PROCEEDINGS

OF THE

GREAT PLAINS SOIL FERTILITY CONFERENCE

DENVER, COLORADO

MARCH 4-6, 1996

Great Plains Soil Fertility Conference Proceedings, Vol. 6

Edited by John L. Havlin

Kansas State University

Manhattan, Kansas 66506-5501

FALLOW REPLACEMENT USING INDIANHEAD LENTILS: WATER USE, YIELD AND SOIL NITROGEN

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ABSTRACT

Because of increased costs of fertilizer and evidence of declining soil quality there has been renewed interest in crop rotations using legumes in the traditional spring wheat-fallow rotation areas of the semiarid northern Great Plains. Objectives were to test a "green fallow" method of farming as a system to build soil nitrogen and efficiently use water. We compared mechanical fallow using sweeps (MF) and chemical fallow (CF) to green fallow. Fallow treatments MF and CF received 30 lb-N/acre as NH_4NO_3 broadcast prior to seeding wheat (*Triticum aestivum* L.). Lentils (*Lens culinaris* Medikus, cv. 'Indianhead') were grown as a green manure crop in a green fallow-spring wheat rotation. The experiment was started in 1991 as a randomized complete block with four replications and MF as control. Soil was a Williams loam (fine-loamy, mixed Typic Argiboroll) 7 miles north of Culbertson Montana. At full bloom, lentils were either killed by disking (GMMF) or chemical burn-down (GMCF). Average dry-weight of Indianhead lentils for 1991, 1992, and 1993 was 1500 lb/acre compared to an average of 4700 lb/acre for 1994 and 1995. Average water use by lentils in 1991, 1992, and 1993 was 10.6 inches. In contrast, MF and CF lost 9.9 inches. Average water use by lentils in 1994 and 1995 was 12.9 inches which was significantly more than the loss of 10.7 inches on MF and CF. At spring planting, there were no differences in soil water content among treatments. Wheat yield was 25% less on green fallow compared to MF and CF. Soil NO_3-N levels were 35 % lower on green fallow rotations than MF and CF rotations. There were no differences among treatments in nitrogen mineralization rates in 1993 following two cycles of green manure. Lack of available nitrogen, rather than lack of soil water, appears to have restricted wheat production on green fallow treatments.

INTRODUCTION

Water is the limiting factor for crop production in the semiarid northern Great Plains and consequently cropping options are severely limited. In Montana, there are 17.82 million acres of cropland (Montana Agric. Stat. Serv., 1994). Because of climatic, economic, cultural, or government program constraints, 1.68 million acres of cropland are summer fallowed making summer fallow a common practice. Benefits of fallow are weed control and mineralization of plant nutrients. Conversely, summer fallow has accelerated soil carbon loss, soil erosion and development of saline seeps. Typically, water storage efficiency of fallow ranges from about 15 to 40% (Black and Power, 1965; Tanaka and Aase, 1987). However, even with low water storage efficiency, summer fallow provides a means of reducing risk by reducing year-to-year variability in soil water and consequently crop yield. This is important in a crop production system where precipitation is extremely variable in both amounts and timing.

Legumes in crop rotations have regained farmers' attention as a potential method to build soil carbon and to provide an inexpensive means to add soil nitrogen. The term "green fallow" has been coined to describe a green manure farming system that is typically used as a partial fallow replacement (Rice et al., 1993) in a wheat-fallow rotation. In this system, a legume is seeded early in the fallow year, grown to about full bloom, and killed by chemicals or tillage. One of the most important aspects of this green fallow system is to balance water use for N_2 fixation to water and nitrogen requirements by the subsequent wheat crop. Achieving this balance in a 14 inch precipitation zone has yet to be demonstrated. Research on the Canadian Prairies show a gradual reduction in fertilizer-N requirement in a wheat-lentil rotation after about 6 years (Campbell et al., 1992). Our objectives were to test the potential of using green fallow to build soil nitrogen, efficiently use soil water, and to determine the effect of green fallow on the subsequent spring wheat crop.

