EFFECT OF ANNUAL LEGUME GREEN MANURES ON YIELD AND QUALITY OF WHEAT ON A BROWN LOAM

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(An ERDAF Funded Project)

INTRODUCTION

It has long been recognized that legume green manures in cereal rotations increase available soil nitrogen, add soil organic matter, reduce soil and water losses, reduce leaching of nutrients, reduce salinization, and often increase the yield of succeeding crops. Yet, despite growing concerns about the alarming rate of loss of fertility due to soil erosion and degradation under the traditional wheat-fallow rotation (Biederbeck et al. 1981; Senate Comm. Rept. 1984) few Prairie grain growers like the idea of including a forage or green manure legume in the rotation to control soil erosion. The aversion to green manuring is particularly strong on grain farms in the drought-prone Brown soil zone of Saskatchewan where, according to the 1982 farm energy survey by Statistics Canada, 0% of farmers questioned were practicing green manuring as compared to about 2% of grain farmers following this practice in the Dark Brown soil zone.

Major reasons for the failure to include legume green manures in cereal rotations on Brown and Dark Brown soils are: the high cost of seed and resultant reduced cash flow, the excessive depletion of soil moisture reserves, the difficulty of establishment and the poor competition with weeds. In earlier reviews of the effects of green manures on dryland cropping systems in the northern Great Plains Army and Hide (1959) and also Brown (1964) concluded that legumes such as alfalfa and biennial sweetclover should not be used for the production of wheat in short rotations on Brown or Dark Brown soils <u>with present cultural techniques</u>.

Thus, new approaches had to be developed and tested in efforts to make legume green manuring an economically viable soil conservation practice in cereal rotations on the Prairies. In the rather dry Brown and Dark Brown soil zones recent research on green manuring has focussed on screening and testing various annual legumes for their potential as fallow replacements (Biederbeck and Looman 1983, 1985; Townley-Smith and Slinkard 1984). The use of annual rather than biennial or perennial legumes in combination with snow trapping was found to result in considerable nitrogen fixation without excessive depletion of soil moisture reserves even in years with severe drought stress (Biederbeck and Carpenter 1986; Slinkard et al. 1987).

Intensive field studies, conducted with support from the ERDAF program, at Swift Current have shown that there are at least three different annual legumes capable of meeting the main criteria required for effective fallow replacement green manuring on Brown soils. These criteria are: fast emergence to provide an early ground cover, high rate of N_2-fixation and biomass production, high water use efficiency (i.e., equal to or better than wheat) and a high level of resistance to insect attacks and fungal diseases. However, the effectiveness of fallow replacement with green manure is affected not only by choosing the most suitable and cost-effective annual legume, but also by selecting the most appropriate management practice from the various alternatives such as incorporation, physical desiccation (i.e., undercutting), temporary chemical desiccation and complete chemical desiccation. Irregardless of the obvious soil conserving benefits, our use of annual legumes to reduce summerfallowing and to develop more bio-resource efficient farming systems for southern Saskatchewan will only be successful if green manuring favors the productivity of the subsequent wheat crop. Consequently, the purpose of this paper is to examine and discuss the effects of type of legume and method of green manuring on the yield and quality of spring wheat in comparison with wheat grown on fallow and on stubble.

MATERIALS AND METHODS

Each year, from 1984 to 1987, at least four different annual legume crops were seeded into wheat stubble with tall stubble snow trap strips in a split plot RCB design with four replicates on a Swinton loam (Orthic Brown Chernozem) at the Swift Current Research Station. The types of annual legumes used varied somewhat from year to year according to seed availability, but Black lentil (*Lens culinaris* cv. 'Indianhead') and Tangier flatpea, TFP (*Lathyrus tingitanus* cv. 'Tinga') were seeded in all four years. Chickling vetch (*Lathyrus sativus* cv. 'NC8-3') was used in 1984, 1986 and 1987. An Austrian winter pea, AWP (*Pisum sativum arvense* cv. 'Melrose') was seeded in 1984 and a feedpea, FP (*Pisum sativum* cv. 'SEMU-SI') in 1985, 1986 and 1987. A 1:1 (equal number of seeds) TFP/AWP mixture was also used in 1984 and a 1:1 TFP/FP mixture in 1985. The main plot treatments in 1984 were rhizobial inoculation and non-inoculation of the green manure crops, with the legume species as sub-plot treatments. In 1985, 1986 and 1987 the main plot treatments were incorporation (tandem disc) and chemical desiccation (diquat) at full bloom with the legume species again as sub-plot treatments. Each replicate also contained a continuous wheat (plus N and P, according to soil test) and a summerfallow plot as low and as high soil moisture controls, respectively. Since 1985, the same legumes as in the inoculated plots were also seeded, each year, without rhizobial inoculation (as RCB with 4 replicates) into nearby wheat stubble to facilitate field measurements of N_2-fixation by the difference method.

