EFFECTS OF FALLOW REPLACEMENT GREEN MANURING WITH ANNUAL LEGUMES ON SOIL WATER RESERVES

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ABSTRACT

Legume green manures are used in crop rotations to add organic matter, enhance N availability and to provide ground cover for soil conservation. In drought-prone regions like the Palliser Triangle, annual rather than perennial legumes could be used for fallow replacement green manuring in short rotations to avoid excessive depletion of soil water reserves. Results from a 6-year study of green manuring with 4 annual legumes in combination with snow trapping on a Brown loam at Swift Current were used to assess water use during legume growth, water use efficiency (WUE) of green manure production and amounts of soil water remaining for subsequent spring wheat. Each spring Black lentil, Tangier flatpea, Chickling vetch and Feedpea were seeded into wheat stubble with tall stubble trap strips along with continuous wheat and wheat-fallow plots. Legumes were incorporated in some and chemically desiccated in other plots as soon as they reached full bloom. Water use by the 4 legumes was generally related to DM production and did not differ from the amount used by wheat during the same vegetative growth period. Most of the water used was extracted from the 0- to 60-cm soil depth. On average, inoculated legumes used only 12% more water but produced much more DM than uninoculated legumes. Thus rhizobial seed inoculation and the enhanced N_2 fixation effected a doubling of the WUE by these green manures. Chickling vetch and feedpea were able to use water at a 20% greater efficiency than well fertilized spring wheat. Contrary to expectations, levels of soil water recharge between legume bloom and the following spring were always as high for incorporated as for desiccated green manures. At seeding time there was generally 20% less water under continuous wheat than in the fallow soil. In green manured soils, water reserves in spring did not differ between legume species and were usually 15% lower than in fallow plots with wheat trap strips. Wheat yields after green manures were affected primarily by weather and legume management but not by legume species. After incorporated green manures grain production was, on average, 12% and 17% greater than after conventional fallow or desiccated green manure, respectively. The presence of wheat strips in the fallow phase increased subsequent grain yields by an average 20%. We concluded that green manuring with annual legumes, when combined with snow trapping, offers a more bio-resource efficient and soil conserving alternative to conventional summerfallowing for wheat production within the Palliser Triangle.

INTRODUCTION

Legume green manures offer several advantages over the soil-degrading effects of conventional summerfallow practices. They can not only add substantial amounts of organic matter and improve soil structure through increased aggregation but when properly inoculated legumes can fix considerable atmospheric N_2 and make it available to succeeding crops as the residues decompose. Green manure growth provides soil cover to protect against wind and water erosion. Water used by the temporary legumes reduces the amount percolating through the soil and contributing to salinity or the leaching of nutrients from the root zone.

Despite these advantages, legume green manuring is not in common use on grain farms in the drought-prone Brown and Dark Brown soil zones where summerfallow is practiced most extensively. In the past, major reasons for the failure to include perennial or biennial legumes as forages or green manures in cereal rotations within this semi-arid region were the excessive depletion of soil moisture reserves, the difficulty of establishment and poor competition with weeds and the incompatibility of chemical weed control in cereals with the underseeding of legumes. In an earlier review of green manure effects on dryland cropping systems in the northern Great Plains Brown (1964), therefore, concluded that legumes such as alfalfa and sweetclover should not be used for wheat production in short rotations on Brown or Dark Brown soils <u>with the then practiced cultural techniques</u>.

Thus new approaches had to be developed and tested in efforts to make fallow replacement with legumes for plow-down or feed a viable soil conservation practice for cereal rotations on the Prairies. Within the rather dry Palliser Triangle recent research on green manuring has focused on screening and testing various annual legumes for their potential as fallow replacements (Biederbeck and Looman 1983, 1985; Slinkard et al. 1987). The use of annual rather than biennial or perennial legumes in combination with snow trapping was found to result in adequate N_2 fixation and seemed to avoid excessive depletion of soil moisture reserves as indicated by subsequent wheat yields (Biederbeck 1988; Biederbeck and Carpenter 1986; Biederbeck and Slinkard 1988; Brandt 1990; Slinkard and Biederbeck 1987).

At Swift Current, the potential of various annual legumes and management practices for fallow replacement green manuring has been studied with financial support from the ERDAF and EMR programs on a loam soil in combination with snow trapping since 1984. The nitrogen cycle of these annual legume wheat rotations, including apparent N_2 fixation estimates and soil N availabilities, were discussed by Bouman et al. (1992) and are reported in these same Soils and Crops Workshop Proceedings. The objectives of this paper are to examine and discuss the effects of type of legume and method of green manuring on: (i) water use during vegetative legume growth; (ii) the water use efficiency of dry matter production, and (iii) the relative amount of soil water remaining for the wheat crop in comparison with fallow-wheat and continuous wheat cropping including their influence on grain yields.