MATERIALS AND METHODS

The study was located 7 miles north of Culbertson Montana on a Williams loam (fine-loamy, mixed Typic Argiboroll) with about a 3% slope. Average annual precipitation is 14 inches, with about 80% of the precipitation occurring during April through September. Prior to the start of the experiment in 1991 wheat was grown in a fallow - spring wheat rotation with no fertilizer. Phosphorus levels were built-up by broadcast application of 200 lb/acre diammonium phosphate (18-46-0) prior to seeding in 1991 and broadcast application of 185 lb/acre triple superphosphate (0-44-0) prior to seeding in 1992. Experimental design was a randomized complete block with 4 replications and 5 treatments. Plots were 40 feet wide and 50 feet long.

Two treatments were cropped in conventional manner of fallow, where all plant growth was killed either by tillage (MF) or herbicides (CF). On CF, stubble remained from harvest until seedbed preparation nearly 21 months later. Glyphosate [(N-phosphonomethyl)glycine] and 2,4-D (2,4-dichlorophenoxyacetic acid) were used as necessary to eliminate weeds. On MF, wheat stubble remained standing the first winter after harvest. Weeds were controlled as necessary during summer fallow with medium-crown sweeps and rodweeder. Prior to seeding spring wheat, both MF and CF treatments were broadcast fertilized with 30 lb N/acre as ammonium nitrate. Seedbeds for both MF and CF treatments were prepared with a tandem disk followed by toolbar sweeps and rod. Plots were seeded to "Lew" spring wheat at about 850,000 viable seeds/acre using a double disk drill with 8 inch row spacing. Seeding was as early as April 2 and as late as May 21.

Two treatments were cropped as a green fallow-spring wheat rotation. During part of the summer portion of the fallow year, Indianhead lentils were grown as a green manure and terminated either mechanically by disking (GMMF) or by herbicides (GMCF). On GMCF, wheat stubble remained from harvest; glyphosate was used for pre-plant weed control; and lentils were no-till seeded. On GMMF, the seedbed was prepared for lentils similarly to that for spring wheat. Lentils were inoculated and seeded on both treatments at about 53 lb/acre using a JD 750 drill with 7.5 inch row spacing. At about full bloom (normally the first part of July) lentil growth was terminated. The following spring, seedbeds for wheat were prepared on both treatments similar to the MF and CF treatments. Wheat seeding date and rate for GMCF and GMMF treatments were the same as MF and CF treatments. No inorganic fertilizer was applied to the green manure treatments.

One treatment was cropped as annual spring wheat. Seedbed preparation, fertilizer rate, and seeding date and rate were the same as MF and CF treatments.

Soil water was measured using neutron attenuation during the growing season to a depth of 6 feet at 1-foot intervals. Access tubes for these measurements were located in the center of each plot. Water use (WU), which is combined evaporation and transpiration water loss, was calculated as:

$$WU = Rain-(Soilwater_2-Soilwater_1)$$

where rain is the amount of precipitation occurring between the first soil water measurement of the season ($Soilwater_1$) and the last soil water measurement of the season ($Soilwater_2$). Soil water is the depth of water in the 6-foot soil profile. Fallow water-use period is thus operationally defined by the first and last water measurements of the season. Crop water use is defined such that $Soilwater_1$ is the water measurement at seeding and $Soilwater_2$ is the measurement at harvest. This calculation assumes that there was no water runoff from the plots and that drainage was negligible.

Soil nitrate and phosphorous were measured prior to wheat planting and fertilizer application. Samples for the 1993 and 1994 crop were taken in late October 1992 and 1993, respectively. Samples for the 1995 crop were taken in April 1995. Three soil cores, 1.4 inches in diameter, to a depth of 24 inches were taken at about 10-foot intervals across each plot. Each core was segmented into sample increments of 0-to 3, 3-to 6, 6-to 12, and 12-to 24- inches for analysis. Soil nitrate was determined using an Alpkem rapid flow analyzer (Perstop Analytical, Clackamas, OR). Soil phosphorous was determined using the sodium bicarbonate method.

Nitrogen mineralization was measured on soil samples taken in late October 1993 from the 0- to 3 and 3- to 6-inch depth. Soil samples were air dried and ground to pass through a 2mm sieve. Incubation vials were set up using 5g of soil wetted to a drained-upper-limit volumetric water content of 21% which corresponds to about 1/3 bar. Incubation temperature was 25°C. Sample vials were taken from the incubator at 7, 14, 28, 56, and 84 days and frozen at -16.0°C to await analysis of nitrate nitrogen.