Just prior to seeding of the legumes in early May four rows of spring wheat were seeded along the west side of each of the 6.75 m x 25 m plots to again provide tall stubble strips, after grain harvesting with a head-clipper, for uniform overwinter snow trapping. Commercial peat-base inoculants and an effective sticking agent were used for the rhizobial inoculation of the various legume seeds. In each legume plot the top growth on an 18-m long portion was incorporated or chemically desiccated as soon as all legumes had reached full bloom, usually during the first week of July. On the remaining 7-m long portion the annual legumes were left unincorporated and unsprayed to grow to seed maturity. However, neither seed nor top growth were removed from these untreated plot portions which served to simulate the soil moisture use of pulses, when grown as cash crops, but without the large legume-N removal from the land that is inherent to grain legume harvesting.

All legume, wheat and fallow plots were cored hydraulically to 120-cm depth before seeding, at green manure incorporation or desiccation and in late summer (wheat harvest) and late fall for soil moisture and nutrient analyses. Measurements of legume growth and root nodulation were made at intervals during the growing season. Just before green manure incorporation or desiccation all top growth of legumes and of weeds was separately collected from two different 1.0 m^2 areas in each plot for dry matter and nutrient content analyses.

The difference in soil moisture between the beginning of the growing season and green manure incorporation, coupled with precipitation, provided an estimate of water consumption and water use efficiency of the various legumes as biomass producers and N_2-fixers. Precipitation was assumed to be identical with that recorded at the meteorological site located 0.2 km north of the plots (Table 1).

Table 1. Precipitation at Swift Current

Year	Yearly total, mm	Yearly total as % of long-term average*	May 1 to July 31 precip., mm	Growing season precip. as % of long-term avg.+
1984	262	73	100	60
1985	279	78	73	44
1986	383	107	205	123
1987	256	72	129	78

* The 102 yr. annual average is 358 mm.

\+ The 102 yr. May+June+July average is 166 mm.

Each year, since 1985, hard red spring wheat (Triticum aestivum cv. 'Leader') was seeded with a farm-size hoe drill across all previous legume, fallow and continuous wheat plots and the solid-seeded wheat field was sprayed with herbicides as required, according to normal weed control practices. A representative portion of the wheat in each sub-plot was harvested with a small-plot combine for determination of yield and grain quality. All grain samples were dried and cleaned before weighing and sub-sampling for determination of protein content, test weight and kernel weight. At harvest time, two representative 2.0 m length of row in each sub-plot were also hand-cut for counting of whole plants to determine plant density, and after air drying these samples were hand-threshed and the grain vs straw plus chaff were weighed for determination of the harvest index (i.e., ratio of grain to total dry matter yield).

The data were analysed by analysis of variance and significant differences in the tabulated data were determined by Duncan's Multiple Range Test.

RESULTS AND DISCUSSION

1. Weather Conditions and Legume Performance

Over the 4-year period that annual legumes were tested as green manures at Swift Current, weather conditions varied extensively (Table 1). Relative to the long-term average growing season precipitation there was one extremely dry year (1985), two dry years (1984 and 1987) and one year with good growing season rainfalls (1986). As annual legumes normally reach full bloom, i.e., green manure maturity, within only 2 months of seeding, July rains have no beneficial effect on green manure production. In addition to moisture supply, biomass production by these green manure legumes, during their short growth period, is also greatly affected by temperature. Thus the growth rate of typical warm season legumes, viz., Tangier flatpea and Black lentil, was depressed much more than that of the Feedpea and Chickling vetch by a prolonged cool period in May 1986.

Under normal weather conditions the 4 different legumes tended to emerge within 10 to 14 days of seeding and reached full bloom within 6 to 7 weeks of emergence. Root nodulation on inoculated legumes usually became visible within 2 weeks of emergence and tended to reach a maximum in terms of numbers and weight, at early bloom. Rhizobial seed inoculation proved to be highly beneficial to green manure production, even during the 2 consecutive drought years.

