yields than the grass monocultures. The mixture of 0·66 sainfoin:0·33 meadow fescue gave the highest mean annual yield (9·07 t DM ha^{-1}) over the 3 years. There was a higher proportion of sainfoin maintained in mixtures with perennial ryegrass than with meadow fescue. The proportion of sainfoin in sainfoin–meadow fescue mixtures declined from 0·62 in the first year to 0·32 in the third year, whereas the proportion in sainfoin–perennial ryegrass increased from 0·48 in the first year to 0·67 in the second year and remained stable in the third year.

Keywords: sainfoin, sainfoin-grass mixture, direct sowing, undersowing

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Received 12 April 2007; revised 18 September 2007

Introduction

Sainfoin (*Onobrychis viciifolia* Scop.) is a leguminous forage crop that is widely grown in warm-temperate and dryland areas of Europe, Asia and western North America (Frame, 2005). It can be grown alone or with a companion grass, and may be undersown with a cereal. Legumes and grasses grown in mixtures are widely reported to provide advantages over either species grown as monocultures, including greater total herbage production, reduced ingression of weed species, an extended peak of seasonal growth and greater sward longevity and herbage quality (Sleugh *et al.*, 2000).

Reasons for the decline in the area of sainfoin over the past century in the UK, where it was often sown in a mixture with non-aggressive companion grasses, such as meadow fescue (*Festuca pratensis*) or timothy (*Phleum pratense*), were discussed by Liu *et al.* (2008). Elsewhere in the world, sainfoin has been grown with various companion species, e.g. Russian wild rye (*Psathyrostachys juncea*) and crested wheatgrass (*Agropyron desertorum*), for grazing in Canada (Goplen *et al.*, 1991). Yields comparable with lucerne, of 4·84–5·78 t DM ha^{-1}, were obtained with proportions of legume in the sward of between 0·39 and 0·61, and the highest yields were associated with the highest proportion of sainfoin (Goplen *et al.*, 1991). Sainfoin, grown with Kentucky bluegrass (*Poa pratensis*), red fescue (*F. rubra*), ladino clover (*Trifolium repens*), birds-foot trefoil (*Lotus corniculatus*) and white clover (*T. repens*), was studied in Montana, USA, over a 4-year period (Cooper, 1972). Birds-foot trefoil was found to be most compatible with sainfoin, whereas the ladino clover and white clover were more aggressive, and there were no differences in yield between any of the sainfoin-grass mixtures. A study on sainfoin sown alone or mixed with grasses in Turkey found that sainfoin-grass mixtures produced higher yields than a sainfoin monoculture (Sengul, 2003). Sainfoin has also been sown in mixtures with lucerne in order to reduce bloat in grazing animals associated with lucerne (McMahon *et al.*, 1999). A 4-year study in the 1950s in southern England showed that sainfoin had higher yields with meadow fescue and timothy than with cocksfoot (*Dactylis glomerata*) as a companion grass but that a sainfoin monoculture had a higher yield of herbage than sainfoin-grass mixtures (Spedding and Diekmahns, 1972).

Undersowing legumes in cereals is a method that has been widely used for the establishment of legume swards (Miller and Stritzke, 1995; Odhiambo and Bomke, 2001). Sainfoin, undersown in a spring-sown cereal crop, is considered in the UK to give enhanced production in the establishment year and to reduce ingression of weed species (Frame *et al.*, 1998).

There is little published information available on the performance of sainfoin-grass mixtures and on undersowing vs. direct sowing under UK conditions. The objectives of this study were to compare the effects of direct sowing and undersowing on the establishment, growth, production and persistence of sainfoin and sainfoin-grass mixtures; to compare the compatibility of sainfoin with meadow fescue or tetraploid perennial ryegrass and to examine the effect of combinations of different seed rates in mixtures on subsequent yields of herbage.

Materials and methods

Site and treatments

The experimental site, its previous history and management and the nutrient content and pH of the soil were described in Liu *et al.* (2008).