Spring wheat grain and straw yield harvest samples were obtained by cutting bundle samples from five 1-m long rows from six areas on each plot. Bundle samples were weighed and threshed, following which the grain was weighed and straw yield determined. Grain protein was determined using NIR. On the green manure treatments, lentil phytomass was sampled in a like manner. Samples were air dried, weighed and ground for nitrogen analysis. Total plant nitrogen was measured using a Carlo Erba NA 1500 C-N analyzer (Carlo Erba Instruments, Milan, Italy) for samples taken in 1991, 1992, and 1993 and by Kjeldahl analysis in 1994 and 1995.

Water use, yield, and soil nitrogen were tested for significant differences among treatments using analysis of variance and least significant differences (LSD) at P=0.05. For all comparisons, MF was the control treatment.

RESULTS AND DISCUSSION

Soil water use by Indianhead lentils during the summer fallow period was not significantly different from traditional fallow treatments for 1991, 1992, and 1993 (Table 1). Average water use for MF and CF treatments was 9.9 inches compared to 10.6 inches for GMMF and GMCF treatments. During 1994 and 1995 there was significantly more water used on green fallow than on fallow. Average water use on fallow was 10.7 inches compared to 12.9 inches on green fallow.

There were no significant differences in water use between chemical and mechanical fallow or between chemically and mechanically killed green fallow treatments.

Differences in soil water use among years (Table 1) by Indianhead lentils underscores the most important aspect of managing green manure in semi-arid climates. A balance must be achieved between using fallow season water and providing for adequate soil water for the subsequent wheat crop. Average dry-weight of lentils for 1991, 1992, and 1993 was 1500 lb/acre compared to 4700 lb/acre in 1994 and 1995. Average water use by lentils in 1991, 1992, and 1993 was 10.6 inches compared to 12.9 inches in 1994 and 1995. Total nitrogen in the above-ground Indianhead lentil plant averaged 27 lb/acre for 1991, 1992, and 1993 compared to an average of 118 lb/acre in 1994 and 1995. Growing season precipitation and number of days between seeding lentils and termination are shown in Table 2.

Wheat yields were significantly less on green fallow plots (GMCF and GMMF) than on fallow plots (MF and CF). In 1992, 1993, and 1994, wheat yield averaged 47 bu/acre on plots following fallow compared to 35 bu/acre on plots following green fallow (Table 3). For those years, there were no significant differences in soil water among treatments at seeding time for the 0 -to 3-ft depth or 0-to 6-ft depth at seeding time (Table 3). On an annual basis, these yields correspond to 24 bu/acre following fallow and 18 bu/acre following green fallow. In contrast, the annual wheat treatment averaged 26 bu/acre for 1993 and 1994.

Soil nitrate-N levels on plots going into wheat were significantly lower after green fallow compared to fallow (Table 4). For 1993, 1994, and 1995, average nitrate-N levels in the top 2 feet of soil was 38 lb/acre on plots that were previously fallowed. Plots that were previously green fallowed averaged 25 lb/acre nitrate-N. Nitrate-N tests do not include the additional 30 lb-N/acre added to MF and CF prior to wheat seeding. No N was added to GMCF and GMMF treatments. In 1994, there was less nitrate-N following CF than GMMF which is contrary to the results for 1993 and 1995. We do not have an explanation for this anomaly. However, it appears that the cause of lower wheat yield following green fallow can be attributed to insufficient nitrogen rather than insufficient soil water. Further, water-use efficiency was significantly lower (Table 3) for wheat following green fallow compared to fallow. Poor water-use efficiency is an attribute of nutrient deficient soil. Crop yields in 1995 were reduced because of hail damage, nevertheless yields were generally lower on treatments following green fallow than fallow

Soil phosphorous content did not differ significantly among treatments. For the wheat production years of 1993, 1994, and 1995, average sodium bicarbonate extractable P in the top 3 inches was 33 ppm on fallow treatments and 29 ppm on green fallow treatments. At the 3-to 6-inch depth, there were 11 ppm on fallow and 9 ppm on green fallow. These levels are adequate for both spring wheat and lentils.

Nitrogen mineralization tests on soil samples taken in October 1993 from the 0-to 3-inch depth and 3- to 6-inch depth were not significantly different between fallow and green fallow treatments. Average nitrate-N levels in soil from the 0-to 3-inch depth following incubation for 84 days was 41 lb/acre on conventional fallow treatments and 46 lb/acre on green fallow treatments. Average nitrate-N at the start of the incubation test was 8 lb/acre. The 84-day incubation roughly corresponds to the growing season for spring wheat.