In 1984 inoculation increased top growth DM production by 102% to a mean of 1330 kg/ha and in 1985 by 129% to a mean of 1940 kg/ha. With more favorable moisture conditions in 1986 inoculation increased legume DM by 101% to a mean of 2270 kg/ha, but an even greater increase (206%) to a mean of 2360 kg DM/ha was effected by inoculation in 1987 although the precipitation in May and June was 40% below the long-term average. In most years, the Feedpea and the Chickling vetch produced 1.5 to 2 times as much top growth DM as did the Black lentil and the Tangier flatpea.

Inoculation and the resultant N_2-fixation also effected large increases in the water use efficiency (WUE) of legume DM production that ranged from a minimum average of 63% in 1984 to a maximum average of 290% in 1987. Generally, the amount of water used by the inoculated legumes was equal to about two-thirds of the amount consumed by stubble-seeded, N-fertilized wheat during the same 8- to 9-week growth period. The WUE of the Feedpea and of Chickling vetch was always considerably greater than that of the Tangier flatpea and Black lentil and it was at least equal, but in most years better, than the WUE of N- + P-fertilized spring wheat.

The inoculated legumes generally obtained between one-half and three-quarters of their plant-N from the atmosphere. However, the average amount of N_2 fixed by the 4 green manure legumes was only 20 kg/ha in 1984 and 35 kg/ha in 1985, due to the severe drought stress. In 1986, the average amount fixed was 62 kg N/ha and the fixation ranged from 41 kg N/ha with Black lentils to 95 kg N/ha with Chickling vetch. N-fixation by the same 4 green manure legumes, grown under some drought stress, in 1987 averaged 46 kg N/ha.

2. Wheat Yield

In 1985 grain yields were rather low, even on fallow, as a result of the extensive drought. Wheat after any of the 5 inoculated and uninoculated green manures that had been incorporated produced as much grain as wheat on fallow (Table 2). Wheat yields on fallow and following all inoculated and incorporated legumes were, on average, 50% greater than the yield on N- + P-fertilized stubble. However, when the legumes were left to grow to seed maturity subsequent wheat yields did not differ significantly from that of stubble wheat. This proves the importance of eliminating any further water consumption by green manure legumes as soon as they bloom so as to prevent significant reduction of subsequent wheat yields, particularly in dry years, due to excessive soil moisture depletion. Although grain yields after inoculated legumes were consistently slightly higher (by an average of 15%) than after similarly managed uninoculated legumes these yield differences were not significant as the benefits of increased N supply after nodulated legumes were largely masked by the severe drought stress.

Table 2. 1985 Yield of wheat (cv. Leader) following annual legume green manure crops under different management practices

Type of Previous Crop	Management of Previous Crop: Inoculated			Uninoculated	
	Incorporated at Bloom	Grown to Maturity		Incorporated at Bloom	Grown to Maturity
	kg/ha				
Chickling vetch cv. NC8-3	1250a*	855cdef		1000abcd	776def
Black lentil cv. Indianhead	1160ab	871cdef		949bcde	646f
Tangier flatpea (TFP) cv. Tinga	1080abc	779def		942bcde	764def
Austrian winter pea (AWP) cv. Melrose	1100abc	773def		1010abcd	695ef
TFP/AWP mixture	1180ab	877cdef		1100abc	759def
Fallow	—	—	1180ab	—	—
Wheat + 41 kg N & 22 kg P_2O_5/ha	—	—	774def	—	—
Avg. after legumes	1150	831	—	1000	728

* Means with the same letter are not significantly different at p=0.1

With good rainfalls during much of the growing season wheat yields in 1986 were generally three to four times greater than those obtained under corresponding green manure management in the drought of 1985. While the type of annual legume grown previously had again no significant effect on subsequent grain yields the management of the previous legumes did have a much greater effect, than in 1985, on subsequent wheat yields (Table 3). In 1986 the highest grain yields were consistently produced following inoculated and incorporated green manure legumes and these yields were generally 23% greater than those of wheat on fallow and 44% greater than those of N- + P-fertilized third year (continuous) wheat.

