Annual Medic and Berseem Clover Dry Matter and Nitrogen Production in Rotation with Corn

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ABSTRACT

Annual medic (*Medicago truncatula* Gaertn.) and berseem clover (*Trifolium alexandrinum* L.) have potential to fix atmospheric N_2 for use by subsequent crops. Our objectives were to determine the dry matter and N production of annual barrel medic and berseem clover, and their effect on grain yield of a subsequent corn (*Zea mays* L.) crop. First-year treatments included spring-seeded annual medic–oat (*Avena sativa* L.) and berseem clover–oat intercrops; summer-seeded annual medic following spring-seeded oat; and a spring-seeded oat monoculture. The second-year corn crop was fertilized with four N rates. In three of four environments, berseem clover had greater average fall dry matter (4392 kg ha^{-1}) and N yield (125 kg ha^{-1}) than spring- or summer-seeded barrel medic. Spring- and summer-seeded medics had similar fall dry matter (1309 kg ha^{-1} avg.) and N yields (38 kg ha^{-1} avg.) in two environments, but spring-seeded medics had greater dry matter and N yield than summer-seeded medic in two environments (avg. dry matter yield of 5304 and 2428 kg ha^{-1}, respectively, and N yield of 138 and 70 kg ha^{-1}, respectively). Berseem clover and medic did not consistently differ in their effects on soil NO_3–N or corn grain yield when no N fertilizer was applied. Legume treatments increased second-year corn grain yields from 9% for the silt loam soil to 82% for the loamy sand soil compared with the no-legume treatment when no fertilizer N was applied; however, this effect decreased as N fertilizer rate increased.

Forage legumes can be important components of sustainable crop rotations. Legume benefits to subsequent crops are attributed to the addition of N and to non-N rotation factors such as disease and weed control, and to improved soil water holding capacity (Heichel and Barnes, 1984; Hesterman, 1988). Because of the historically low costs of synthetic N fertilizers and the lack of livestock on many grain farms, the land area devoted to perennial forage legumes has declined and crop diversity has decreased. As an alternative to perennial systems, the nondormant 'Nitro' alfalfa (*Medicago sativa* L.) was released in 1989 as a source of N in Upper Midwest crop rotations (Sheaffer et al., 1989). Nitro has been successfully used as a N source, but its failure to consistently winterkill has necessitated use of extra tillage or herbicides to prevent competition with the succeeding crop from surviving plants. Information is needed on alternative annual forage legumes that have potential to provide N for subsequent crops and that will reliably winterkill.

Annual medics are important winter annual forage species for rotations in the Mediterranean region and Australia (Sheaffer and Lake, 1997). In the north central USA, annual medics have shown potential as summer annual forage sources when spring seeded (Zhu et al., 1996; Shrestha et al., 1998). For spring-seeded medics harvested about 70 d following planting, maximum herbage yields of 5.4 Mg ha^{-1} in Michigan (Shrestha et al., 1998) to 10.6 Mg ha^{-1} in Minnesota (Zhu et al., 1998) have been reported. Medic regrowth following harvest was usually limited except for 'Mogul' barrel medic (*Medicago truncatula* Gaertn.). Shrestha et al. (1998) reported that Mogul had similar N yields as Nitro alfalfa and berseem clover when harvested or stockpiled following spring seeding. Zhu et al. (1998) reported that spring-seeded barrel medic (*Medicago truncatula* Gaertn.), burr medic (*M. polymorpha* L.), and snail medic [*M. scutellata* (L.) Mill.] produced from 120 to 210 kg ha^{-1} of biologically fixed N_2 within 90 d of spring seeding. Burr medic cv. Santiago was consistently among the highest producers of fixed N_2. Moynihan et al. (1996) evaluated the agronomic performance of annual medics intercropped with spring barley (*Hordeum vulgare* L.) grown for grain. They reported that N available in the aboveground herbage for incorporation into the soil for subsequent crops ranged from 66 to 140 kg ha^{-1}. Mogul barrel medic provided the best herbage regrowth and N production following a midsummer barley harvest. The effect of annual medics on yield of a subsequent corn crop has not been evaluated.

Berseem clover is an upright legume that is also used as a winter annual in the Mediterranean region. It has also been extensively evaluated as a cover crop in the USA (Sustainable Agricultural Network, 1998). Shrestha et al. (1998), in Michigan, reported total season yields of 5 Mg ha^{-1} when berseem clover was harvested twice following spring seeding. In Montana, Westcott et al. (1995) reported herbage yields from a two-harvest system of 7.7 Mg ha^{-1} with a N plowdown potential of 62 kg ha^{-1}. Barley grain yields were similar following berseem clover and alfalfa; however, barley N uptake was greater following alfalfa.

