COVER CROPPING IN THE SEMI-ARID WEST: EFFECTS OF TERMINATION TIMING, SPECIES, AND MIXTURES ON NITROGEN UPTAKE, YIELD, SOIL QUALITY, AND ECONOMIC RETURN

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ABSTRACT

Summer fallow still dominates some areas of the northern Great Plains (NGP), providing an opportunity to grow a partial season cover crop for increased soil health or nutrient availability. Over 12 years of research on single species cover crops in semi-arid Montana have revealed the benefits of early termination and multiple cover crop cycles on N availability, subsequent crop yield, soil health, and economic return. Due to high N fixation, pea cover crops have fairly consistently increased subsequent grain protein, yet have had mixed effects on grain yield compared to fallow after one cover crop cycle. In a multi-species cover crop study, increased cover crop biomass often resulted in lower grain yield. In that study, very few soil quality parameters were different among fallow, an 8-species mix, and sole pea, the spring after cover crop termination. In the 7th to 10th year of a longer term study in a 16 inch rainfall zone with a pea cover crop grown every other year, net revenue was higher with cover crop - wheat than with fallow - wheat at a low N rate, and available N in the cover crop system during the 8th year was at least 100 lb N/ac higher than in the crop-fallow system. In the same study, microbial biomass C and wet aggregate stability were not different between cover crop and fallow systems after the 8th year, yet potentially mineralizable C and N were both higher in the cover crop than the fallow systems. The adoption potential of cover crops in the western U.S. is most likely greater in areas with lower potential evapotranspiration, higher precipitation, or irrigation, because of the strong influence of cover crop water use on subsequent crop yield.

INTRODUCTION

Many regions of the NGP are still dominated by crop-fallow systems despite their known detrimental effects on soil and water quality. Some producers in the NGP have replaced fallow with cover crops or green manures to offset these negative effects; however, legume green manure (LGM) adoption by conventional producers has been slow because of the availability of relatively inexpensive N fertilizer and the potential for decreased yields of the following crop because of LGM water use. Higher N fertilizer prices combined with NRCS programs promoting cover crops have increased interest in the use of LGMs and cover crop mixtures (CCMs), yet there are few published studies documenting clear benefits from their use, especially in no-till (NT) systems. Our objectives were to determine short and long term effects of LGMs and CCMs on yield, grain protein, and soil quality, with a focus on NT systems.

MATERIALS AND METHODS

Study 1 – Short term NT vs T effects on wheat response to LGM vs fallow

Field experiments were conducted in southwestern MT from 2007 to 2010 at a farm field site with an average annual precipitation of 14 inches. The study was a completely randomized split-plot design with four blocks (replicates). Spring-planted pea (cv. Arvika) and lentil (cv. Richlea) were grown as LGMs in 2007, 2008, and 2009, direct seeded into wheat or barley stubble. All LGMs were terminated at first bloom (50% of plants with at least one open flower), which occurred between the 15th and 29th of June each year. Green manures were terminated with either herbicide (NT) or tillage (T), and subsequent weed control was performed with herbicide or tillage, resulting in four tillage treatments (NT – No Till, herbicide only; NTT – Herbicide termination, tilled a month or more after for weed control; T – Tilled only; TNT – Tillage termination, herbicide after). No-till LGM termination was accomplished with 22 oz/ac of a 5.5 lb/gal (acid equivalent) formulation of glyphosate. Tillage was performed with a tandem offset disc for pea termination, a chisel plow for lentil termination and fallow maintenance, and a field cultivator with trailing roller-baskets for spring seedbed preparation of all treatments that had been tilled. Tilled plots received three or four tillage operations depending on year, while the NTT and TNT treatments generally received one fewer tillage operation. At termination, green manure was collected for analysis of total N (TN) and N fixation amounts for the 2009 LGMs were calculated with the N difference method (Unkovich et al. 2008). Fallow check plots were maintained by the same methods. In year 2, spring wheat (cv. Choteau) was planted at four fertilizer rates (0, 22, 45 and 90 lb N/ac). More details are provided in Burgess et al. (2014).