Table 3. 1986 Yield of wheat (cv. Leader) following annual legume green manure crops under different management practices

Type of Previous Crop	Management of Previous Crop			
	Inoculated			Uninoculated
	Incorporated at Bloom	Desiccated at Bloom		Grown to Maturity
	kg/ha			
Black lentil cv. Indianhead	3580ab*	2780c		1700d
Tangier flatpea (TFP) cv. Tinga	3250b	2690c		1830d
Feedpea (FP) cv. SEMU-SI	3410b	2690c		1610d
TFP/FP mixture	3860a	2850c		1800d
Fallow	--	--	2860c	--
Wheat (W-W) +40 kgN/ha	--	--	2450c	--
Avg. after legumes	3530	2750	--	1740

* Means with the same letter are not significantly different at p=0.1

When the previous legumes were desiccated at bloom and left unincorporated until next spring the following wheat yielded 22% less than when the legumes had been incorporated at bloom. This very significant yield reduction suggests that the desiccated legume residues, upon soil incorporation 9 months after desiccation, did not decompose fast enough to release sufficient nutrients for optimum yield to the vigorously growing wheat crop. Another possible cause for the yield reduction could be that plant-absorbed residues of the desiccant (diquat) may be inhibiting or delaying the legume decomposition by microorganisms in the soil. This possibility is currently being studied with incubation tests at the Swift Current laboratory. In legume green manure tests at Saskatoon, Townley-Smith and Slinkard (1985) also obtained significantly lower yields of wheat after desiccated than after incorporated annual legumes.

The lowest wheat yields in 1986 were consistently produced after uninoculated legumes that were grown to maturity (Table 3). On average, these yields were barely half of those produced following inoculated and incorporated legumes and they were also 30% lower than the 2480 kg/ha average grain yield obtained after inoculated legumes that were grown to maturity (data not shown). The latter comparison is an example of yield increases derived by wheat, grown under favorable moisture conditions, from symbiotic N_2-fixation by preceeding legumes. In contrast to 1985, wheat yields in 1986 were affected primarily by differences in N-fertility rather than by differences in soil moisture use according to management of the previous legume green manures.

In 1987 some drought stress did occur during May and June and consequently wheat yields were generally only about half as great as those obtained under corresponding management in 1986 but they were still significantly greater than the wheat yields from the severe drought of 1985 (cf. Tables 2, 3 and 4). As in previous years, grain yield was again unaffected by the type of

Table 4. 1987 Yield of wheat (cv. Leader) following annual legume green manure crops under different management practices

Type of Previous Crop	Management of Previous Crop			
	Inoculated			Uninoculated
	Incorporated at Bloom	Desiccated at Bloom		Incorporated at Bloom
	kg/ha			
Chickling vetch cv. NC8-3	1670b*	1470bcd		1160def
Black lentil cv. Indianhead	1590bc	1380bcdef		1120ef
Tangier flatpea cv. Tinga	1520bc	1270cdef		1070f
Feedpea cv. SEMU-SI	1430bcde	1270cdef		1140def
Fallow	--	--	2040a	--
Wheat (W-W-W)+17 kg N & 17 kg P_2O_5/ha	--	--	1070f	--
Avg. after legumes	1550	1350	--	1120

* Means with the same letter are not significantly different at p=0.1

annual legume grown previously but it was greatly affected by the manner in which the previous legumes were managed. Following inoculated and incorporated legumes the yield of wheat was, on average, 24% lower than that of wheat on fallow but it was 45% greater than the yield of N & P fertilized fourth year (continuous) wheat (Table 4). When the previous legumes were desiccated at bloom subsequent wheat did again produce less grain than when the legumes had been incorporated at bloom, but in 1987 the average yield reduction due to desiccation was only 13% as compared to the 22% reduction in 1986. Grain yields after uninoculated and incorporated legumes were as low as the yield of continuous wheat and they were, on average, 28% lower than yields after inoculated and incorporated legumes. This yield difference indicates that spring wheat, grown in 1987, was able to benefit significantly from N- fixation by preceeding legumes, despite the occurrence of some drought stress in late spring.

3. Plant Density

In 1985 stand densities of wheat at grain harvest varied very little and ranged only from a minimum of 89 plants/m^2 after uninoculated Austrian winter peas (AWP) grown to maturity to a maximum of 107 plants/m^2 after inoculated and incorporated AWP (data not shown). Wheat plant densities were generally unaffected by the type or management of the five legume green manures grown previously as only the densities after inoculated and uninoculated AWP, when grown to maturity, differed significantly (at p=0.1) from and were lower than the mean 105 plants/m^2 stand density of wheat on fallow. However, as the observed reductions in plant density occurred only after one legume that was grown to seed maturity any phytotoxic effect must be attributed to the presence of decomposing legume seeds rather than decomposition of vegetative legume tissues in surface soil at the time of wheat seeding and thus this effect is not of agronomic significance for the practice of green manuring.

