Establishing Perennial Legume Seed Stands with Annual Companion Crops[1]

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ABSTRACT

The effect of establishing perennial legume seed crops stands in alternating rows with annual crops was investigated. Alfalfa (*Medicago sativa*), alsike clover (*Trifolium hybridum*) and red clover (*T. pratense*) were sown in alternating rows with companion crops, namely, barley (*Hordeum vulgare*), oats (*Avena sativa*) and canola (*Brassica campestris*). The companion crops were sown at the recommended rate and one half that rate. The main effect of the companion crop was highly significant, and canola and barley reduced legume seed yields, although this did not extend beyond the first legume seed crop. If a companion crop is to be used, of the three considered here, oats is clearly to be preferred. There was no evidence that the legumes responded differently to the rate at which the species of companion crop was sown. A 50% reduction in the sowing rate of the companion crop did not offer reduced competition to the undersown legume, and so the reduced sowing rate is likely to have some economic significance. For the companion crops, yields were unaffected by sowing rate or by having been established with any one of the three legumes.

Additional index words: **seeds, *Medicago* spp., *Trifolium* spp., alfalfa, alsike clover, red clover, companion crops.**

INTRODUCTION

The use of an annual cereal or oilseed companion crop during the establishment of legume seed crops is a long standing practice in the Peace River region of Alberta and British Columbia, Canada. The annual crop yields an economic return of grain during the establishment year of the legume, while the legume will produce a seed crop the following year.

It is frequently assumed that annual companion crops reduce invasion by weeds and are generally less competitive than the weeds they displace (Schmidt and Behrens, 1972). Nevertheless, these annual crops do compete with the legumes, and a number of studies (Smith, Lowe, Strommen and Brooks, 1954; Peters, 1961; Moyer, 1985) have shown that competition from companion crops reduced vegetative growth and consequently, herbage yield. In contrast, the reduced vegetative growth and the thin stands that result from low sowing rates are recommended for high yielding seed crops (Rincker, Marble, Brown and Johansen, 1988), and it is therefore possible that the deleterious effects of companion crops may be minimal in seed crops. The likelihood of deleterious effects following establishment of perennial legume seed crops in alternating rows with annual crops, and the accompanying changes in yield of the latter were investigated in the present study.

MATERIALS AND METHODS

Experiments were conducted at the Agriculture Canada Research Station at Beaverlodge, Alberta (lat 55° 13'N, long 119°26'W), on a clay loam soil with a pH 6.0-6.5. Prior to sowing, 100 kg ha^{-1} of 11:48:0 fertiliser was applied to the soil to obtain a non-limiting fertility status. A clean seed bed which had been fallowed for the previous two years was used, and competition from plants other than those used in these experiments was eliminated by their mechanical removal (hoeing and inter-row cultivation). Herbicides were not used during the experiment.

Alfalfa (*Medicago sativa* cv. 'Peace'), alsike clover (*Trifolium hybridum* cv. 'Dawn') and red clover (*Trifolium pratense* cv. 'Altaswede') were the forage legumes used in this study. Barley (*Hordeum vulgare* cv. 'Bonanza'), oats (*Avena sativa* cv. 'Random') and canola (*Brassica campestris* cv. 'Tobin') were used as companion crops in the establishment year for each legume cultivar. Sowing rates, based on viable seed numbers as determined by germination tests prior to sowing, were based on recommendations for optimum seed production in legumes (Bolton, 1985), cereals (Agdex, 1984) and oilseeds (Canola Growers' Manual, 1987). All legume seeds were inoculated with the appropriate *Rhizobium* spp. prior to sowing. Leafcutting bees, *Megachile rotundata* Fab., at a population of 50,000 ha^{-1}, were used to pollinate the legumes. There was an abundance of pollinators present during crop bloom; in addition to the introduced *Megachile*, other species of feral *Megachile, Bombus* and *Apis mellifera* visited the plots.

Legume seed production from row sown pure stands was compared with that obtained from stands established with a companion crop sown in alternate rows. One sowing rate was selected for each legume species, and two for each companion crop, namely, the recommended rate and half that rate. Thus there were seven treatments for each legume species (Table 1). A treatment plot consisted of 4 legume or companion crop rows, each 6 m long and 0.3 m apart. A row length of 1.8 m from each of the two centre rows was harvested for seed. Samples were air dried and threshed, and the seed

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Table 1. Sowing rate for legumes and companion crops.

Treatment	Plot	Companion crop sowing rate kg ha^{-1}
1	Legume[1]	
2	Legume established with barley	100
3	Legume established with barley	50
4	Legume established with oats	45
5	Legume established with oats	22
6	Legume established with canola	12
7	Legume established with canola	6

[1]alfalfa, alsike clover and red clover sown at 3.5 kg ha^{-1}, 2.5 kg ha^{-1} and 4.5 kg ha^{-1} respectively.

weighed.

