Managing An Annual Legume Green Manure Crop For Fallow Replacement in Southwestern Saskatchewan

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Abstract

Some scientists have suggested that in the Brown soil zone an annual legume green manure crop (GM) could be used as a partial-fallow replacement to protect the soil against erosion and increase its N fertility, particularly when combined with a snow trapping technique to replenish soil water used by the legume. We assessed this possibility by comparing yields, N economy, water use efficiency, and economic returns of hard red spring wheat (W) grown in rotation with Indianhead black lentil (i.e., GM-W-W) vs. that obtained in a F-W-W system. Further, we assessed whether a change in management of the GM crop (i.e., moving to earlier seeding and earlier turn-down) was advantageous to the overall performance of this practice. The study was conducted over 12 years (1988-99) on a loam soil at Swift Current, SK. (wheat stubble was left tall to trap snow, tillage was kept to a minimum, and the wheat was fertilized based on soil tests). When examined after 6 years, the results suggested that by waiting for full bloom of the legume (usually late July or early August) to maximize N_2 fixation, soil water was being depleted to the detriment of yields of the following wheat crop. However, the change in management of the GM crop since 1994 has resulted in wheat yields following GM equalling those after fallow. It also produced a significant increase (after one rotation cycle) in grain protein and N yields of above-ground parts of wheat in the GM-W-W compared to the F-W-W system, and lead to a gradual decrease in fertilizer N requirements of wheat in the GM system in the last 6 years. These savings in N fertilizer, together with savings in tillage and herbicide costs for weed control on partial-fallow vs conventional-fallow areas, and higher revenues from the enhanced grain protein, more than offset the added costs for seed and management of the GM crop. Thus, our results imply that, with proper management and given sufficient time, an annual legume GM-cereal rotation is a viable option for area producers.

Introduction

In the semiarid Brown soil zone, frequent summerfallowing (F) is traditionally used to reduce the water deficit associated with cereal production, but this practice has resulted in soil organic matter loss and a reduction in N-supplying capacity of the soil (Campbell et al. 1997). Some scientists (Biederbeck et al. 1993; Slinkard et al. 1987) have suggested that an annual legume green manure crop (GM) could be used as a partial fallow replacement to protect the soil against erosion and increase its N fertility, particularly when it is combined with a snowtrapping technique to replenish the water used by the legume. We assessed the agronomic and economic merits of this management practice over a 12-year period on a medium textured soil in southwestern Saskatchewan by comparing yields, N economy, water use efficiency, and net returns for hard red spring wheat (W) grown in a 3-year rotation with Indianhead black lentil green manure (i.e., GM-W-W) versus that obtained in a F-W-W rotation.

Materials and Methods

The experiment was initiated in 1987 on a Swinton loam soil at Swift Current, SK. The rotations compared were F-W-W versus GM-W-W, with all phases and each rotation present each year and each rotation cycled on its assigned plots. Plots were arranged in a randomized complete block design with three replicates. Tillage was kept to a minimum, and seeding of all crops was either no-till or with as little soil disturbance as possible. During the first 6 years of the study, the date of seeding lentil was early- to mid-May; in the latter 6 years the lentil was seeded in mid- to late-April. The dates of turndown of the lentil during the first 6 years was late-July or early-August after the legume reached full bloom so as to maximize N_2 fixation; thereafter, the lentil was turned down in early- to mid-July in an attempt to reduce soil water depletion by the legume. Any weed growth after GM turndown was controlled by one tillage with the wide V-blade cultivator.

Wheat received ammonium nitrate fertilizer midrow banded, based on NO_3-N levels in 0-60 cm depth of soil measured the previous fall. Wheat grown on fallow received N fertilizer at an average rate of 28 kg ha^{-1} during 1988-93 and 43 kg ha^{-1} during 1994-99, while wheat grown on GM partial- fallow received N at 38 and 30 kg ha^{-1} in the first and second 6-year periods, respectively. Wheat grown on stubble in the F-W-W rotation received N fertilizer at 42 kg ha^{-1} during 1988-93 and 55 kg ha^{-1} during 1994-99, while wheat grown on stubble in the GM-W-W rotation received N at 38 and 46 kg ha^{-1} during these same periods. All wheat received P fertilizer applied with the seed at 9.6 kg P ha^{-1}, while lentil received only P at a rate of 4.9 kg P ha^{-1}. The wheat was harvested at maturity using a direct cut header combine with the stubble cut as tall as possible (usually >30 cm) to enhance snow trap and reduce in-crop evapotranspiration demands of the subsequent crop.

Soil samples by depths to 120 cm were taken prior to commencement of field operations in early spring, at plow-down of the GM or immediately after wheat harvest, and in mid-October. The samples were analyzed for gravimetric soil water, NO_3-N, and bicarbonate extractable P.