In 1987 plant densities after inoculated and incorporated and also after third year wheat were significantly lower (i.e., by about 28%) than the density of wheat on fallow (Table 5). Following desiccated legumes stand densities were slightly but not significantly greater than after incorporated legumes while stand densities after uninoculated and incorporated legumes were as high as those of wheat on fallow.

Although some observed differences in stand density were statistically significant they do not suggest or indicate that any phytotoxic effects were exerted by decomposing legume green manures on the subsequent germination, emergence or growth of wheat because (i) stand densities after any legume type or green manure management were at least similar and generally greater than that of wheat on stubble, and (ii) densities after three of the four desiccated legumes and after all uninoculated and incorporated legumes did not differ significantly from that of wheat on fallow. Furthemore, statistically significant differences in wheat plant density after legumes were agronomically inconsequential as they failed to effect corresponding differences in grain production. Thus in 1987 wheat following uninoculated and incorporated legumes had a 43% greater plant density but produced 28% less grain than after the corresponding inoculated and incorporated legumes (cf. Tables 4 and 5).

Table 5. 1987 Plant density of wheat (cv. Leader) following annual legume green manure crops under different management practices

Type of Previous Crop	Management of Previous Crop			
	Inoculated			Uninoculated
	Incorporated	Desiccated		Incorporated
	----------plants/m^2----------			
Chickling vetch cv. NC8-3	88cde*	97bcd		126a
Black lentil cv. Indianhead	73e	95bcde		110abc
Tangier flatpea cv. Tinga	81de	82de		101bcd
Feedpea cv. SEMU-SI	86de	97bcd		131a
Fallow	—	—	113ab	—
Wheat (W-W-W) + 17 kg N & P_2O_5/ha	—	—	79de	—
Avg. after legumes	82	93	—	117

* Means with the same letter are not significantly different at p=0.1

4. Harvest Index

In 1985 the harvest index (HI) of wheat following any of the annual legumes and the HI after fallow were significantly higher than the HI of N and P fertilized wheat on stubble (Table 6). The HI of wheat was generally unaffected by the type or management of legumes grown previously although there was a rather consistent trend toward slightly lower HI after legumes grown to maturity than after the corresponding incorporated legumes. The markedly lower HI of stubble wheat and the slight decreases in HI of wheat after legumes grown to maturity could be attributed to increased drought stress. These water stress effects seem to agree with results of studies with spring wheat in Utah, which according to Hanks and Sorensen (1985) "showed a slight trend for the harvest index to be lower at the lowest water levels (highest stress) for some years and for some cultivars".

Table 6. 1985 Harvest index of wheat (cv. Leader) following annual legume green manure crops under different management practices

Type of Previous Crop	Management of Previous Crop: Inoculated			Uninoculated	
	Incorporated at Bloom	Grown to Maturity		Incorporated at Bloom	Grown to Maturity
	kg/ha				
Chickling vetch cv. NC8-3	0.450abc*	0.444abc		0.445abc	0.415bc
Black lentil cv. Indianhead	0.428abc	0.434abc		0.425abc	0.432abc
Tangier flatpea (TFP) cv. Tinga	0.444abc	0.410c		0.455ab	0.437abc
Austrian winter pea (AWP) cv. Melrose	0.445abc	0.440abc		0.443abc	0.438abc
TFP/AWP mixture	0.454ab	0.425abc		0.458a	0.436abc
Fallow	---	---	0.423abc	---	---
Wheat + 41 kg N & 22 kg P_2O_5/ha	---	---	0.368d	---	---
Avg. after legumes	0.444	0.431	---	0.445	0.432

* Means with the same letter are not significantly different at p=0.1

In 1986, under greatly improved moisture conditions, the HI varied very little, ranging only from a minimum of 0.423 after desiccated Black lentils to a maximum of 0.466 after desiccated Tangier flatpeas. The HI of third-year (continuous) wheat (i.e., 0.450) was very similar to that of wheat on fallow (i.e., 0.443) and neither did the HI after any legume type or any green manure management differ significantly (at p=0.1) from that of wheat on fallow (data not shown).