MATERIALS AND METHODS

Each year, from 1984 to 1990, 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. Details of experimental design, agronomic practices and sampling procedures have been discussed previously (Biederbeck 1988; Biederbeck and Slinkard 1988). Therefore, only a brief review is presented here. Usually, the annual legumes Black lentil (BL, <u>Lens culinaris</u> cv. 'Indianhead'), Tangier flatpea (TFP, <u>Lathyrus tingitanus</u> cv. 'Tinga'), Chickling vetch (CV, <u>Lathyrus sativus</u>, line 'NC8-3') and a feedpea (FP, <u>Pisum sativum</u> cv. 'Sirius') were seeded together with spring wheat trap strips in the legume phase as green manure. In each (6.75 m x 25 m) legume plot the top growth on an 18 m-long portion was incorporated (Tandem disc) or chemically desiccated (Diquat) as soon as the legumes reached full bloom to prevent further soil water use. On the remaining 7 m-long portion the legumes were left to grow to seed maturity and simulate moisture use by grain legumes when grown as cash crops. In addition to the four legume plots each replicate also contained a continuous wheat (hard red spring wheat, *Triticum aestivum* cv. 'Leader') and a summerfallow plot for comparative purposes. Commercial peat-base inoculants and a sticking agent were used for inoculation of the various legume seeds with appropriate strains of *Rhizobium leguminosarum*. All phases of each rotation were present every year and each rotation was cycled on its assigned plots. The same legumes were also seeded, each year from 1985 to 1989, without rhizobial seed inoculation into nearby wheat stubble to facilitate field measurements of inoculation effects. All rotations received P fertilizer at rates based on soil tests of the individual plots but only continuous wheat was also fertilized with nitrogen. Soils were sampled in all plots to 120-cm depth before seeding, at legume bloom, in late summer (wheat harvest) and in late fall for moisture and nutrient analyses. Gravimetric moisture contents were converted to volumetric units using different bulk densities for the five depth segments (0- to 15-, 15- to 30-, 30- to 60-, 60- to 90- and 90- to 120-cm) sampled. 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 (WUE) of the various legumes and spring wheat as biomass producers. Precipitation was assumed to be identical with that recorded at the meteorological site located 0.2 km north of the main plot area.

RESULTS AND DISCUSSION

Over the 7-yr 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) three dry years (1984, 1987 and 1988), one normal year (1990) and two years with good growing season rainfalls (1986 and 1989).

Table 1. Precipitation and evaporation at Swift Current

Year	Growing season precip. (May 1-July 31) as mm	% of long-term avg.	Growing season Class A pan evapor'n mm	Annual total precipitation mm
1984	100	60	844	262
1985	73	44	908	279
1986	205	123	705	383
1987	129	78	802	256
1988	143	86	1085	287
1989	210	127	695	430
1990	179	108	699	296
Long-term (105 yr)avg	166	100	740†	357

†31 year mean for pan evaporation.

Although growing season precipitation in 1988 was 86% of normal this was the year with the most severe conditions of drought stress as growing season evaporation was about eight-fold greater than precipitation (Table 1) following a winter with little or no moisture recharge and as temperatures and winds were much above normal early in the growing season.

As annual legumes normally reach full bloom within only two months of seeding July rains have practically no beneficial effect on green manure production.

Under normal weather conditions the four different legumes tended to emerge within 10 to 14 days of seeding and reached full bloom within 6 to 7 weeks of emergence, which usually occurred during the first week of July. Root nodulation on inoculated legumes became visible within two 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 four drought years, as it effected an average 110% increase in legume dry matter (Biederbeck 1988; Bouman et al. 1992).

During vegetative growth the extent of soil water use by the feedpea was usually very similar to that of N- and P-fertilized spring wheat and only in 1985 and 1986 did the other three legumes use significantly less soil water than was used by wheat (Table 2). As expected, water use by these green manure legumes was directly related to their average biomass production except for the black lentil who generally used as much soil water as the chickling vetch but consistently produced much less dry matter. In two of the three years when weather conditions were favorable (viz. 1986 and 1990) it seemed that May and June rains did provide all the water required for vegetative legume growth because in those years soil water contents sid not change significantly between seeding and green manure incorporation at full bloom (cf. Tables 1 and 2). Most of the water used by both legumes and wheat during vegetative growth was normally extracted from the 0- to 30-cm soil depth with less being extracted from 30- to 60-cm depth and very little being taken up from below 60 cm (data not shown). In fact, the green manure legumes were never able to remove any significant amount of soil water from the 90- to 120-cm depth.