The experiment took place between April 2003 and September 2005 and had a split-plot design with three replicates. Direct sowing and undersowing constituted the main treatments. Monocultures of sainfoin, meadow fescue and perennial ryegrass, and four sainfoin: grass mixtures (0·33 sainfoin:0·66 meadow fescue, 0·66 sainfoin:0·33 meadow fescue, 0·33 sainfoin:0·66 perennial ryegrass and 0·66 sainfoin:0·33 perennial ryegrass) made up the subplots, which were 2 m × 4 m each. Sainfoin and the two grasses were mixed in two ratios based on the seed rates of the monocultures.

Establishment and management of swards

Barley was drilled on 21 April 2003 at a seed rate of 120 kg ha^{-1}. Sainfoin, meadow fescue, perennial ryegrass and their mixtures were sown on 21 May 2003 when the barley was at approximately the three-leaf stage (Zadoks1·3; Zadoks *et al.*, 1974). Seeds were broadcast by hand, and raked into the soil to about 1·0 cm deep, and then rolled. The sainfoin, the meadow fescue and the tetraploid perennial ryegrass varieties were Cotswold Common, Lifara and Condesa respectively. The monoculture seed rates were 90 kg ha^{-1} for sainfoin (hulled seed), 22 kg ha^{-1}for meadow fescue and 29 kg ha^{-1} for perennial ryegrass.

The herbicide, MCPA + MCPB (Bellmac Plus; United Phosphorus, Warrington, UK), was used to control broad-leaved weeds and applied after the sainfoin had reached the first trifoliate leaf stage. Nitrogen (50 kg ha^{-1} as ammonium nitrate, 0·35 N) was applied to all plots in the spring in the first and second full-harvest years. Phosphorus and potassium were applied in accordance with MAFF (2002) recommendations for forage legumes. In the establishment year, 30 kg ha^{-1} P_2O_5 was applied to all plots after the barley harvest on 27 August 2003 on the undersown plots, and after the directly sown plots had been harvested. In the first and second full-harvest years, 20 kg ha^{-1} P_2O_5 and 30 kg ha^{-1} K_2O were applied after the first harvests, and 40 and 20 kg ha^{-1} K_2O were given after the second and third harvests respectively.

Harvests and measurements

A 25 cm × 25 cm quadrat was used as the sampling unit to assess plant populations and dry matter (DM) yields, and two determinations were made in each subplot. In the establishment year, plant population measurements were made after the barley harvest. In the first and second full-harvest years, the determinations were made in early June, after the first cuts. One harvest was taken from the direct sown treatments, and barley was harvested from the undersown treatments in early August 2003. No herbage was harvested from the undersown treatments in the establishment year, as there was no measurable yield. The dates of subsequent harvests over the following 2 years are shown in Table 1. Complete plot harvests were carried out immediately after sampling with a BCS 610 Power Scythe (Tracmaster Ltd, Burgess Hill, UK) with plants cut to about 5 cm above the soil surface.

Table 1 Harvest dates of direct sown and undersown treatments in 2003–2005.

	Harvest		
	1	2	3
Establishment year	8 August 2003		
First full harvest year	26–27 May 2004	17–18 July 2004	15 October 2005
Second full harvest year	29 May 2005	13 July 2005	12 September 2005

Laboratory analyses

The determination of crude protein (CP) and neutral-detergent fibre (NDF) concentrations of sainfoin were as described in Liu *et al.* (2008).

Statistical analysis

Data were analysed as a split-plot design with direct sowing and undersowing as the main treatments and sainfoin, grasses and mixtures as sub-treatments using GenStat 7 (Payne *et al.*, 2003). Multiple comparisons of treatment means were carried out by applying the Fisher's least significant difference test when the significance was found. Differences were determined at the $P \leq 0{\cdot}05$ level of significance.

Results

Meteorological data

Rainfall and average monthly temperature data recorded over the experimental period are given in Liu *et al.* (2008).