In 1987 all harvest indices were higher than those obtained in the two preceeding years and they ranged from a low of 0.476 for wheat on fallow to a high of 0.514 after uninoculated and incorporated Black lentils. The HI of fourth year (continuous) wheat (i.e., 0.484) did not differ significantly from that of wheat on fallow, but both were significantly lower than the HI after the following three green manures: uninoculated and incorporated Black lentils, uninoculated and incorporated Chickling vetch and also inoculated and desiccated Black lentils (data not shown).

A comparison of harvest indices over the three years from 1985 to 1987 does show that green manuring with annual legumes has definitely not lowered the HI of subsequent wheat crops below that of wheat on fallow but has generally had a beneficial effect on grain production by effecting small increases in HI above that of wheat on fallow.

5. Grain Quality

The quality of grain produced following different legume types and green manure management practices was evaluated by comparison of its protein content, test weight and kernel weight with that of wheat on fallow and that of adequately fertilized stubble wheat.

(a) Protein Content - In 1985 the protein content of N & P-fertilized stubble wheat was significantly greater than that of wheat on fallow or those of wheat after annual legumes (Table 7). In fact, the protein concentration of the stubble wheat was considerably higher than the long-term average for fertilized stubble wheat at Swift Current (Campbell et al. 1983) due primarily to the very low grain yield under extreme drought stress (cf. Tables 1 and 2). Thus yield and protein levels of stubble wheat in 1985 were rather similar to those prevalent during the 1973 drought. Following inoculated legumes, grain protein did not differ significantly from that of wheat on fallow except for wheat after Black lentils and after TFP/AWP mixture when both were grown to maturity. However, wheat after any uninoculated legumes grown to maturity and after two uninoculated and incorporated legumes had significantly lower protein contents than wheat on fallow (Table 7). These differences indicate some beneficial effects from N-fixation by the legumes on protein production by subsequent wheat, particularly in terms of total quantity of grain protein harvested per unit area.

Table 7. Protein content (%) of wheat (cv. Leader) in 1985 following annual legume green manure crops under different management practices

Type of Previous Crop	Management of Previous Crop				
	Inoculated			Uninoculated	
	Incorporated at Bloom	Grown to Maturity		Incorporated at Bloom	Grown to Maturity
Chickling vetch cv. NC8-3	13.5bcde*	13.5bcde		13.9bcde	13.3cde
Black lentil cv. Indianhead	13.9bcde	13.3cde		14.2bc	13.2cde
Tangier flatpea (TFP) cv. Tinga	14.0bcd	13.6bcde		13.9bcde	13.2cde
Austrian winterpea (AWP) cv. Melrose	13.6bcde	13.6bcde		13.4cde	12.9de
TFP/AWP mixture	13.5bcde	12.8e		13.3cde	13.0de
Fallow	—	—	14.6b	—	—
Wheat + 41 kg N & 22 kg P_2O_5/ha	—	—	17.0a	—	—
Avg. after legumes	13.7	13.4	—	13.7	13.1

* Means with the same letter are not significantly different at p=0.1

In 1986, under good moisture conditions, the protein content of fertilized stubble wheat was about the same as that of wheat on fallow and both were not significantly different from protein concentrations of wheat grown after inoculated and either incorporated or desiccated legumes (Table 8). While protein contents following inoculated legumes were considerably greater in 1986 than in 1985, despite a more than threefold increase in grain yield, the protein contents after uninoculated legumes were even slightly lower in 1986 than in 1985 (cf. Tables 2, 3, 7 and 8) thereby indicating a much greater benefit from legume N-fixation on subsequent grain protein production.

Table 8. Protein content (%) of wheat (cv. Leader) in 1986 following annual legume green manure crops under different management practices

Type of Previous Crop	Management of Previous Crop			
	Inoculated			Uninoculated
	Incorporated at Bloom	Desiccated at Bloom		Grown to Maturity
Black lentil cv. Indianhead	14.7a*	14.5a		11.8d
Tangier flatpea (TFP) cv. Tinga	14.1ab	14.4ab		13.4bc
Feedpea (FP) cv. SEMU-SI	14.9a	14.9a		13.0c
TFP/FP mixture	14.4ab	14.6a		12.5cd
Fallow	--	--	14.7a	--
Wheat (W-W) + 40 kg N/ha	--	--	14.8a	--
Avg. after legumes	14.5	14.6	--	12.7

* Means with the same letter are not significantly different at p=0.1

In 1987 protein contents of wheat ranged from a low of 14.4% after uninoculated Chickling vetch and also uninoculated Tangier flatpeas to a high of 15.6% after inoculated and incorporated Tangier flatpeas. Wheat on fallow and fertilized stubble wheat had the same protein concentration (i.e. 15.5%) despite a twofold difference in grain yield (cf. Table 4). Only the grain protein after the two aforementioned uninoculated legumes was significantly lower than that of wheat on fallow and of wheat after inoculated legumes (data not shown) which were all well above 14.5% and thus would qualify for payment of the Canadian Wheat Board's new protein premium that takes effect on August 1, 1988.