Potential wheat yields based on the amount of nitrogen available for the crop year were similar to average yields. An estimate of wheat yield was made assuming adequate water and that nitrogen mineralization rates for the wheat year were similar to those measured for the fallow year.

Expected availability of N on the fallow treatments (MF and CF) was approximately 109 lb/acre (38 lb/acre soil test + 30 lb/acre broadcast at seeding + 41 lb/acre anticipated from mineralization during the wheat year). On the green fallow treatments (GMMF and GMCF) there was approximately 71 lb/acre (25 lb/acre soil test + 46 lb/acre anticipated from mineralization during the wheat year) Average potential wheat yields for these N levels, using an estimate of 2 lb-N/bu (Brown et al., 1981), were 54 bu/acre on the fallow plots and 36 bu/acre on the green fallow plots and are similar to the average yield for 1992, 1993, and 1994 of 48 bu/acre on fallow and 35 bu/acre on green fallow.

CONCLUSION

Managing water use for annual cropping appears to be easier than to attempt storing soil water during summer fallow. For three out of five years there were no differences in soil water use by green fallow as compared with soil water loss from fallow. In those years, lentil growth was terminated at about full bloom when average dry-weight of lentils was about 1500 lb/acre. Green fallow used more water than fallow when lentils matured past full bloom and average dry-weight of lentils was about 4700 lb/acre. However, in all years soil profile water contents to a depth of six feet were the same for green fallow and fallow in the spring of the year, suggesting that the profile filled to an upper drained limit. Soil nitrate-N content was least on green fallow treatments, which did not receive additional N. Wheat yield was 25% less on green fallow treatments compared with fallow treatments. Nitrogen rather than soil water was the limiting factor for competitive wheat yields on the green fallow-spring wheat rotation as compared with the fallow-spring wheat rotation. Low nitrogen content on green fallow treatments after two complete rotations underscores the need for long term field experiments to assess the capability of green fallow to build soil organic matter with limited inputs in a semiarid climate.

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Table 1. Water loss during fallow and green fallow. Dry weight, nitrogen content, and C/N ratio of Indianhead lentils.

	Fallow Treatment	Water Loss inches[1]	Dry Weight lb/acre[2]	Nitrogen lb/acre	C/N
1991	Mechanical	9.3			
	Chemical	9.4			
	Lentils disked	10.1	917	12.9	27.5
	Lentils sprayed	9.9	461	9.9	17.7
	LSD (0.05)	ns			
1992	Mechanical	9.4			
	Chemical	9.2			
	Lentils disked	10.1	2256	40.1	21.5
	Lentils sprayed	10.1	1120	22.7	18.7
	LSD (0.05)	ns			
1993	Mechanical	11.1			
	Chemical	10.9			
	Lentils disked	11.6	2052	36.6	21.5
	Lentils sprayed	11.5	2189	42.1	19.8
	LSD (0.05)	ns			
1994	Mechanical	9.2			
	Chemical	9.3			
	Lentils disked	*11.5	5133	116.4	16.6
	Lentils sprayed	*12.4	6163	153.2	15.1
	LSD (0.05)	0.8			
1995	Mechanical	12.3			
	Chemical	12.1			
	Lentils disked	*13.4	3548	98.6	13.4
	Lentils sprayed	*14.2	3943	105.4	14.0
	LSD (0.05)	0.8			

Significant at the 0.05 probability level (*) or not significant (ns)
1) Water loss to a depth of 6 feet.
2) Lentils damaged from residual 2,4-D in 1991 and 1992 and hail damaged in 1995

Table 2. Precipitation (inches) during growing season and summer fallow.

Soil Water Balance Parameters	1991	1992	1993	1994	1995
Precipitation during lentil growing season[1]	7.01	6.62	7.81	7.10	7.27
Precipitation during summer fallow[2]	9.99	10.76	11.65	9.15	13.08
Days from seeding to termination of lentils	61	83	91	93	86
First soil water measurement	22 May	2 Apr	10 May	21 Apr	17 May
Last soil water measurement	30 Sep	11 Aug	26 Oct	21 Oct	20 Oct

1) Time period from seeding to termination of lentils. 2) Time period from first to last soil water measurement.