Effects of direct sowing and undersowing

Undersowing in spring barley generally reduced the annual average DM yields of sainfoin, meadow fescue, perennial ryegrass and their mixtures in the establishment year and in the first full-harvest year ($P < 0{\cdot}001$) (Table 2). However, the yields of the undersown treatments were comparable with the direct sown treatments in the second year. Direct sowing gave an average DM yield of 1·80 t ha^{-1} in the establishment year but there was no measurable yield from the undersown plots except that of barley. In the first full-harvest year, mean DM yield from the direct sown treatments was 12·22 t ha^{-1}, which was 1·74 t DM ha^{-1} greater than that of the undersown treatments. There was no yield difference in the second full-harvest year.

Table 2 Mean dry matter yields (t ha^{-1}) of direct sown and undersown treatments.

	Harvest 1	Harvest 2	Harvest 3	Annual
Establishment year				
Direct sown	1·80	–	–	1·8
Undersown	–	–	–	–
First full harvest year				
Direct sown	8·11^{a}†	1·98^{a}	2·13^{b}	12·22^{a}
Undersown	6·74^{b}	1·69^{b}	2·05^{b}	10·48^{b}
Least significant difference ($P < 0{\cdot}05$)	0·68	0·17	0·23	1·50
Second full harvest year				
Direct sown	5·85^{a}	0·81^{b}	1·01^{a}	7·70^{a}
Undersown	6·0^{a}	0·89^{a}	1·00^{a}	7·90^{a}
Least significant difference ($P < 0{\cdot}05$)	0·43	0·07	0·13	0·47

†Values in the same column followed by a different superscript letter are significantly different at $P = 0{\cdot}05$.

Sainfoin and grass monocultures, and mixtures

The sainfoin monoculture (7·53 t DM ha^{-1}) and sainfoin-grass mixtures (7·69–9·07 t DM ha^{-1}) outyielded meadow fescue (4·72 t DM ha^{-1}) and perennial ryegrass (3·2 t DM ha^{-1}), and the mixture of 0·66 sainfoin:0·33 meadow fescue outyielded sainfoin and grass monocultures and all other mixtures, averaged over the 3 years of the experiment (Table 3). Sainfoin monoculture and sainfoin-grass mixtures gave three harvests in the first and second harvest years, but the grass monocultures only gave two harvests in the first harvest year and one in the second. The first harvest of sainfoin and the mixtures constituted 0·60–0·65 of annual yield in the first full-harvest year and 0·65–0·78 in the second year. Yields peaked in the first full-harvest year and declined in the second.

Proportion of sainfoin in mixtures

The proportion of sainfoin in mixtures varied substantially over the 3-year period. In the establishment year, the sainfoin proportions of 0·66 sainfoin:0·33 meadow fescue and 0·33 sainfoin:0·66 meadow fescue mixtures were 0·69 and 0·54 respectively. This declined to 0·53 and 0·51 in the first harvest year and to 0·32 (for both) in the second year. However, the proportion of sainfoin was significantly different only between the first and second full-harvest years, and there were no significant differences within sainfoin:meadow fescue mixtures. In the mixtures with perennial ryegrass, the proportions of sainfoin of the 0·66 sainfoin:0·33 perennial ryegrass and 0·33 sainfoin:0·66 perennial ryegrass mixtures increased substantially from 0·58 and 0·38 in the establishment year to 0·73 and 0·61 in the first full-harvest year. The proportion of sainfoin of the 0·66 sainfoin:0·33 perennial ryegrass mixture was consistently higher than that of the 0·33 sainfoin:0·66 perennial ryegrass mixture over the 3 years. In the undersown mixtures, proportions of sainfoin showed a similar trend to the direct sown crops. The proportions of sainfoin of the 0·66 sainfoin:0·33 meadow fescue and 0·33 sainfoin:0·66 meadow fescue mixtures were 0·65 and 0·58, respectively, in the first full-harvest year and declined to 0·36 and 0·47 in the second. The proportion of sainfoin in

Table 3 Dry matter yield (t ha^{-1}) of sainfoin (SF), meadow fescue (MF) and perennial ryegrass (PRG) and sainfoin-grass mixtures (0·66SF:0·33MF, 0·33SF:0·66MF, 0·66SF:0·33PRG and 0·33SF:0·66PRG) over 3 years.