(b) Test Weight - The density of grain is generally a good measure of its quality. In 1985 all test weights of wheat following annual legumes and also of wheat on fallow were well above the 75 kg/hl minimum required for CWRS Grade No. 1 but the density of N & P fertilized stubble wheat was considerably lower and barely met the minimum required for CWRS Grade No. 2 (Table 9). The density of this stubble wheat grain fell far below the 12-year average test weights for fertilized stubble wheat and continuous wheat at Swift Current (Campbell et al. 1983). This abnormally low grain density must be attributed to a much greater soil moisture deficit and drought stress suffered by the stubble wheat which, in turn, resulted in a high percentage of shrivelled kernels. Test weights of wheat following legumes were generally unaffected by legume type or management and did not differ significantly from those of wheat on fallow (Table 9).

Table 9. Test weight of wheat (cv. Leader) in 1985 following annual legume green manure crops under different management practices

Type of Previous Crop	Management of Previous Crop				
	Inoculated			Uninoculated	
	Incorporated at Bloom	Grown to Maturity		Incorporated at Bloom	Grown to Maturity
	--------------------------	----------	kg/hl*	----------	--------------------------
Chickling vetch cv. NC8-3	79.5ab+	79.5ab		79.2ab	79.2ab
Black lentil cv. Indianhead	79.5ab	78.9ab		78.6ab	77.9b
Tangier flatpea (TFP) cv. Tinga	78.9ab	78.9ab		78.9ab	78.9ab
Austrian winter pea (AWP) cv. Melrose	79.8a	78.6ab		79.5ab	78.3ab
TFP/AWP mixture	79.8a	78.6ab		78.9ab	78.9ab
Fallow	—	—	78.6ab	—	—
Wheat + 41 kgN & 22 kg P_2O_5/ha	—	—	72.6c	—	—
Avg. after legumes	79.5	78.9	—	79.0	78.6

* 75 and 72 kg/hl is the minimum required for Grades No. 1 and No. 2 of CWRS, respectively.

\+ Means with the same letter are not significantly different at p=0.1

In 1986, greatly improved moisture conditions caused all grain densities to be very high and very similar, ranging only from a low of 78.4 kg/hl to a high of 80.1 kg/hl. There was no significant difference in test weights between stubble wheat, wheat on fallow and wheat following inoculated and incorporated or inoculated and desiccated legumes (data not shown).

In 1987 some drought stress was experienced in late spring and this resulted in a general decrease of grain densities below the range found in 1986. However, the test weights of wheat from all treatments were still above the minimum required for CWRS Grade No. 1 and extended from a low of 75.3 kg/hl for fourth year (continuous) wheat to a high of 77.9 kg/hl for wheat on fallow. Due to differences in previous soil moisture use, the test weight of stubble wheat was significantly lower than those of wheat on fallow and all wheat after legumes except after desiccated Feedpeas and desiccated Chickling vetch. Grain densities after most incorporated legumes did not differ significantly from that of wheat on fallow (data not shown).

(c) Kernel Weight - In 1985 kernel weights ranged from a low of 19.3 mg/kernel for stubble wheat to a high of 25.2 mg for wheat after uninoculated and incorporated TFP/AWP mixture. The kernel mass of stubble wheat was significantly lower (at $p=0.1$) than that after fallow or after any legumes and kernel weights following legumes did not differ from that of wheat on fallow (data not shown).

In 1986 the very favorable moisture conditions caused all kernel weights to be very high and very similar ranging only from 28.9 to 30.9 mg/kernel. There was no significant difference between kernel weights of wheat following stubble, fallow or any inoculated legumes (data not shown).

In 1987, with moderate drought stress, kernel weights were generally below those found in 1986 and ranged from a low of 25.8 mg for fourth year (continuous) wheat to a high of 29.1 mg for wheat on fallow. Only kernel weights of stubble wheat and of wheat following three inoculated and desiccated legumes were significantly lower than that of wheat on fallow (data not shown) due probably to differences in previous soil moisture depletion.