Weather data were measured at a meteorological station located 0.5 km east of the test site. Available spring soil water (AvSpSW) was computed as spring soil water minus the lower limit of available water (i.e., 83 mm in 0- to 120-cm depth). Water use efficiency (WUE) was calculated as yield divided by soil water at seeding plus precipitation (1 May to 31 August for wheat, and date of seeding to turndown for GM) minus soil water at harvest (or GM turndown).

Costs of production and net returns were determined annually for each cropping system. All purchased inputs and machine operations were valued and held constant at their 2001 cost levels (Saskatchewan Agriculture and Food, 2001; University of Saskatchewan, 2001). Participation in the Canada/Saskatchewan Crop Insurance Program was assumed to be at the 70% yield coverage for wheat. Premium rates and payout criteria for Risk Area #10 of Saskatchewan were assumed (Saskatchewan Crop Insurance Corporation, 2001). The research plot data were extrapolated to the farm-level using a 907 ha representative farm with a typical complement of machinery and labor supply for each treatment. The farm-gate price for spring wheat was set at a base level of $177 t^{-1} (12% protein), with the price adjusted by treatment, replicate and year for grain protein content in accordance with the 2001 protein price schedule as established by the Canadian Wheat Board.

Results and Discussion

Indianhead Black Lentil Production and Water Use

The aboveground yields of GM biomass averaged 29% higher in the 1993-98 period than in the previous 1987-92 period (3231 vs 2500 kg ha^{-1}) (Table 1). This occurred despite terminating growth of the GM crop earlier in the later period, but we also seeded the legume several weeks earlier. The higher GM yields in the later period mainly reflect higher soil water contents at seeding time rather than any major difference in growing season precipitation between the two periods (data not shown). Because water use by the legume was generally similar for the two periods (196 mm for 1987-92 vs 183 mm for 1993-98), water use efficiency (WUE) of GM crop was greater during the later period (due to the higher yields). Nitrogen concentration and N uptake by the GM crop were also higher in the later period (Table 1). These results suggest that even though we are now turning down the legume before full bloom (i.e., the stage recommended for maximum N fixation), we are still gaining significant N benefits to the soil system and this is becoming reflected in reduced fertilizer N requirements for the subsequent wheat crops in the GM rotation.

Wheat Yields

Yields of wheat following GM averaged 26% lower ($P < 0.05$) than that following fallow in the 1988-93 period of the experiment, while the yields of wheat grown on stubble in the two rotations were generally similar (Table 2). Zentner et al (1996) showed that this response was directly related to the lower AvSpSW in the GM-(W)-W system due to water depletion by the legume (Table 3). In contrast, in the 1994-99 period, since our change to earlier GM turndown, AvSpSW has been similar to that in F-(W)-W, [except in 1999 when it was significantly lower because we turned down the GM late (July 23) due its slow growth], and yields for GM-(W)-W has been generally the same as for F-(W)-W. Similarly, the stubble-crop wheat yields for the two rotations have been similar except in two instances (1994 and 1997) when yields of GM-W-(W) significantly exceeded that of F-W-(W).

Table 1. Yield, N concentration, N content, water use and water use efficiency (WUE) of Indianhead black lentil green manure.

	Year											
Green manure	1987	1988	1989	1990	1991	1992	1993	1994	19 95	1996	1997	1998
Yield (kg ha^{-1})	1300	1378	3961	3375	2282	2700	3423	3121	3393	2604	3622	3223
N concentration (g kg^{-1})	ND	30.9	28.1	33.8	19.3	25.7	30.8	31.3	34.8	34.3	28.9	27.7
N content (kg ha^{-1})	ND	42	111	114	44	70	105	97	118	89	105	89
Water use (mm)	82	155	268	169	300	194	156	240	160	183	166	195
WUE (kg ha^{-1} mm^{-1})	16.0	8.9	14.8	20.1	7.6	14.2	21.9	13.0	21.4	14.5	22.2	16.7

Table 2. Effect of legume green manure on wheat yield, N concentration, and N yield.

Year	F-(W)-W	GM-(W)-W	F-W-(W)	GM-W-(W)	F-(W)-W	GM-(W)-W	F-W-(W)	GM-W-(W)
	------------------------Yield (kg ha^{-1})--------------------				------------------N Concentration (g kg^{-1})-----------------			
1988	1168	700	420	407	33.9	34.5	36.4	36.4
1989	1815	1626	1655	1738	30.8	31.7	30.5	30.8
1990	2321	1136	1778	1879	29.4	29.7	26.9	27.7
1991	2478	2270	2581	2638	27.0	30.1	23.6	25.1
1992	2756	2055	1521	1616	22.0	24.9	19.5	21.6
1993	3362	2533	2232	2030	22.7	25.2	22.0	24.8
1994	1992	1817	1546	2112	23.5	28.1	18.7	22.9
1995	3085	3200	2703	2673	21.8	25.5	20.2	23.3
1996	2395	2501	2566	2488	25.3	28.3	19.5	22.7
1997	2998	3155	2647	3075	23.0	24.0	21.3	24.8
1998	2587	2290	870	657	27.5	29.6	31.5	36.9
1999	3574	2876	3014	2961	21.6	26.5	20.9	24.4
Mean	2544	2180	1961	2203	25.7	28.2	24.3	26.8
LSD (P<0.05) Treat x year	427					2.9		