Study 2 – Cover crop mixtures effect on soil quality

This study was initiated in 2012 at one site in southwest Montana and one site in the Golden Triangle (north central Montana). Two additional sites (Dutton and Bozeman) were added in 2013. In the first year, cover crops were grown, and in the second, spring wheat or winter wheat was grown. Cover crop treatments included four "functional groups" of two species mixes (N fixers, tap roots, fibrous roots, and brassicas), a full mix that had all eight species, four treatments of six species that contained all but one functional group, a monoculture pea, and a fallow control. All cover crops were seeded in April in 2012 and May in 2013, and were terminated with glyphosate when the pea reached first bloom. The subsequent year wheat crop was grown with three different N rates (0, 40, and 80 lb N/ac in 2013; 0, 60, and 120 lb N/ac in 2014). In a companion field scale study, producers seeded their choice of cover crop cocktail on one side of a field, and left the other field in chemical fallow.

Study 3 – Long term NT wheat response to LGM vs fallow

This study was established in 2003 at Montana State University's Arthur. H. Post Agronomy Research Farm, located six miles west of Bozeman, MT, as a completely randomized split-plot design with four blocks. Additional site characteristics, experimental design, and some management information in this Greenhouse Gas Rotation Study (GGRS) have been described elsewhere (Dusenbury et al. 2008; Miller et al. in press). Here, we focus on yield and protein from two NT systems (fallow-wheat and LGM-wheat) within the larger study treated either with a full N rate (3 lb available N/bu) or ½ N rate. Winter pea for hay was grown in 2003, 2005, 2007, and spring pea green manure was grown in 2009 in the LGM-wheat system. Spring wheat was grown in even years of the LGM-wheat system. In the fallow – wheat system, winter wheat was grown 2004, 2006, and 2008, and spring wheat in 2010. The 2010 spring wheat crop was managed identically in both systems except for N fertilizer application which was based on soil tests. Soils were collected in September 2008 for total soil N (0-10, 10-20, 20-30, and 30-60 cm depths) in all rotations and in April 2010 for potentially mineralizable N (PMN) for the top 15 cm in the fallow-wheat, continuous wheat, pea-wheat and LGM-wheat rotations.

Analyses

Soil nitrate was analyzed in all studies via Cd reduction with a Lachat flow injection analyzer (Lachat Instruments, Loveland, CO). PMN was determined in Study 2 with a 14-d anaerobic incubation (Keeney and Nelson, 1982), and modeled in Study 3 using results from a 112-d aerobic incubation. Tissue and soil total N (TN) were analyzed by combustion with a LECO CNS combustion analyzer (LECO Corp., St. Joseph, MI).

RESULTS AND DISCUSSION

Short term studies

In Study 1 (NT vs T), spring wheat grain yield was generally about 10 bu/ac higher at the highest N rate than in the 0N control (Figure 1). Grain yields were not different among LGM and fallow treatments in the NT system, yet were higher after LGM than fallow at the three lowest N rates in the T system. Grain protein after pea green manure (GM) was higher than after fallow at all N rates and in all tillage systems, yet grain protein after lentil GM was not different than after fallow. The different responses between pea and lentil can be attributed to higher N fixation by pea than lentil (McCauley et al. 2012).