In Iowa, regrowth of berseem clover that was intercropped with oat produced an average of 2.7 Mg ha^{-1} of herbage and had a N fertilizer replacement value of 44 kg ha^{-1} for a subsequent corn crop (Ghaffarzadeh, 1997). Yields of a subsequent corn crop averaged 10% higher following berseem clover than following solo-seeded oat.

Annual forage legumes that will reliably winterkill can be important components of organic production systems that depend on legume N and also for conventional systems if synthetic fertilizer N prices increase. Annual medics and berseem clover have the potential

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Abbreviations: ANOVA, analysis of variance; DM, dry matter; FRV, fertilizer replacement value.

to diversify crop rotations, to produce forage and N, and to affect yields of a subsequent crop, but these legumes have not been compared in an annual legume–corn rotation in the upper Midwest. Our objectives were to determine the forage and N production of annual barrel medic and berseem clover and their effect on grain yield of a subsequent corn crop. Because oat is commonly used to protect soil, provide income, and suppress weeds during small-seeded legume establishment in the Midwest (Simmons et al., 1992), we evaluated these annual legumes when grown as intercrops with spring-seeded oat or following harvest of a spring seeded oat monoculture.

MATERIALS AND METHODS

A crop rotation study was conducted in which the first-year crops were spring-seeded medic–oat or berseem clover–oat intercrops, summer-seeded medic following spring-seeded oat, or an oat monoculture control; and the second-year crop was corn. The study was initiated in 1995 at Potsdam and Rosemount, MN, and in 1996 at Becker and Rosemount, MN. The soil was a Port Byron silt loam soil (fine-silty, mixed, mesic, Typic Hapludoll) at Potsdam, a Waukegan silt loam (fine-silty over sandy or sandy-skeletal, mixed, mesic Typic Hapludoll) at Rosemount, and a Hubbard loamy sand soil (sandy, mixed Udorthentic Haploboroll) at Becker. The Potsdam and Rosemount soils derive from loess parent material and have organic matter content of about 30 g kg^{-1}, whereas the Becker soil is derived from glacial outwash and has an organic matter content of about 10 g kg^{-1}. Potassium and P fertilizers were applied to maintain soil test levels at or above recommended for legume and corn production (Rehm et al., 1995). Soil pH averaged 6.5, P $>$ 25 mg ha^{-1}, and K $>$ 175 mg ha^{-1} at all locations. Irrigation occurred at Becker with total water application of 23.9 and 27.7 cm in 1996 and 1997, respectively.

The experimental design for the first year was a randomized complete block with a split plot restriction on randomization and four replicates. Main plots (9 by 64 m) were two N fertilization rates (0 or 45 kg ha^{-1}), applied as urea and incorporated, immediately before oat–legume planting to assess the effects of N fertility rate on oat and legume growth. Four subplots (9 by 16 m) were: (i) 'Dane' oat and Mogul medic planted together in spring (avg. of 2 May); (ii) Dane Oat and 'Multicut' berseem clover planted together in the spring; (iii) Dane oat planted in spring and Mogul medic planted in midsummer (1 August); and (iv) Dane oat planted alone (solo-oat). The berseem clover cultivar, Multicut, and the annual barrel medic, Mogul, were selected for this trial based on results of Minnesota studies showing their ability to recover after cutting and to have good fall yields compared with other cultivars of the same species (Moynihan et al., 1996). Also, we did not include a summer-seeded berseem clover treatment, because in preliminary trials in Minnesota, berseem clover was inferior to barrel medic in terms of fall DM and N production. Oat was planted at 75 kg ha^{-1} and inoculated legumes were sown at a rate to obtain 400 plants m^{-2}. Spring-seeded oat monocultures and oat–legume intercrops were harvested when oat reached soft dough stage on about 7 July. No herbicides were applied in the first year of the study.

Forage yields of oat and legumes in summer and legumes in the fall (21 October) were determined by cutting two 5.0-m^2 areas within each subplot to a 7-cm stubble height. At the 7 July harvest, a 1000-g subsample was collected, separated into oat, legume, or weed components, and dried at 60°C to determine dry matter (DM) concentration. At the fall harvest, the forage accumulated since the summer harvest of the legume–spring oat treatments and since summer medic planting was weighed, and except for a 1000-g subsample, was returned to the harvest area within each plot and evenly distributed. After the fall forage yield was measured, root and crown samples were collected to a 30-cm depth from a 0.5 m^2 area. Plants in the sampled area were counted. Root and crown samples were washed and dried at 60°C. Nitrogen content of the dried herbage, root, and crown samples was determined by the Kjeldahl procedure. First-year crop fall forage, roots, and crowns were incorporated into the soil using a disc in early November.