	Establishment year	First full harvest year				Second full harvest year				Three-year average
		Harvest 1	Harvest 2	Harvest 3	Annual	Harvest 1	Harvest 2	Harvest 3	Annual	
SF	2·03^{a}†	7·79^{a}	2·24^{ab}	2·20^{d}	12·23^{c}	5·43^{c}	1·36^{a}	1·55	8·33^{b}	7·53^{b}
MF	1·42^{ab}	5·73^{b}	0·85^{c}	–	6·58^{d}	6·17^{c}	–	–	6·17^{c}	4·72^{c}
PRG	1·13^{b}	4·48^{b}	0·97^{c}	–	5·54^{d}	3·02^{d}	–	–	3·02^{d}	3·20^{d}
0·66SF:0·33MF	2·21^{a}	8·72^{a}	2·19^{ab}	3·62^{a}	14·54^{a}	8·12^{a}	0·97^{b}	1·39	10·48^{a}	9·07^{a}
0·33SF:0·66MF	1·74^{ab}	8·64^{a}	2·00^{b}	3·31^{ab}	13·96^{ab}	7·29^{b}	0·90^{b}	1·50	9·72^{a}	8·47^{b}
0·66SF:0·33PRG	2·15^{a}	8·76^{a}	2·38^{a}	2·98^{bc}	13·52^{abc}	5·66^{c}	1·29^{a}	1·58	8·48^{b}	8·08^{b}
0·33SF:0·66PRG	1·94^{a}	7·87^{a}	2·19^{ab}	2·52^{cd}	12·59^{bc}	5·82^{c}	1·39^{a}	1·34	8·55^{b}	7·69^{b}
Least significant difference ($P < 0·05$)	0·81	1·27	0·32	0·32	1·50	0·81	0·13	0·24	0·88	0·58

†Values in the same column followed by a different superscript letter are significantly different at $P = 0·05$.

Table 4 Population density of sainfoin (SF) plants (plants m^{-2}) in mixtures of SF, meadow fescue (MF) and perennial ryegrass (PRG), 0·66SF:0·33MF, 0·33SF:0·66MF, 0·66SF:0·33PRG and 0·33SF:0·66PRG, over 3 years.

Mixture	Establishment year	First full-harvest year	Second full-harvest year
0·66SF:0·33MF	73^{a}†	48^{b}	33^{bc}
0·33SF:0·66MF	38^{a}	37^{a}	32^{a}
0·66SF:0·33PRG	56^{a}	48^{a}	44^{a}
0·33SF:0·66PRG	36^{a}	36^{a}	25^{a}
Least significant difference ($P < 0·05$)		16·9	

†Values in a row (comparisons made within mixtures) followed by a different superscript letter are significantly different at $P = 0·05$.

the 0·66 sainfoin:0·33 perennial ryegrass and 0·33 sainfoin:0·66 perennial ryegrass mixtures declined from 0·71 and 0·64 in the first full-harvest year to 0·61 in the second. Changes in the population density of sainfoin plants are summarized in Table 4.

Herbage quality

Yields of CP of the swards of sainfoin and the sainfoin-grass mixtures were significantly higher than that of meadow fescue and perennial ryegrass swards. The lowest CP yield from the sainfoin sward and the sainfoin-grass mixtures was from the sward with the 0·33 sainfoin:0·66 meadow fescue mixture (Table 5). Sainfoin and the herbage of the 0·66 sainfoin:0·33 perennial ryegrass mixture had the highest annual average CP concentrations, whereas the herbage of meadow fescue and perennial ryegrass had the lowest CP concentrations. The CP concentrations of herbage of sainfoin, meadow fescue and sainfoin–meadow fescue mixtures generally increased as the season progressed (Table 5). For the sainfoin–perennial ryegrass mixtures, CP concentration at the third harvest was highest. Meadow fescue had the highest NDF concentration, and sainfoin and perennial ryegrass had the lowest NDF concentrations (Table 6). The NDF concentration also varied between the three harvests taken in the first full-harvest year. For sainfoin and meadow fescue, herbage at the second harvest had the lowest NDF concentrations. For perennial ryegrass, herbage at the second harvest was more fibrous than at the first harvest. For the mixtures, herbage had the highest NDF concentrations at the first harvest and the lowest at the second harvest.