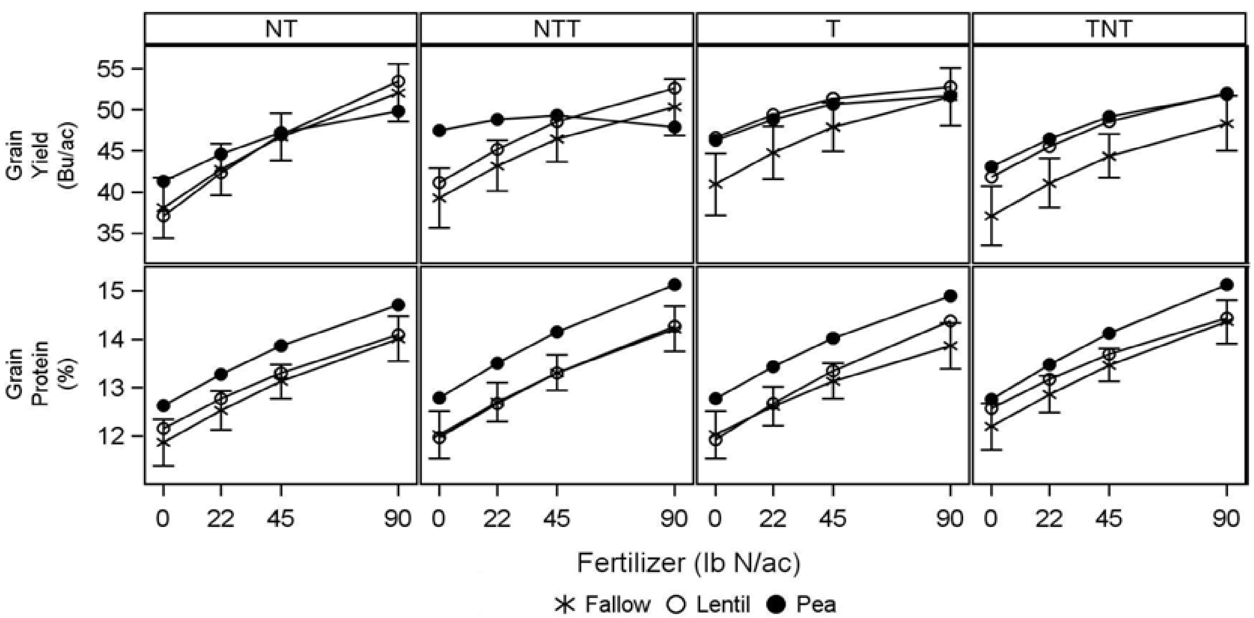

Figure 1. Spring wheat yield and protein following pea or lentil green manure or fallow treatments under four tillage regimes: No-till (NT), No-till-Till (NTT), Till (T), Till-No-till (TNT), Amsterdam, MT 2008-2010 (Study 1). Lentil or pea means that do not overlap with fallow error bars indicate significant differences ($P<0.05$).

In Study 2 (cover crop cocktails), drought resulted in very low cover crop biomass in 2012, but good moisture in 2013 yielded high cover crop biomass (~1 – 2 ton/ac) at both Dutton and

Bozeman. Cover crop biomass was generally not different among treatments. Spring wheat grain yield was higher following fallow than following any of the ten cover crops at Dutton (Figure 2). There was an N rate by cover crop treatment interaction (P=0.08) with generally larger differences between legume only and non-legume treatments at low N, as expected. Grain yield was higher after the pea and N-fixing treatments than after the full eight species mix when averaged across the three N treatments. Protein was higher (more than 1 percentage point) after pea and N-fixing treatments than any of the other CCMs when no N was applied. Soil quality parameters (e.g., soil penetration resistance, PMN, soil enzyme activity, Olsen P, etc.) were not different between pea and the full mix after one cycle, but will be measured again after two cycles. Temperature at two inches below the surface was 10 to 15 degrees F lower under cover crops than under fallow at the hottest part of the day, for at least 2 weeks before and after termination.