The experimental design for second-year corn was a randomized complete block with treatments in a split-split plot arrangement. Whole plots were the two first-year N rates; subplots were the three legume–oat and oat monoculture treatments; and sub-subplots were four N rates (0, 56, 112, and 168 kg ha^{-1}). Corn (cultivar '36H36'; relative maturity of 100 d) was established about 1 May at populations of about 66 000 plants ha^{-1} in four rows per plot spaced 0.76 m apart. Chemical and cultural practices were used at each location to adequately control weeds (Gunsolus, 1996). First-year subplot treatments were divided into 9 by 4 m sub-subplots and N fertilizer (urea) was broadcast-applied and incorporated. Nitrogen was applied just before planting except at Becker, where one-half of each annual N rate was applied preplant and one-half at the seven-leaf stage. All N applications were incorporated. Corn grain yield was measured at physiological maturity (about 20 October) in 3.0-m sections of the middle two rows of each four-row plot. The grain was shelled from the cob and grain yields were adjusted to 155 g kg^{-1} moisture.

Soil NO_3–N concentration was measured preplant in mid-April and when corn was at the 12-leaf stage (~30 cm tall) on about 20 June. Eight soil cores were taken from each non-N fertilized sub-subplot using a 1.9-cm diameter probe and were combined to form one composite sample. Samples were taken to a 60-cm depth in April and to a 30-cm depth in June and analyzed for NO_3–N using the colorimetric Cd-reduction method (Keeney and Nelson, 1982).

Analyses of variance (ANOVA) were calculated to ascertain the statistical significance ($P \leq 0.05$) of treatment effects and treatment interactions on first-year summer oat, legume, and weed DM yield; first-year fall DM and N production; and second-year soil NO_3–N (SAS Inst., 1993). At Potsdam and Rosemount in 1995, herbage and root (root + crown) DM and N data were combined before statistical analysis. Separate root (root + crown) and herbage DM and N data were analyzed for Becker and Rosemount in1996. The experimental design for this analysis was a randomized complete block with main plots assigned to first-year N fertilizer rates and subplots assigned to the four legume treatments (spring-seeded medic–oat or berseem clover–oat intercrops, summer-seeded medic following spring-seeded oat, or an oat monoculture control). To test for legume effects on second-year corn yields, a separate ANOVA was conducted within each N fertilizer rate using the same experimental design as for the first-year data. In all analyses, comparisons of treatment means were made using LSD ($P \leq 0.05$) if the ANOVA indicated that differences among treatments or treatment interactions existed. For all variables, location × treatment interactions were determined by inserting locations as a whole plot treatment in the ANOVA. Nitrogen response analysis was conducted using the regression procedure (PROC REG) of SAS (SAS Inst., 1993). Where the quadratic regression was significant ($P \leq 0.05$), the full model was selected; otherwise, the simple linear regression is presented.

RESULTS AND DISCUSSION

Treatment effects are discussed within location because significant location × treatment interactions for first- and second-year variables occurred. Although differences among locations existed for all variables, the greatest contrasts occurred between Becker and the other locations. This result is most likely due to the soil textural and organic matter content differences that have a strong influence on the amount and persistence of inorganic N in each soil's profile. The sandy, low organic matter soil at Becker mineralizes less organic N and retains less inorganic N than the silt loam, medium organic matter soils at Rosemount and Potsdam.

First-Year Legumes

Summer Forage Yields

Nitrogen fertilizer had no effect on summer total forage or oat yield at Potsdam or Rosemount in 1995. At Becker, N fertilizer significantly increased total forage yield from 2499 to 3399 kg ha^{-1} and oat yield from 1558 to 2235 kg ha^{-1}. At Rosemount in 1996, N fertilization significantly increased total forage yield from 4543 to 5321 kg ha^{-1} and oat yield from 4048 to 4748 kg ha^{-1}. Nitrogen fertilizer or N fertilizer × crop treatment interactions had no effect on legume or weed yields at any location (data not shown).