For each year, a different region of the same field was used. The field layout consisted of 6 columns, each of which formed a complete replicate of the seven treatments; within each replicate, the treatments were independently randomised. The design therefore had a rectangular arrangement which was not balanced with respect to the layout rows (referred to subsequently as LayoutRows), although balanced with respect to the columns (referred to as Reps in the analyses) which complicated the statistical analyses (see below).

There were five establishment years (E1-5) from 1984 to 1988, and plots were sown between May 12 and 24 in each year. Also, in each of these years, the annual cereal companion crops were harvested for seed. For canola, seed harvests were taken for four years, E1, E2, E3 and E5. In E4 the stand was thinned by damage by flea beetles, *Phyllotreta* spp., and a harvest for seed yield was not taken. In this region of Canada, perennial legumes do not produce seed in the year of establishment, and the first legume seed crop is harvested the following year. The number of legume seed crops from stands of each species varied from two to three. Only those stands where 50 percent plant survival was recorded in the early spring were harvested for seed. The experiment was completed in 1990.

Statistical analyses

The 7-level factor representing the treatments in Table 1 was subdivided into two factors, one with four levels representing the companion crops (treatments {1}, {2, 3}, {4, 5}, {6, 7}), and the other, with three levels, representing the sowing rate (treatments {1}, {2, 4, 6}, {3, 5, 7}); obviously, these two factors are not completely orthogonal. There were no valid measures of random variation for a number of terms, as indicated in Table 2. Initial analyses of variance were by the use of instrumental variables ("fitting constants") because the design did not form a balanced incomplete block with respect to the LayoutRows and columns (see above) and because of the lack of orthogonality between the factors representing sowing rate and companion crops. There was a strong relationship between the fitted values and the residuals for both the companion crop yields and first harvest seed yields of the legumes. In consequence, it was decided to analyse both responses assuming a constant coefficient of variation; this was achieved by fitting a generalised linear model with gamma errors and the canonical (i.e. inverse) link (McCullagh and Nelder, 1989). Tests of significance for a term were carried out by determining the ratio of its mean deviance to the appropriate estimate of the mean deviance for random variation, and regarding this as an F-statistic; terms were deemed significant if the probability was less than 5%. For the means, multiple range tests were not used because of their dubious application in circumstances either of non-constant variances, or if the design is not balanced, or if some of the factors are not orthogonal; in this paper, estimated means are presented each with its standard error.

All computations were made using Release 1.3 of Genstat 5 (Lawes Agricultural Trust, 1987)

RESULTS

Legume Crop Yield

Legume seed yield data were complete only for the first seed harvest. In most instances, two seed crops were produced for alsike clover stands, and up to three for alfalfa and red clover. Where possible for each species, seed yield data for the second and subsequent harvests were analysed, but because these yields were not significantly affected by the companion crops, these analyses are not reported. The first seed crop from an established stand produced a higher yield than that of subsequent harvests. Thus the yield (standard error) of the first crop of alsike clover was 345 kg ha^{-1} (11) and that for the second crop was 188 kg ha^{-1} (9). The yields (standard errors) of the first, second and third crops were respectively 424 kg ha^{-1} (12), 240 kg ha^{-1} (17) and 135 kg ha^{-1} (8) for alfalfa and 445 kg ha^{-1} (18), 319 kg ha^{-1} (14) and 154 kg ha^{-1} (9) for red clover.

The analysis of deviance revealed that only the main

Table 2. Analysis of deviance for the yield of the first legume seed crop.

Source of variation	DF	Mean deviance	Probability
Year (Y)[1]	4	3.594	
Legume (L)	2	3.575	0.742
L.Y	8	11.576	
L.Y.Reps[1]	75	0.356	
L.Y.LayoutRows[1]	90	0.134	
Sowing rate of companion (S)	2	0.244	0.117
L.S	4	0.009	1.000
Companion crop (C)	2	1.330	<0.001
L.C	4	0.152	0.256
S.C	2	0.037	0.726
L.S.C	4	0.034	0.878
Residual	424	0.113	

Coefficient of variation approximately 34%

[1]No valid test of significance possible.

effect of the companion crop was significant (Table 2), i.e. there was no evidence of a differential effect of the sowing rate of the companion crop. The mean seed yields and standard errors for each legume species with and without a companion crop (Table 3), used an approximating model restricted to year x legume + sowing rate + crop. This can be regarded as very conservative since it is likely to increase the standard errors, but appears to be appropriate since all the other terms involving the treatments of interest can be regarded as random variation with approximately the same mean deviance. However, there was no other choice since the standard errors could not be calculated using the operating model that included all the terms in the analyses of deviance in Table 2 because of computational limitations (a 197 x 197 matrix would have had to have been formed). The mean legume yield with oats was approximately the same as in the absence of a companion, but was reduced with either barley or canola (Table 3).

Companion Crop Yields

Companion crop yields were unaffected by the rate at which each was sown or by establishment with each of the three legume crops used in this study (Table 4). Differences in seed yields between all companion crops were highly significant. Mean yields and standard errors for the companion crops are presented in Table 5. Standard errors were calculated using the same approximating model as in Table 3.