Table 2. Water use by legumes and wheat during vegetative growth measured as decrease in moisture contained at 0- to 1.2-m soil depth between seeding and green manure incorporation

	Crop						
Year	Black lentil	Tangier flatpea	Chickl'g vetch	Feed-pea	Contin. wheat	Summer-fallow	
	mm						LSD 0.05
1984	77	34	86	95	52	12	43
1985	51	44	36	62	84	2	32
1986	-17†	-23	-9	5	23	-65	26
1987	58	28	60	54	45	-11	41
1988	23	22	11	26	26	-29	30
1989	44	49	39	45	41	-38	36
1990	2	-4	-4	5	4	--	28
Mean	34	21	31	42	39	-22	

†A negative value denotes an increase in soil water content.

In semi-arid regions summerfallowing is commonly practiced to increase stored soil moisture yet our soil water use data (Table 2) show that in 1984 and 1985 drought stress and evaporation demand were so severe that even under fallow there was a net loss of soil water in the 0- to 1, 2-m depth between late April and early July. During the other years soil water under fallow was significantly recharged by early summer rains.

When soil water use by green manures was averaged across legume types and compared for inoculation treatment there were only two years (1984 and 1989) during the six-year study when inoculated legumes used significantly more water than uninoculated legumes. As shown in Table 3, inoculated legumes used, on average, only 12% more soil water than the corresponding uninoculated legumes yet they generally produced 110% more dry matter (DM). One reason for the disproportionately high soil water use by uninoculated legumes is that, because of slower and weaker legume growth, these plots were usually much more heavily infested with weeds (Bouman et al. 1992). Another reason is simply that rhizobial seed inoculation with the resultant root nodulation and symbiotic N_2 fixation has enabled these legumes to use the rather limited soil water resources much more effectively (due to greater physiological growth synchronization) for green manure biomass production.

Examination of water use efficiency (WUE) data over a span of five years clearly shows that the WUE of green manure legumes was influenced much more by management practices, such as rhizobial seed inoculation, than by species specific attributes (Table 4). Thus inoculated legumes were, on average, twice as efficient as uninoculated legumes in using water for DM production during vegetative growth. Within each management system water tended to be used more effectively by the feedpea and chickling vetch who also accumulated much more biomass than the less productive black lentil and Tangier flatpea (Table 4). A comparison of inoculated legumes with adequately N- and P-fertilized continuous wheat indicates that the rather drought-tolerant chickling vetch and feedpea were, on average, able to use water for vegetative growth at a 20% greater efficiency than even 'Leader', a spring wheat cultivar that had been bred for growth and grain production within the frequently drought-stressed Palliser Triangle. Consequently, we emphasize that WUE measurements and field evaluations are of major importance in selecting legume species for green manuring that will match prevailing water and temperature conditions and produce acceptable growth and N_2 fixation rates.

Our results on water use by green manure legumes disagree with those by Badaruddin and Meyer (1989) that green manure legumes used 10 to 25% more water than hard red spring wheat at two locations in North Dakota. The greater water use by green manures in the North Dakota study was simply due to the use of more deeply rooted, forage-type legumes for green manuring and allowing legume growth to extend well into autumn. However, the finding that the mean WUE of inoculated green manure legumes was 0 to 25% greater than that of wheat at both locations in North Dakota tends to corroborate our WUE evaluations.

Table 3. Water use by inoculated and uninoculated legumes during vegetative growth from 0- to 1.2-m soil depth between seeding and green manure incorporation

Year	Legume† treatment: Inoculated	Uninoculated	
	------------- mm	--------------	LSD 0.05
1984	73	46	23
1985	48	42	34
1986	-11	22	48
1987	50	49	31
1988	20	14	30
1989	44	25	9
Mean	37	33	

†Mean of Black lentil, Tangier flatpea, Chickling vetch and Feedpea.

In agreement with our observations results from a recent greenhouse study by Zachariassen and Power (1991) on growth rate and water use by eight legume species generally showed that species that grow best usually extract soil water at higher rates and have the greatest WUE. They also found that legume WUE normally decreased with plant age and with increasing soil temperatures. This confirms that the WUE of green manure legumes can be affected more by environmental and management factors than by species characteristics.