Total summer forage yields were similar for the spring medic–oat, spring berseem clover–oat, and spring oat–summer medic (solo seeded oat) at Rosemount and Potsdam in 1995 (Table 1). At Rosemount in 1996, total forage yields were similar for spring oat–summer medic and berseem clover–spring oat, but were less for spring medic–oat than for spring oat–summer medic. At Becker, where total forage yield (avg. of 2949 kg ha^{-1}) was less than at Potsdam and Rosemount (avg. of 4707 kg ha^{-1}), total forage yield was increased by seeding medic or berseem clover with oat compared with spring oat–summer medic. The advantage of intercropping legumes with oat at Becker may be related to the lower native soil N status at Becker compared with the other locations. At Becker the legumes contributed 38% to the total yield; however, at Rosemount and Potsdam legumes contributed <10% to the total forage yield. Legume yields were similar for spring medic and spring berseem clover at each location, and oat and weed yields were not affected by crop treatment; except at Rosemount in 1996, where weed yields were highest in the spring oat–summer medic treatment. Generally, legume yields were much greater for the 1996 seedings at Rosemount (414 kg ha^{-1}) and Becker (1138 kg ha^{-1}) than for the 1995 seedings at Potsdam (94 kg ha^{-1}) and Rosemount (98 kg ha^{-1}); however, this did not appear to be related to weather conditions (data not shown) or levels of weed or oat competition.

Fall Forage and Nitrogen Yields

Berseem clover had greater fall dry matter and N yield than spring or summer seeded medic at Rosemount (1995 and 1996) and at Becker (Table 1). The exception occurred at Potsdam where spring medic and berseem clover had similar DM and N yield. Spring medics had similar DM and N yields as summer medics at Rosemount (1995 and 1996), but greater yields at Becker and Potsdam. On average, forage of spring-seeded medics was older (104 d of regrowth since summer harvest) and usually had a lower N concentration than forage of summer seeded medics (81 d of growth since seeding). Spring N application had no residual effect on fall DM or N yields at any location (data not shown). Although spring N fertilization increased oat yields at Becker, the competition provided by oat appar-

Table 1. Summer dry matter yield and fall stand density, dry matter yield (DM), and nitrogen (N) concentration and yield of medic or berseem clover seeded in spring with oat companion crop or medic seeded in summer after spring oat in four environments.†

Treatments		Summer yield				Fall sampling			
								N	
Location/year	Crop	Total forage	Oat	Legume	Weed	Population	DM yield‡	Conc.	Yield
		kg DM ha^{-1}				plants m^{-2}	kg DM ha^{-1}	mg kg^{-1}	kg ha^{-1}
Potsdam/1995	Spring medic–spring oat	4537	4332	77	128	136	5161	26.5	137
	Spring oat–summer medic	4541	4444	–	97	334	1295	31.3	41
	Spring berseem–spring oat	4476	4325	111	40	104	3968	28.2	112
	Mean	4518	4367	94	88	191	3474	28.7	96
	LSD (0.05)	ns	ns	ns	ns	46	1273	1.7	38
Rosemount/1995	Spring medic–spring oat	4870	4408	100	362	33	748	27.5	21
	Spring oat–summer medic	4601	4397	–	204	205	492	38.0	19
	Spring berseem–spring oat	4539	4110	95	334	115	2711	28.0	76
	Mean	4670	4305	98	300	118	1317	31.2	38
	LSD (0.05)	ns	ns	ns	ns	81	1647	1.6	44
Rosemount/1995	Spring medic–spring oat	4754	4166	460	128	152	2307	27.2	63
	Spring oat–summer medic	5071	4611	–	460	286	1688	29.0	49
	Spring berseem–spring oat	4972	4472	367	134	188	3845	28.3	109
	Mean	4932	4416	414	240	209	2613	28.1	73
	LSD (0.05)	255	ns	ns	305	45	892	1.1	25
Becker/1996	Spring medic–spring oat	3120	1726	1139	256	106	5446	25.3	138
	Spring oat–summer medic	2439	2153	–	286	166	3560	27.6	98
	Spring berseem–spring oat	3289	1811	1138	340	159	6622	28.9	191
	Mean	2949	1897	1138	294	144	5209	27.2	142
	LSD (0.05)	292	ns	ns	ns	ns	526	2.1	20

† Values are average of two N fertilizer rates (0 and 45 kg ha^{-1}) applied at spring planting.

‡ Includes herbage, root, and crown.

ently did not suppress legume regrowth, possibly because irrigation was used.

Root (root + crown) DM and N yield from Becker and Rosemount in 1996 was similar for the three legume treatments and contributions to fall whole plant DM and N yield were small (data not shown). At Becker, average root DM and N yield were 1140 and 28 kg ha^{-1}, respectively, and contributed 24 and 15% to the total fall DM and N yield, respectively. At Rosemount, where total fall dry matter and N yields were less than at Becker, root DM and N yield were only 442 and 9 kg ha^{-1}, and these contributed 14 and 12% to the total DM and N yield, respectively. Although separate root data were not analyzed for Rosemount or Potsdam in 1995, it is expected that results would be more similar to those collected from Rosemount in1996 than from Becker, where legume herbage yields were higher. These results support our previous findings with annual alfalfa (Sheaffer et al., 1989), which showed that fall herbage production was more important than roots + crowns for production of DM and N for incorporation into soils.