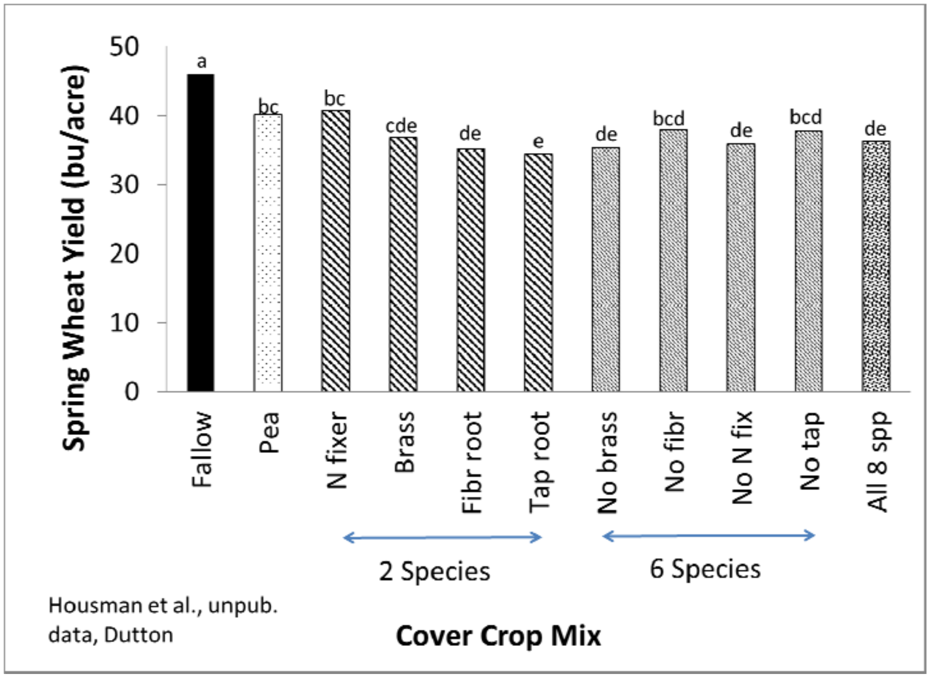

Figure 2. Spring wheat grain yield at Dutton in 2014, averaged across three N rates (0, 60, and 120 lb N/ac) following ten cover crop treatments and a fallow control. Brass-brassica; Fibr- Fibrous rooted. All 8 spp = full mix.

In the companion field study, grain yields following CCMs were up to ~15 bu/ac lower than following fallow. High water and N use from late termination (mid-July to September) were the likely causes of these large differences.

Based on these two-year studies, yield was generally not enhanced in NT systems following cover crops compared to fallow, even though there may have been other unmeasured benefits of growing cover crops such as reduced nitrate leaching, more crop residue returned to soils, and less erosion.

Long-term study

After four legume green manure (LGM) cycles, grain yield at the full N rate was 5 bu/ac higher following LGM than following fallow (Figure 3). Grain yield was 16 bu/ac higher following LGM than fallow at the ½ N rate. Due to high residual N in the LGM system, the ½ N rate LGM system received 5 lb N/ac of fertilizer (as monoammonium phosphate) whereas the ½ N rate fallow system received 46 lb N/ac. Most notably, grain yield at the ½ N rate following the LGM was equal to grain yield at the full N rate following fallow which received 129 lb N/ac. The results suggest that conditions were ideal in 2010 for substantial N mineralization of accumulated organic N. Notably, April to June precipitation in 2010 was higher than in any previous study year, and about 1.5 inches higher than the 30-yr average. This not only would have increased N mineralization of legume residues, but would have increased the likelihood that N, rather than water, limited grain yield.

Grain protein was a full percentage point higher following LGM than fallow at the full N rate and approximately two percentage points higher at the ½ N rate (Figure 4). From 2009 to 2012, economic return was similar between NT fallow-wheat and NT LGM-wheat at both N rates for both flat and steep protein discounts (Miller et al. in press). Perhaps more importantly,

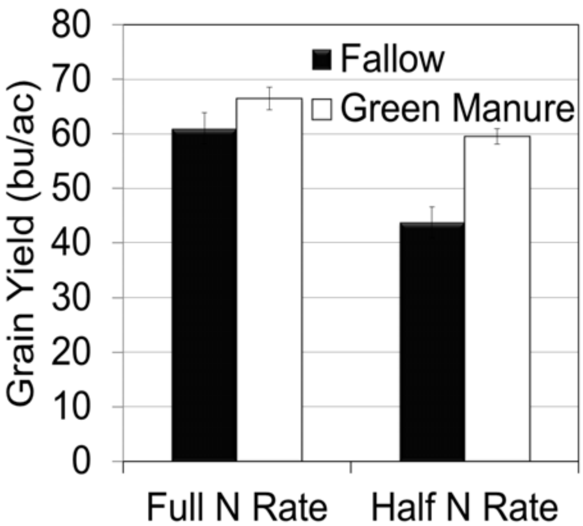

Figure 3. No-till spring wheat grain yield (12% moisture) following fallow or pea green manure after four cycles for full and ½ available N rates, GGRS, Bozeman MT