Table 4. Water use efficiency of inoculated and uninoculated legumes and of wheat during vegetative growth

Treatment and Crop	Year: 1985	1986	1987	1988	1989	5-Year mean
	----------------		L/kg†	---------------		
<u>Inoculated</u>:						
Blk. lentil	689	840	598	701	669	699
T. flatpea	613	902	439	815	702	694
Ch. vetch	452	586	464	668	613	557
Feedpea	485	572	348	777	553	547
<u>Uninoculated</u>:						
Blk. lentil	1737	1736	1157	1650	726	1401
T. flatpea	1167	1868	987	1433	846	1260
Ch. vetch	1300	1408	864	1350	713	1127
Feedpea	1017	1738	752	1162	664	1067
Continuous N&P-fertilized wheat	725	572	587	868	560	662

†WUE as liters of water used per kg of dry matter produced.

Table 5. Water contained within 0- to 1.2-m soil depth at time of wheat seeding and after inoculated legume green manures, wheat or fallow

	Preceding Crop						
Year	Black lentil	Tangier flatpea	Chickl'g vetch	Feed-pea	Contin. wheat	Summer-fallow	
	mm†						LSD 0.05
1986	261	256	254	253	239	290	20
1987	217	216	218	209	191	255	11
1988	180	187	165	158	165	190	24
1989	173	177	188	181	178	203	24
1990	184	194	187	191	179	250	12
Mean	203	206	202	198	190	238	

†Volumetric soil water content.

After incorporation or desiccation of the four legumes at full bloom for green manuring some recharge of soil moisture occurred usually during fall and overwinter. The level of soil water recharge fluctuated extensively over the six year study at Swift Current and ranged from a net gain of 73 mm in 1985-86 to a net loss of 11 mm in 1986-87. Contrary to our expectations, the amount of overwinter soil water recharge differed never significantly between the two green manuring practices (data not shown) and was, when averaged across all years, 26 mm and 22 mm following incorporated and following desiccated legumes, respectively. This suggests that, in the presence of tall wheat stubble trap strips (in legume, wheat and fallow plots), soil cover and shading by the desiccated legume stands failed to effect further improvements in soil moisture conservation or increased overwinter recharge. Our results agree with those reported by Brandt (1990) who also found in green manure studies with black lentils on a Dark Brown loam at Scott that soil water contents after incorporated vs. desiccated lentils differed neither in late fall nor in spring prior to seeding of a wheat crop.

During five years at Swift Current the amount of soil water present at wheat seeding each spring, did not differ following any of the four legume species but for one exception in 1988 when significantly more water remained after green manured Tangier flatpea than after feedpea (Table 5). Consequently, the mean soil water reserves, over time, following all four green manures were very similar, around an average of 202 mm. Since soil water availability to subsequent wheat was generally not affected by the type of annual legume grown, our results would suggest that species producing more legume biomass and fixing more N_2 should be used preferentially for green manuring so as to maximize improvements in soil structure and fertility.

Soil water reserves in the well fertilized continuous wheat rotation were, as expected, each spring significantly lower than in fallow (Table 5). On average, the continuously cropped soil contained 20% less water than the fallowed soil just prior to wheat seeding.

During three years (viz. 1986, 1987 and 1990) soil water contents after all green manures were in spring lower than under fallow while water reserves in the other two years (1988 and 1989) were only less after two of the four legumes. Averaged across legumes and years the green manured soils contained 15% less water than fallow before wheat seeding. When compared to the water content under continuous wheat water reserves after green manures were generally similar for most legumes in most years (Table 5). Only in 1987 were spring soil water reserves after all legumes significantly greater than in continuous wheat.

Soil water depletion during green manure or wheat growth and subsequent overwinter recharge affected primarily the moisture status within the top 60 cm with very minor changes occurring below that depth. In a wet spring, such as 1986, the same amount of water was stored in fallow as after green manures or continuous wheat at the 0- to 60-cm depth. However, below 60 cm most water was stored in fallow and the least in continuous wheat with water reserves in green manured soils being intermediate (data not shown). A comparison of soil water distribution patterns with depth across years and cropping systems demonstrated very consistently that the greatest amount of water each spring was contained at the 30- to 60-cm soil depth.