Fall legume populations were not consistently related to fall legume DM and N yield (Table 1). Summer-seeded medic often had the greatest plant populations, whereas spring medic or berseem clover had the least. Lower plant populations for the spring-seeded legumes than the summer-seeded medic is likely a result of plant mortality due to competition with the companion crops. In addition, because neither species has been selected for common Midwest diseases, it is likely that some mortality arose from plant pathogens. Annual medics generally have limited regrowth after close cutting or grazing, especially when subject to low moisture and high temperature (Sheaffer and Lake, 1997); however, in this and previous research (Moynihan et al., 1996), Mogul barrel medic regrew following the July harvest. Additional research is warranted to develop cultivars of both species that are specifically adapted to produce DM and N in this system.

Second-Year Soil Nitrogen and Corn Grain Yields

Soil Nitrate-Nitrogen

Preplant (April) or in-season (June) soil NO_3–N concentration for the no legume treatment varied considerably among locations, with the lowest at Becker and highest at Rosemount (Table 2). For both samplings, legume treatments did not consistently affect soil NO_3–N level. At Becker, the no-legume treatment had lower preplant and in-season NO_3–N concentration than the legume treatments; however, at the other locations soil NO_3–N levels for the no-legume treatment often did not differ from one or more of the legume treatments.

Although preplant soil NO_3–N data were correlated with legume N production at Becker ($r = 0.78$), a nonsignificant correlation would normally occur because in-season soil N tests are more indicative of legume N mineralization than preplant soil N tests (Magdoff, 1991). Although some differences in preplant soil NO_3–N were measured among these treatments, the absolute amount of residual NO_3–N was quite low. In Minnesota, spring preplant soil NO_3–N quantities <6 mg kg^{-1} occur naturally in most soils (Schmitt and Randall, 1994). The positive relationship between preplant soil N and legume N mineralization at Becker is hypothesized to be related to the relatively high mineralization rates on these soils as well as to the lack of the soil's organic matter buffering potential to immobilize the N in microbial biomass. The in-season (June) soil NO_3–N data indicated that legume N mineralization was present and significant depending on location.

Table 2. Effect of first-year legume treatments on second-year preplant and sidedress soil NO_3–N levels in four environments.†

Location/year	Crop	Soil N‡ April	Soil N‡ June
		— mg kg^{-1} —	
Potsdam/1996	Spring medic–spring oat	4.1	10.1
	Spring oat–summer medic	3.3	9.4
	Spring berseem–spring oat	3.8	10.8
	No legume	3.6	9.4
	LSD (0.05)	0.4	1.2
Rosemount/1996	Spring medic–spring oat	4.5	14.3
	Spring oat–summer medic	4.6	16.4
	Spring berseem–spring oat	5.3	15.8
	No legume	4.0	11.8
	LSD (0.05)	0.6	3.7
Rosemount/1997	Spring medic–spring oat	4.8	12.1
	Spring oat–summer medic	3.9	11.4
	Spring berseem–spring oat	5.1	13.8
	No legume	4.2	9.9
	LSD (0.05)	0.5	1.5
Becker/1997	Spring medic–spring oat	3.3	11.9
	Spring oat–summer medic	3.1	11.3
	Spring berseem–spring oat	2.6	13.0
	No legume	1.8	4.3
	LSD (0.05)	0.9	2.9

† Samples collected from plots not treated with N during the second year.
‡ Preplant NO_3–N taken to a depth of 60 cm in April, sidedress NO_3–N taken to a depth of 30 cm in June.

Other researchers have reported that incorporation of legumes like hairy vetch (*Vicia villosa* Roth), red clover (*Trifolium pratense* L.), and alfalfa increased soil NO_3–N; however, factors such as C/N ratio and lignin content of the legume may influence N mineralization rates (Bruulsema and Christie, 1987; Stute and Posner, 1995). For example, Westcott et al. (1995) reported that incorporation of Nitro alfalfa resulted in greater spring soil NO_3–N levels than incorporation of berseem clover; however, they did not report a relationship between species differences in the amount of legume fall N incorporated for plowdown and spring soil NO_3–N levels, possibly due to differences in root N accumulation.

Soil NO_3–N values in April (preplant) and June (sidedress) of the second year were not affected by N fertilizer applied the previous year (data not shown). Although total N removal was not measured, based on forage yields it is presumed that the oat–legume intercrop treatments removed more N at harvest than was applied in the 40 kg ha^{-1} rate; thus, any residual effect was nonexistent.