Table 3. Mean yield (standard errors in parentheses; no multiple range tests - see text) and percent change due to companion averaged over years and sowing rates for the first seed crop of legumes (kg ha^{-1}).

	Yield (kg ha^{-1}) of Legume Crop					
Companion Crop	Alfalfa	%	Alsike Clover	%	Red Clover	%
None	448 (33)		369 (26)		486 (38)	
Barley	415 (21)	-7	307 (16)	-17	435 (24)	-10
Oats	472 (24)	+5	381 (19)	+3	476 (26)	-2
Canola	378 (19)	-16	337 (18)	-9	396 (22)	-19

Table 4. Analyses of deviance for the companion crop yields.

Source of variation	DF	Mean deviance	Probability
Year (Y)[1]	4	3.840	
Legume (L)	2	0.831	0.302
L.Y	8	0.595	
L.Y.Reps[1]	75	0.262	
L.Y.LayoutRows[1]	90	0.208	
Sowing rate of companion (S)	1	0.655	0.040
L.S	2	0.328	0.121
Companion crop (C)	2	26.655	<0.001
L.C	4	0.233	0.196
S.C	2	0.114	0.478
L.S.C	4	0.098	0.643
Residual	307	0.154	
Coefficient of variation approximately 39%			

[1]No valid test of significance possible.

Table 5. Mean yields of companion crops (standard errors in parentheses).

(a) At recommended (1.0) and one half (0.5) recommended sowing rates.

Sowing rate	Seed yield (kg ha^{-1})		
	Barley	Oats	Canola
1.0	3252 (139)	3207 (137)	1278 (59)
0.5	3150 (134)	2804 (119)	1258 (59)

(b) In relation to establishment with legume species

Legume	Barley	Oats	Canola
Alfalfa	3043 (162)	2762 (145)	1227 (70)
Alsike clover	3315 (171)	3345 (173)	1430 (81)
Red clover	3244 (170)	2906 (152)	1147 (66)

DISCUSSION

Current software enables the analysis of experiments whose designs do not explicitly include the recognition of the field layout, and therefore are not protected against fertility trends. In the present experiment, it was somewhat fortunate that the deviances for the term involving the LayoutRows in the analyses (Tables 2 and 4) of the rectangular plan were relatively small, and probably indicated no more heterogeneity than the replicate (= columns) effect. However, there was no escape from the assumption of heterogeneous variances. A logarithmic transformation followed by ANOVA is likely to be effective with heterogeneous variances only if the coefficients of variation are less than about 15% (McCullagh and Nelder, 1989); here, they were approximately 34% and 35%.

The results of the present study indicate that establishing legume seed crops with companion crops influenced the legume seed yields, but this effect was restricted only to the first seed harvest. While oats had virtually no effect, barley reduced the yield by about 11%, and canola by about

15%, depending on the legume (Table 3). While any reduction is likely to have an impact on the productivity of a stand over years - in the present study up to a maximum of 3 years - the extent of this reduction was less than 15%. By contrast, a larger reduction (up to 50%) in legume seed yield occurred with increasing age of stand. In view of the potential benefits of companion crops (e.g. an economic yield in the establishment year when there is no legume seed yield, reduced seed costs with a 50% lower sowing rate, control of weed ingression during legume establishment) it appears that the establishment of legume seed crops with companion crops in a shorter rotation may provide greater economic advantages compared with the establishment of legume monocultures. Furthermore, if a companion crop is to be used, of the three considered here, oats is clearly to be preferred.

The biological mechanisms by which these different between-species interactions may have arisen are worth some consideration. Cereal crops have been shown to germinate faster than legumes and to compete effectively for moisture and light (Smith *et al.*, 1954). While legume species respond differently to low light intensities (Gist and Mott, 1957), legume seedling growth generally decreases as light intensities decrease. The faster growing cereals usually can get greater access to moisture, so further intensifying their impact on the slower-growing legumes. This probably explains why the companion crop yields were unaffected by all three legume species.

Barley has been shown to be more competitive than oats (Pavlychenko and Harrington, 1934). This was certainly true in the present study, where barley yields were generally higher than those for oats or canola. The higher yield of barley than oats may account, to some extent, for the difference in the first-harvest legume seed yield associated with these companions; barley, perhaps is the more effective competitor. The indeterminate flowering pattern and consequent continuous tillering probably provided the mechanism by which canola reduced legume seed production. In addition to this, the requirements of the Canada Seeds Act and Seeds Regulations (1989) specify a zero *Brassica* content for Canada Foundation No. 1, the highest grade of seed, and the possibility of contamination of the legume seed harvests with volunteer canola makes this species the least desirable companion crop.

The purpose of varying the sowing rate of the companion crop was to offer different levels of competition to the undersown legumes. However, this did not appear to have had any effect in the present study. It is quite likely that there was a compensation between tiller numbers and sowing rate of the companion, which may explain the lack of a significant effect among the yields of each companion crop at the two sowing rates. While this compensation is not uncommon in cereals (Puckridge and Donald, 1967), it appears to have occurred with canola as well in the present study.

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