In our study spring moisture levels in green manured soils were, in general, significantly lower than in fallow and rather close to water reserves under continuous wheat (cf. Table 5). The average 15% reduction in soil water reserves due to green manuring was more extensive than would have been expected from the results of other green manure studies with annual legumes. For example, Brandt (1990) reported from a 5-year and another 2-year study at Scott that spring soil moisture levels after green manured (incorporated or desiccated) black lentils were consistently as high as after conventional summerfallow. Similarly, Badaruddin and Meyer (1989) found in North Dakota that soil water depletion by some annual legumes, even when grown to grain maturity, was as low as in conventional fallow. The persistent and sizeable difference in spring soil moisture levels between green manured and fallowed soil in our study must be attributed to the fact that even the summerfallow plots in our experiment had tall stubble wheat strips throughout the fallow phase which would reduce evaporation of soil water and increase snow trapping; hence the soil water status of these plots was enhanced and certainly not representative of 'conventional summerfallow' conditions.

The yield of wheat following fallow replacement green manures was greatly affected by weather conditions and legume management, as shown in Table 6, but it was never significantly altered by the species of annual legume used as green manure. Wind breaking and snow trapping with tall wheat stubble strips was very effective as it increased grain yields on fallow by an average 20% over yields on conventional summerfallow.

Similarly, Brandt (1990) was able to effect significant increases in wheat yields after lentil green manures by growing mustard trap strips or leaving lentil trap strips after incorporation of the legume topgrowth. Over a five year period at Swift Current, grain production after inoculated and disced-in green manures with wheat trap strips was 12% above that on conventional fallow and also 17% greater than after chemically desiccated green manures (Table 6). However, yields after legumes that were grown to maturity and after uninoculated and disced-in green manures were as low as those of N- and P- fertilized continuous wheat, emphasizing moisture and N-fertility stress effects, respectively.

Table 6. Effect of weather conditions and management of legume green manures on yield of subsequent spring wheat and monoculture wheat rotations at Swift Current

Preceding crop and treatment	Grain Yield		
	Moist yr. (1986)	Dry yr. (1988)	5-yr mean (1985-89)
	kg/ha		
Conventional summerfallow	2820	826	1650
Fallow with wheat trap strips	3070	1062	1980
Continuous wheat, N&P-fertilized	2460	329	1240
Annual Legumes†:			
- Inoculated & incorporated at bloom	3540	504	1850
- Inoculated & desiccated at bloom	2750	410	1580
- Inoculated & grown to maturity	2480	242	1180
- Uninoculated & incorporated at bloom	2500	222	1280

†Mean of Black lentil, Tangier flatpea, Chickling vetch and Feedpea.

Although soil water reserves when seeding wheat after incorporated green manure were usually 15% lower than in fallow with trap strips (cf. Table 5) grain yields following these green manures were only reduced by 6% compared to fallow (Table 6). These comparisons suggest that the soil fertility enhancement or the beneficial 'rotation effect' provided by green manures can largely offset any negative effects of moisture utilization by the legumes on subsequent grain crop productivity which augurs well for greater integration of legumes into cereal rotations to achieve sustainable crop production systems in western Canada (Biederbeck 1990). From our field research at Swift Current it can be implied that green manuring with annual legumes, especially when combined with snow trapping, offers a more bio-resource efficient and soil conserving alternative to conventional summerfallowing for wheat production on drought-prone soils within the Palliser Triangle.

CONCLUSIONS

Water use by four annual legumes when grown for green manure was generally related to DM production and did not differ from the amount used by wheat during the same vegetative growth period. Most of the water used by green manures and wheat was extracted from the 0- to 60-cm soil depth. Inoculated legumes used, on average, only 12% more soil water than uninoculated legumes but produced 110% more DM. Thus rhizobial seed inoculation and resultant N_2 fixation effected a doubling of the water use efficiency (WUE) by these legumes. The two more productive legumes, i.e., chickling vetch and feedpea, were able to use water at a 20% greater efficiency than a well fertilized and well adapted spring wheat cultivar.

Surprisingly, the level of soil water recharge between legume bloom and the following spring was always as high for incorporated as for desiccated green manures. At seeding time the soil under continuous wheat contained generally 20% less water than the fallow soil. In green manured soils, water reserves in spring did not differ between legume species and were usually 15% lower than in fallow plots with wheat trap strips.

Wheat yields after green manuring were always greatly affected by weather and legume management but not by legume species. Over five years grain production after incorporated green manures was 12% and 17% greater than for wheat grown on conventional fallow or chemically desiccated green manure, respectively. Growing wheat trap strips during the fallow phase increased subsequent grain production by an average 20%. Some data indicated that potentially negative effects of soil water use by the legumes on grain crop productivity are being largely offset by beneficial fertility and rotation effects from the green manures.

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