Table 3. Soil water at spring wheat seeding for the 0- to 3 and 0- to 6-foot soil profile, water use by spring wheat from seeding to harvest, wheat yield, efficiency of water use by wheat (WUE), and wheat protein.

Crop Year	Previous Year Treatment	3-Foot Profile inches	6-Foot Profile inches	Water Use inches	Yield[2] bu/acre	WUE bu/inch	Wheat Protein[3] %
1992	Mechanical Fallow	7.6	17.1	13.8	54.3	3.9	15.2
	Chemical Fallow	6.9	16.2	13.8	53.7	3.9	14.8
	Lentils disked	7.0	16.7	*11.9	*36.1	*3.0	*9.4
	Lentils sprayed	7.4	16.4	13.0	*39.4	*3.0	13.0
	Annual Wheat[1]	--	--	--	--	--	--
	LSD (0.05)	ns	ns	1.0	9.9	0.7	2.4
1993	Mechanical Fallow	7.6	17.4	12.3	42.8	3.5	14.2
	Chemical Fallow	7.9	17.4	11.7	45.6	3.9	14.0
	Lentils disked	8.3	17.7	*11.4	38.7	3.4	*13.4
	Lentils sprayed	8.0	17.5	*11.2	*31.6	*2.8	*12.9
	Annual Wheat	7.1	16.3	*10.0	*25.3	*2.5	13.9
	LSD (0.05)	ns	ns	0.8	6.1	0.6	0.6
1994	Mechanical Fallow	7.9	17.5	12.0	46.0	3.8	12.8
	Chemical Fallow	7.3	16.8	12.0	42.3	3.5	*11.6
	Lentils disked	7.9	17.9	11.7	*34.1	*2.9	*10.3
	Lentils sprayed	7.8	17.1	*10.7	*31.0	*2.9	*10.6
	Annual Wheat	7.6	17.0	*10.2	*27.3	*2.7	*10.4
	LSD (0.05)	ns	ns	1.1	3.8	0.4	0.4
1995	Mechanical Fallow	7.5	17.2	10.5	20.3	1.9	
	Chemical Fallow	7.8	17.3	10.5	22.0	2.1	
	Lentils disked	7.8	17.0	*9.2	18.4	2.0	
	Lentils sprayed	7.4	16.7	*8.9	*16.2	2.0	
	Annual Wheat	7.5	16.9	*8.6	*15.4	1.8	
	LSD (0.05)	ns	ns	0.8	2.8	ns	

Significant at the 0.05 probability level (*) or not significant (ns)

1) Information not available for annual wheat in 1992

2) Crop was hail damaged in 1995

3) Protein analysis not complete for 1995

Table 4. Soil nitrate-N prior to seeding spring wheat.

Crop Year	Previous Year Treatment	0-3 inch Depth	3-6 inch Depth	6-12 inch Depth	12-24 inch Depth	Total
		lb Nitrate-N/acre				
1993	Mechanical Fallow	8.4	6.0	10.2	16.5	41.1
	Chemical Fallow	7.0	5.2	9.7	15.7	37.6
	Lentils disked	6.7	*4.4	*7.7	*9.8	*28.5
	Lentils sprayed	*5.0	*3.9	*7.5	*7.5	*23.9
	LSD (0.05)	1.8	0.9	2.5	3.6	5.9
1994	Mechanical Fallow	11.6	4.4	5.6	8.3	29.9
	Chemical Fallow	*4.9	*1.8	*3.4	*5.7	*15.8
	Lentils disked	10.3	3.4	*3.8	*4.2	*21.7
	Lentils sprayed	*5.0	*1.4	*1.9	*3.1	*11.4
	LSD (0.05)	2.0	1.1	1.8	2.3	5.7
1995	Mechanical Fallow	2.6	3.6	17.3	26.8	50.3
	Chemical Fallow	1.5	*1.0	*11.8	*38.3	52.7
	Lentils disked	*5.1	2.3	*4.5	22.4	*34.2
	Lentils sprayed	3.7	*1.4	*6.4	*17.2	*28.7
	LSD (0.05)	1.5	2.1	3.7	8.6	8.0

Significant at the 0.05 probability level (*) or not significant (ns)