Nitrogen Concentration in Wheat

Grain N concentration in wheat grown on GM partial fallow was generally higher than that of wheat grown on fallow, especially after the first 3 years of the study (Table 2). The same was true for wheat grown on stubble. Generally, the differences favoring wheat grown in the GM system were significant (P <0.05) in the last 6 years of the study. In the first 3 years the N concentration in wheat grown on GM-W-W (partial fallow or stubble) was ? 3% greater than that for the corresponding F-W-W treatment. In the second 3 years of the study the difference favoring the GM-W-W system ranged between 6-13%; in the 1994 -96 period the range was 12-22%; and except for values of 4 and 7% for GM-(W)-W in 1997 and 1998, the range for the 1997-99 period was 16-22%. This suggests a gradual widening with time in the advantage of N concentration of wheat grown in the GM-W-W versus the F-W-W system.

Water Use Efficiency of Wheat

Water use efficiency of wheat was generally similar for crops grown on fallow and stubble and for the F-W-W and GM-W-W systems (Table 3). In the first 6-year period there were two instances, 1990 and 1993, when WUE was greater for F-(W)-W than for GM-(W)-W, reflecting lower yields in the latter. However, because of better management and equivalent yields of the treatments in the later period, there was no significant difference in WUE between the two cropping systems.

Table 3. Available spring soil water and effect of legume green manure on water use efficiency of wheat.

	Av. SP SW (mm/120 cm)				Water use efficiency (kg ha^{-1} mm^{-1})			
Year	F-(W)-W	GM-(W)-W	F-W-(W)	GM-W-(W)	F-(W)-W	GM-(W)-W	F-W-(W)	GM-W-(W)
1988	148	124	105	96	4.60	3.65	2.06	2.05
1989	147	104	108	115	5.65	6.04	6.20	6.22
1990	194	131	148	161	6.10	3.50	5.30	5.50
1991	204	140	177	174	4.98	5.28	5.77	5.78
1992	198	135	134	100	8.01	7.16	5.92	6.74
1993	217	155	131	138	10.36	8.67	9.28	8.45
1994	216	220	210	199	5.84	5.03	4.71	6.31
1995	222	191	173	199	8.41	9.23	8.24	7.83
1996	242	233	196	199	6.59	6.98	8.23	7.68
1997	241	239	202	205	7.95	8.60	8.25	9.19
1998	187	165	113	99	7.15	6.63	3.16	2.51
1999	217	145	124	151	8.90	8.45	9.89	8.60
Mean	203	165	152	152	7.05	6.6	6.42	6.41
LSD ($P<0.05$) Treat x year		34				1.6		

Production Costs and Net Returns

Production costs for the complete rotations averaged \$230 ha^{-1} for both cropping systems (Fig 1). In the early years of the experiment, costs averaged \$20 ha^{-1} higher for GM-W-W than for F-W-W, but in later years, costs for the GM system were similar or \$5 to \$10 ha^{-1} lower. These results imply that the added costs for seed and managing the GM crop were offset, or more than offset, by the savings in N fertilizer for wheat grown after GM plus the savings in costs for weed control (i.e., tillage and herbicides) on partial fallow versus conventional fallow areas.

Net returns during the 1988-93 period averaged \$68 ha^{-1} for F-W-W and \$38 ha^{-1} for GM-W-W, but after the change in management of the GM crop in the 1994-99 period, net returns averaged \$69 and \$99 ha^{-1} for F-W-W and GM-W-W, respectively (Fig. 1). In this later 6-year period, net returns for the GM-W-W system were significantly ($P<0.05$) higher than for F-W-W in 4 of 6 years, similar in one year, and significantly lower in another year. Future increases in the cost of N fertilizer and/or increases in the cost of fossil energy used for machinery operation and herbicide manufacture will further improve the relative profitability of the GM system.