Corn Grain Yields—No Fertilizer Nitrogen

First year legume treatments increased corn grain yields at all locations compared with the oat–no legume

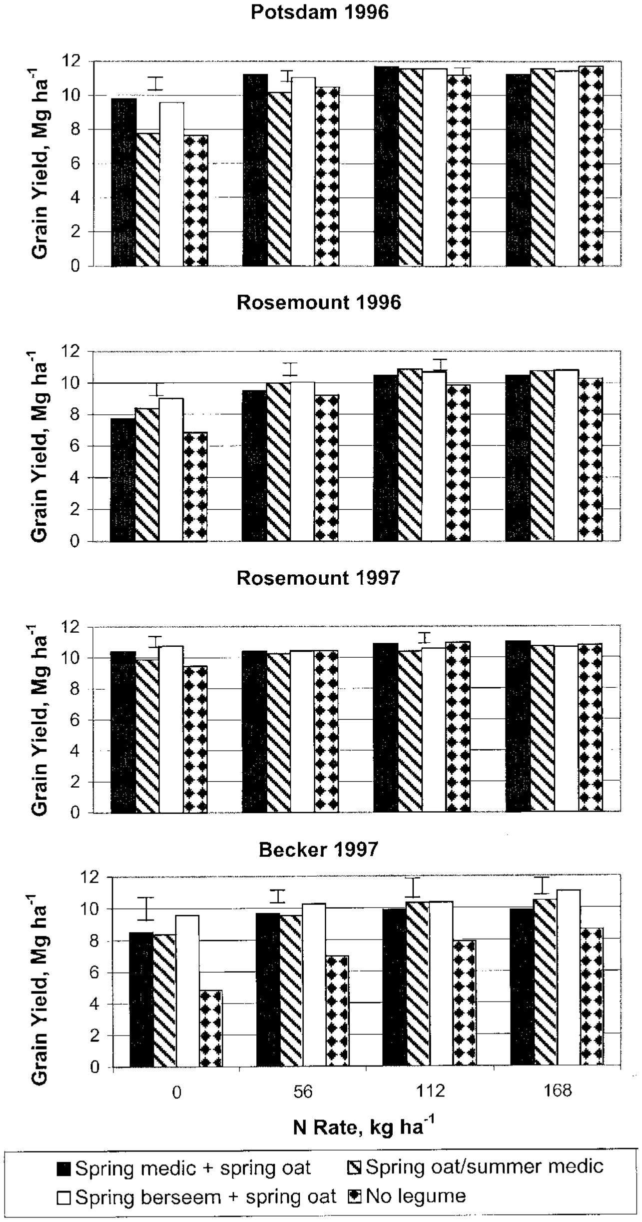

Fig. 1. The effect of four N fertilizer rates and previous legume treatments on corn grain yield in four locations. The LSD(0.05) bars are for comparison of corn grain yields following legume treatments within a N fertilizer rate when significant differences existed.

control (Fig. 1). Berseem clover was consistently among the previous crop treatments that resulted in the highest corn grain yields across all locations. However, corn grain yields were similar for berseem clover and spring medic at Potsdam in 1996 and Rosemount in 1997. Corn yields following spring- or summer-seeded medic were not consistently different over locations. Corn yields were greater following spring medic at Potsdam and Rosemount (1997); but at Becker, yields were similar for the two medic treatments. At Rosemount (1996), yields following summer medic exceeded those following spring medic.

Corn grain yields at all locations were correlated with fall legume N incorporated into the soil; however, this relationship varied with location. This relationship was greatest at Becker ($r = 0.85$), intermediate at Potsdam and Rosemount in 1996 ($r = 0.69$), and least at Rosemount in 1997 ($r = 0.61$). Likewise, corn grain yield was related to in-season (June), but not to spring preplant soil NO_3–N levels, which is what Minnesota and Iowa data would predict (Schmitt and Randall, 1994; Blackmer et al., 1997). The relationship between June soil samples and grain yield was greatest at Becker ($r = 0.72$) and Rosemount in 1996 ($r = 0.69$), but considerably less at Potsdam and Rosemount in 1997 ($r = 0.54$ and 0.60, respectively). The lack of a consistently strong relationship between annual legume N incorporated in the fall and corn grain yield indicates the significance of a soil's N immobilization:mineralization or N supplying capacity. Previous research in Minnesota has consistently found the N supplying capacity of loess soils, like those found at Potsdam and Rosemount, to be very great (Rehm et al., 1995). Another confounding issue when evaluating the impact of annual legume N contributions on yield of subsequent crops is whether the N incorporated is symbiotically fixed or recycled soil N.

Response to Fertilizer Nitrogen

As fertilizer N rate increased (Fig. 1), corn grain yield differences between previous crop treatments decreased. Differences among legume treatments and between legume treatments and the no legume control continued to exist for the 168 kg ha^{-1} N fertilizer rates only at Becker.