Discussion

Direct sown crops gave an average yield of 1·8 t DM ha^{-1} in the establishment year and 12·2 t DM ha^{-1} in the first full-harvest year. Undersown crops produced no yield (except 4·8 t DM ha^{-1} as spring barley grain) in the establishment year and 10·3 t DM ha^{-1} in the first full-harvest year. This was attributed to competition by the spring barley, which not only suppressed weed germination and growth, but also competed with the undersown forages for light, moisture and nutrients in the establishment phase, and negatively affected DM yield in the establishment and first full-harvest years. However, undersowing had no effect in the second full-harvest year, and yields were

Table 5 Crude protein (CP) concentrations (g kg DM^{-1}) and annual CP yields (t CP ha^{-1}) from sainfoin (SF), meadow fescue (MF) and perennial ryegrass (PRG), and their mixtures (0·66SF:0·33MF, 0·33SF:0·66MF, 0·66SF:0·33PRG and 0·33SF:0·66PRG), in the first full harvest year.

	Concentration of CP			Mean annual concentration of CP	Total annual CP yield
	Harvest 1	Harvest 2	Harvest 3		
SF	158·9^{c}†	196·4^{b}	207·0^{a}	174·5^{a}	2·13^{a}
MF	94·7^{b}	102·7^{a}	–	95·8^{e}	0·63^{d}
PRG	111·3^{a}	78·3^{b}	–	105·0^{d}	0·58^{d}
0·66SF:0·33MF	148·0^{c}	166·8^{a}	155·4^{b}	152·7^{b}	2·23^{a}
0·33SF:0·66MF	130·0^{b}	159·0^{a}	160·3^{a}	141·2^{c}	1·51^{b}
0·66SF:0·33PRG	171·9^{b}	155·4^{c}	181·0^{a}	171·0^{a}	2·17^{a}
0·33SF:0·66PRG	152·4^{b}	143·2^{c}	172·8^{a}	155·2^{b}	1·94^{a}
Least significant difference (P < 0·05)		6·3		6·2	0·37

Comparisons made between harvests or within the same column for annual values.
†Values followed by a different superscript letter are significantly different at P = 0·05.

Table 6 Neutral-detergent fibre concentration (g kg DM^{-1}) in herbage from sainfoin (SF), meadow fescue (MF), perennial ryegrass (PRG) and their mixtures (0·66SF:0·33MF, 0·33SF:0·66MF, 0·66SF:0·33PRG and 0·33SF: 0·66PRG) in the first full harvest year.

	Harvest			Annual mean
	1	2	3	
SF	450·1^{a}†	399·3^{b}	455·7^{a}	441·6^{d}
MF	622·0^{a}	512·7^{b}	–	607·7^{a}
PRG	446·2^{b}	485·9^{a}	–	454·4^{d}
0·66SF:0·33MF	536·1^{a}	466·3^{c}	520·9^{b}	521·7^{b}
0·33SF:0·66MF	540·0^{a}	469·3^{c}	494·3^{b}	519·0^{b}
0·66SF:0·33PRG	488·2^{a}	453·2^{c}	481·8^{b}	480·4^{c}
0·33SF:0·66PRG	491·4^{a}	459·7^{c}	475·8^{b}	482·3^{c}
Least significant difference (P < 0·05)		6·0		6·9

Comparisons made between harvests or within the same column for annual values.
†Values followed by a different superscript letter are significantly different at P = 0·05.

comparable with the direct sown crops. Although there is no published research information comparing direct sowing and undersowing of sainfoin, the undersowing of other legumes, such as lucerne, with a cereal crop, is reported to provide an additional DM yield in the establishment phase (e.g. Sheaffer *et al.*, 1988).