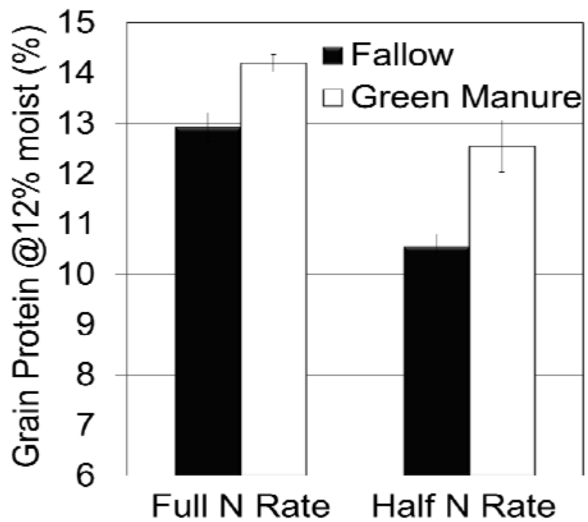

Figure 4. No-till spring wheat grain protein following fallow or pea green manure after four cycles for full and ½ available N rates, GGRS, Bozeman MT (Study 3).

the mean 2009-2012 net returns for those four scenarios had a much narrower range for the LGM-wheat system ($378 - $441 ac^{-1}) than for the fallow-wheat system ($303 – $477 ac^{-1}), suggesting LGMs can reduce uncertainty about economic returns without reducing the expected value of those returns. The long-term benefits of LGMs, despite lack of short-term benefits, have been previously documented in lentil green manure systems, though only in one tilled system in the NGP (Zentner et al. 2004). In the only published long-term NGP study on LGMs in NT systems, Allen et al. (2011) found grain yield was always lower following lentil GM than fallow in the first five years, yet never different between the two systems in the next six years, again suggesting that benefits accrue over time.

Soil TN concentrations were approximately 6% higher in the LGM-wheat NT system than the fallow-wheat NT system in the upper 12

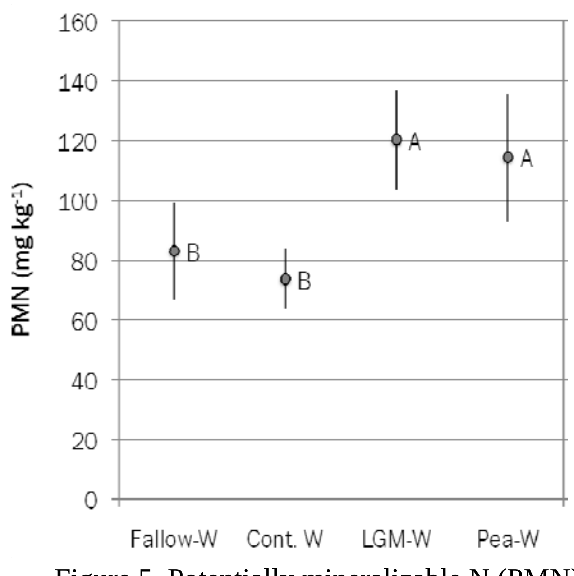

Figure 5. Potentially mineralizable N (PMN) from soils collected in four NT systems of Study 3 averaged across control (N-) and fertilized (N+) treatments. Values are for the PMN asymptote obtained from a nonlinear mixed-effects model. Different letters indicate significant differences (P<0.10).

inches in fall 2008. It is unknown if fallow depleted TN or the presence of legumes increased TN. More importantly, PMN was nearly 50% higher in the LGM-W system than the fallow-W system in spring 2010 (Figure 5; O'Dea in review).

SUMMARY

Wheat grain protein following cover crops in two-year studies was generally similar or higher than after fallow. Grain yield following cover crops was generally similar or lower than following fallow, especially in NT. In stark contrast to these findings, grain yield and protein were substantially increased following pea green manure compared to fallow after four cycles. Increased mineralizable N was the likely cause of these differences, strongly suggesting that the benefits of cover crops in semiarid systems are not realized in the short term, but after several cycles.

ACKNOWLEDGMENTS

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