There was a significant grain yield response to fertilizer N for most treatments. At Potsdam and Rosemount in 1996, the corn grain yield response to applied N following all oat–legume treatments was quadratic (Table 3), indicating that an optimum N rate had been achieved. This also occurred for the summer medic treatment at Becker and the no legume treatment at Rosemount in 1997. However, at Becker, corn grain yield response to fertilizer N was linear for the other treatments. There was no response to N following berseem clover and only a slight positive linear response following other treatments at Rosemount in 1997. The reasons for a lack of significant quadratic response, used to indicate maximum N rates, are different for Rosemount (1997) and Becker. At Rosemount (1997), the lack of an overall response to N was the primary reason for a lack of treatment differences, most likely attributable to adequate N supplied from the soil. In contrast, Becker's soil, even with fertilization, did not supply enough N to maximize corn yields. University of Minnesota fertilizer recommendations would indicate that the N recommendation for Becker would be much greater than for the other sites and these yield responses support those recommendations (Rehm et al., 1995).

The positive response of corn grain yield to fertilizer N, even with the legumes, indicated that except for berseem clover at Becker and Rosemount in 1997, legumes did not provide sufficient N for maximum corn grain yields. Hesterman et al. (1986) had previously reported a quadratic response in corn grain yield with N fertilizer application following nondormant alfalfa at

Becker, but no response to N fertilizer following legumes at Rosemount. Lory et al. (1995) also confirmed limited responsiveness of grain DM yield to fertilizer N following alfalfa on this loess soil.

One estimate of the fertilizer replacement value (FRV) of berseem clover was reported to be about 44 kg N ha^{-1} (Ghaffarzadeh, 1997). Fertilizer replacement value estimation, however, has been criticized because of the confounding of N with other non-N rotation effects (Hesterman, 1988); therefore, we did not calculate FRV using traditional regression techniques. However, based on the responses shown in Fig. 1 for the no N fertilizer rate, it is apparent that annual medic and berseem clover do provide some fertilizer replacement value. This quantity would be greatest at Becker, where the legume N contribution is a significant component to the soil N pool. A lesser FRV would be predicted for the loess soils due to the much larger inherent soil N pools.

SUMMARY AND CONCLUSIONS

When spring seeded with oat, annual barrel medic and berseem clover had similar legume forage yields at a summer harvest in four environments. On silt loam soils, intercropping medic and berseem clover with oat did not increase total forage (oat + legume + weed) yield at a summer harvest, but on a loamy sand, total forage yield was increased by intercropping the legumes with oat compared with solo-seeded oat, likely due to the DM contribution by the legumes.

In three of four environments, berseem clover had greater fall DM and N yield than spring- or summer-seeded medic; however, the legume treatments did not consistently differ in their effect on soil NO_3–N level or on grain yield of a subsequent corn crop when no fertilizer N was applied. Spring soil NO_3–N was related to legume N incorporation the prior fall in a loamy sand ($r = 0.61$), but poorly related to legume N incorporation in the silt loam soils. Legume treatments increased second-year corn grain yields from 9% (silt loam) to 82% (loamy sand) compared with the no-legume treatment when no fertilizer N was applied. However, legume treatment effects on second-year corn grain yield decreased as N fertility rates increased. At N fertility rates commonly used for corn production, effects due to previous legumes were only observed on the loamy sand soil with lower inorganic N retention and N mineralization than the silt loam soils.

Barrel medic and berseem clover can produce N for incorporation in cropping systems when established in spring or summer. The impact of this legume N on yield of a subsequent grain crop will be most evident in organic production systems where no synthetic or natural N fertilizers are applied and on soils with a low N status such as the loamy sand used in our experiment. The challenge of promotion of widespread use of annual legumes in modern cropping systems has been due to the availability of relatively inexpensive synthetic N fertilizers and government subsidization of grain crop production. As demonstrated in this research, N fertilizers can lessen the effect of legume N on crop yields and in many cases have been more economical for producers than production of an annual legume. An increase in price of synthetic N fertilizers and development of farm programs that reward crop diversification will promote the use of annual legumes in cropping systems.

Table 3. Regression equations relating second-year corn grain yield (dependent variable) response to N fertilization for four first-year cropping treatments.