During the three years of this study, kernel weights were affected much more by differences in soil moisture availability than by differences in N-fertility. As expected, changes in kernel weight from year to year and according to treatments generally did seem to correspond closely to changes in grain test weights. In a recent 3-year study of winter wheat quality at Swift Current, there was also considerable similarity between the pattern of kernel mass and that of test weights (McLeod et al. 1988).

SUMMARY AND CONCLUSIONS

The potential for use of four different annual legumes as fallow replacement with green manure in support of sustainable grain production in the Brown soil zone was evaluated on a Swinton loam at Swift Current over a 4-year period (1984-87) that included one normal (1986) and three dry years. Each spring, inoculated and uninoculated legumes were seeded into wheat stubble with tall stubble trap strips. When the legumes reached full bloom, usually within 6-7 weeks of emergence, their topgrowth in the main portion of some plots was incorporated (tandem disc) while it was chemically desiccated (diquat) in others to minimize moisture use, and in a small plot portion the legumes were left to grow to seed maturity to effect greater soil moisture depletion. Even in dry years, the performance of all legumes was greatly improved by proper seed inoculation with rhizobia when seeded on land that had never grown annual legumes. From 1985 to 1987, inoculation effected, on average, a 136% increase in DM production (i.e., from 930 to 2200 kg/ha/yr) and also a 134% increase in the efficiency of water use for vegetative growth (i.e., from 1490 to 637 kg H_2O used/kg DM produced) by the four legumes. During their short growth period, the inoculated legumes fixed an average of 49 kgN/ha/yr, worth about $27.00/ha.

The effects of type and management of fallow substitute annual legumes on yield and quality of subsequent spring wheat were assessed from 1985 to 1987 by comparison with wheat on fallow and with N-fertilized stubble wheat. The yield of wheat following green manure legumes was always greatly affected by management of the legumes but never by legume type. A strong (weather-related) year effect on grain yield was observed in all treatments. Over the 3-year period, grain production, after inoculated and incorporated legumes, averaged 2080 kg/ha/yr and was as high as on fallow (avg. 2030 kg/ha/yr) and about 400 kg/ha greater than after inoculated and desiccated legumes. However, when the legumes were grown to maturity, subsequent wheat yields averaged only 1370 kg/ha/yr and were as low as those of N-fertilized stubble wheat (avg. 1430 kg/ha/yr) due to greater soil moisture depletion. Wheat after uninoculated and incorporated legumes yielded, on average, 550 kg/ha less grain than after the respective inoculated legumes i.e., a difference indicative of a significant boost in grain production due to N-fixation by the preceeding legumes.

When wheat followed green manure legumes, adequate plant stands were always established. As these wheat plant densities, at grain maturity, were generally between those of stubble wheat and wheat on fallow, there was no indication that any phytotoxic effects could have been exerted by decomposing green manures on subsequent germination, emergence or growth of spring wheat. Similarly, green manuring had no depressive effect on harvest index as the HI of wheat following green manure legumes was always at least as high, and in some cases, even higher than that of wheat on fallow.

The quality of grain produced following inoculated legumes was neither affected by the type of legume grown nor by the method of green manuring (incorporation vs. desiccation). In each of the three years, grain quality after legume green manures was in terms of protein content, test weight and kernel weight, at least as high as that of wheat grown on fallow and with regard to test weight and kernel weight, it was generally much better than the quality of N-fertilized stubble wheat.

As neither yield nor grain quality of wheat was significantly affected by the type of annual legume grown previously, we must conclude that the Black lentil cv. Indianhead with its very small seeds, low seeding rate (34 kg/ha) and seed cost ($0.55-$0.70/kg) is at present the only economical choice for fallow replacement green manuring in the Brown and most likely also in the Dark Brown soil zone. Larger seed size and seed prices that are still unreasonably high ($1.10-$1.35;kg) have rendered the Feedpea (cv. SEMU-SI) and the Tangier flatpea unattractive for green manuring while seed of the Chickling vetch is not yet commercially available.

Our research to date proves that green manuring with annual legumes, when combined with snow trapping, can be a more bio-resource efficient and soil conserving alternative to the conventional practice of summerfallowing for wheat production on drought-prone Brown soils.

ACKNOWLEDGEMENT

The authors are grateful to Mr. H.J. Geissler, Mr. D. Carpenter, Miss H. Scott, Mr. M.D. Grayczyk and Mr. D. Ulrich for excellent technical assistance in the field and laboratory.

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