The sainfoin monoculture and sainfoin-grass mixtures had higher DM yields than meadow fescue and perennial ryegrass monocultures. The 0·66 sainfoin:0·33 meadow fescue mixture had the highest DM yields, with a 3-year mean of 9·07 t DM ha^{-1}; other mixtures and the sainfoin monoculture yielded 7·53–8·47 t DM ha^{-1} with no significant differences. These results are consistent with previous results for sainfoin-grass mixtures. Dubbs (1968) found that a sainfoin monoculture had similar DM yields to mixtures in most cases. Cooper (1972) and Sengul (2003) also reported no yield differences between sainfoin and sainfoin-grass mixtures. Goplen *et al.* (1991), however, found that sainfoin yield in monoculture was greater than when grown with companion forages [Russian wild rye, crested wheatgrass and pubescent wheatgrass (*A. trichophorum*)].

The proportion of sainfoin in direct-sown sainfoin–meadow fescue mixtures declined significantly over the duration of the experiment, from 0·62 in the establishment year to 0·32 in the second year. This was probably because of the early-heading characteristics of the variety of meadow fescue sown (cv. Lifara), which was much more competitive than expected in the spring. Over the same period, the proportion of sainfoin in the mixtures with tetraploid perennial ryegrass (cv. Condesa) increased from 0·45 in the establishment year to 0·67 in the first full-harvest year. The reasons for this are not clear but may have been related to weather conditions [low precipitation in August and September of 2003 and a further dry period in June and July 2004], or to the rapid growth of sainfoin in the spring, which competed with the late-heading cv. Condesa, for light, or to other characteristics of this ryegrass variety, notably its low tillering ability relative to diploid perennial ryegrasses (NIAB, 2004). This suggests that, under the growing conditions of this experiment, tetraploid perennial ryegrass cv. Condesa is likely to be a better companion grass for sainfoin than meadow fescue cv. Lifara, which is contrary to the information provided by Sheldrick *et al.* (1995).

The CP concentration of sainfoin increased as the season progressed and averaged 174·5 g kg^{-1} DM. This is probably due, at least in part, to an increase in the proportion of leaf (Fagan and Rees, 1930). Meadow fescue showed the same pattern as sainfoin with an increase in CP concentration as the season progressed. This could be for two reasons. First, when meadow fescue cv. Lifara was cut at the first harvest, it was already quite mature and at the heading stage. Second, according to Minson *et al.* (1964), the proportion of leaf blade in meadow fescue declines from about 0·58 on 6 May to 0·15 by 27 May, and then increases to about 0·23 on 9 June and to 0·26 by 16 June. The average annual CP concentration of the perennial ryegrass was 105 g kg^{-1} DM, and this declined during the season. This is also probably because the proportion of leaf blade declined. Terry and Tilley (1964) noted that the proportion of leaf blade in perennial ryegrass declines from 0·70 on 27 April to 0·18 on 29 May, and then to 0·11 by 11 June.

Conclusions

Undersowing reduced the production of sainfoin, meadow fescue, tetraploid perennial ryegrass and their mixtures in the establishment year and in the first full-harvest year in comparison with direct sowing, but this effect did not extend into the second full-harvest year. The highest yielding mixture was the 0·66 sainfoin:0·33 meadow fescue mixture. The sainfoin monoculture and all other mixtures had similar DM yields. Yields of both sainfoin and sainfoin-grass mixtures peaked in the first full-harvest year and declined in the second year. Meadow fescue cv. Lifara was not suitable as a companion grass for sainfoin because of its early-heading characteristics. The tetraploid perennial ryegrass cv. Condesa was more compatible with sainfoin over the 3-year period of this study.

Acknowledgments

The authors would like to appreciate the sponsorship from Royal Agricultural College's 100 Club, Forage Legumes Special Interest Group of the British Grassland Society and Cotswold Seeds Ltd.

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