Location/year and treatments	Regression equations	R^2
Potsdam/1996		
Spring medic–spring oat	$Y = 9.8063 + 0.03318x - 0.0001461x^2$	0.68
Spring oat–summer medic	$Y = 7.7431 + 0.05491x - 0.0001908x^2$	0.92
Spring berseem–spring oat	$Y = 9.6001 + 0.03192x - 0.0001253x^2$	0.81
No legume	$Y = 7.7474 + 0.05384x - 0.0001836x^2$	0.90
Rosemount/1966		
Spring medic–spring oat	$Y = 7.7277 + 0.03963x - 0.0001380x^2$	0.81
Spring oat–summer medic	$Y = 8.3717 + 0.03694x - 0.0001340x^2$	0.74
Spring berseem–spring oat	$Y = 8.9911 + 0.02306x - 0.0000730x^2$	0.68
No legume	$Y = 6.9168 + 0.04550x - 0.0001547x^2$	0.83
Rosemount/1997		
Spring medic–spring oat	$Y = 10.305 - 0.00414x$	0.34
Spring oat–summer medic	$Y = 9.915 - 0.00465x$	0.42
Spring berseem–spring oat	$Y = 10.614 - 0.00021x$†	0.01
No legume	$Y = 9.4508 + 0.02324x - 0.0000902x^2$	0.75
Becker/1997		
Spring medic–spring oat	$Y = 8.725 + 0.01111x$	0.32
Spring oat–summer medic	$Y = 8.3484 + 0.02644x - 0.0000810x^2$	0.73
Spring berseem–spring oat	$Y = 9.651 + 0.00795x$†	0.21
No legume	$Y = 5.256 + 0.02199x$	0.63

† All equations statistically significant ($P \leqslant 0.05$) except where identified by †.

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Legume Cover Crops with Winter Cereals in Southern Manitoba: Establishment, Productivity, and Microclimate Effects

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ABSTRACT

The opportunity to include late-season cover crops in northern cropping systems has been enhanced with the adoption of winter cereal production; however, cover crop feasibility has not been evaluated in these regions. Field experiments were conducted at two sites in Manitoba in 1998 and 1999 to (i) assess establishment and dry matter (DM) production of legume cover crops that were relay-cropped [alfalfa (*Medicago sativa* L.) and red clover (*Trifolium pratense* L.)] or double-cropped [chickling vetch (*Lathyrus sativus* L.) and black lentil (*Lens culinaris* Medik. subsp. *culinaris*)] with winter cereals [winter wheat (*Triticum aestivum* L.) and fall rye (*Secale cereale* L.)], (ii) assess the effect of relay cover crops on cereal grain yield, and (iii) characterize the effects of a red clover cover crop on the microclimate after winter wheat harvest. Establishment and midseason DM of the relay crops were not affected consistently by cereal crop type. Legume DM at freeze-up was similar in winter wheat and fall rye systems and ranged from 190 to 1800 kg ha^{-1}, with moisture availability being the critical factor. Across all site-years, final DM for red clover, alfalfa, chickling vetch, and lentil averaged 1157, 690, 746, and 634 kg ha^{-1}. Relay crops did not affect main-crop grain yield but did significantly reduce main-crop DM production in some cases. The red clover cover crop created a moderating effect on late summer and fall surface (5-cm height) air temperatures and decreased soil moisture availability. Including relay and double crops in winter cereal-based cropping systems appears feasible in southern Manitoba.

Increasing interest in the sustainability of agricultural systems has led to significant developments in cropping practices over the past number of years. A great deal of emphasis has been placed on the prevention of soil erosion and degradation, with major movements toward minimum and zero tillage systems in many parts of the Canadian prairies and northern U.S. Great Plains and significant reduction in the practice of summer fallow. There is also increasing interest in alternative forms of nutrient management, particularly the role of legumes in supplying N to nonleguminous crops through rotation and intercropping.

The role of forage legume crops in improving agricultural sustainability is well recognized. Benefits include higher grain protein levels, higher yields, weed suppression, increased soil N, and improved soil properties (Spratt, 1966; Hesterman, 1988; Campbell et al., 1991; Entz et al., 1995; Hoyt and Leitch, 1983). Many of the above benefits can also be realized with single-season green manure or forage crops (McGill et al., 1986; Badaruddin and Meyer, 1989; Bremer and van Kessel, 1992; Biederbeck et al., 1996; Kelner and Vessey, 1995). However, the use of single-year systems may not be an attractive option to many producers who have found continuous grain cropping to be feasible in their climate and soil type.

Relay and double cropping represent an option for incorporating legume crops into annual cropping systems without sacrificing a season of grain production. These systems have been shown to have potential in longer growing season areas such as the southern USA (e.g., Parsch et al., 1991) but have been adapted to areas with somewhat shorter growing seasons as well. A number of cover-cropping studies have been conducted in shorter growing season areas such as the north-central USA and south-central Canada in conjunction with corn (*Zea mays* L.) production (Bruulsema and Christie, 1987; De Haan et al., 1997; Adbin et al., 1998), and a few studies were conducted in the

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Abbreviations: DM, dry matter.