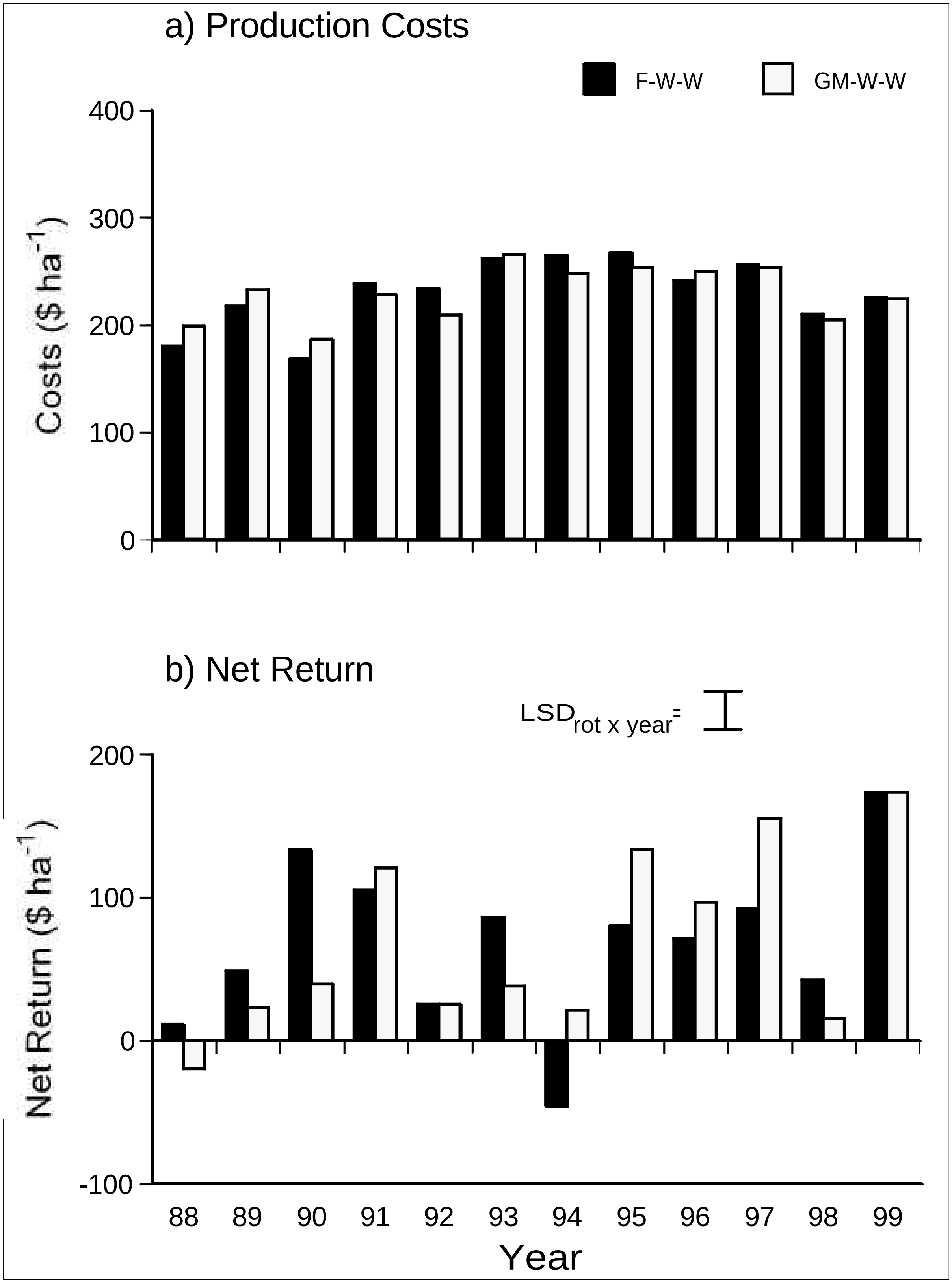

Figure 1. Annual production costs and net returns for F-W-W and GM-W-W rotations.

Conclusions

This study shows that it is possible to employ an annual legume green manure crop, such as Indianhead black lentil, in rotation with wheat in the semiarid prairies without sacrificing yield or grain quality compared to conventional fallow-wheat systems. The key is to employ a snow management technique, together with minimum or zero tillage, seed the legume as early as practical (usually April in southwestern Saskatchewan) and turn it down by mid-July even if it is not at full bloom so as to minimize soil water depletion by the legume. Because GM yields are generally modest in the semiarid prairies, it will require 5-6 years (one or two rotation cycles) before the soil N fertility benefits of the GM system become apparent in terms of increasing grain protein and N uptake of the associated cereal (and therefore less potential N loss to the environment), and result in at least similar yields as those obtained on conventional fallow. Fertilizer N requirements will also be reduced in the GM system. Further, the gains in protein content of the wheat crops grown after GM, together with the savings in N fertilizer and the savings in tillage and/or herbicides costs on partial fallow areas (versus conventional fallow) more than compensate for the added costs for seed and management of the GM crop, which bodes well for the adoption of this management practice by area producers.

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