SOIL QUALITY AND NITROGEN AVAILABILITY AFTER EIGHT YEARS OF A MIXED COVER CROP - WHEAT ROTATION

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ABSTRACT

Despite a large interest in cover crops in the northern Great Plains, little is known about their effect on both the following wheat crop and soil quality. In 2012, a cover crop study was started in Montana to compare wheat production and soil quality after growing cover crop mixes containing 2-, 6-, or 8-species, with both summer fallow and a sole pea cover crop control, in a 2-yr rotation with wheat. The 2-species mixes represented functional groups (legumes, brassicas, tap rooted, or fibrous rooted species), the 8-species mix consisted of all four functional groups, and the 6-species mixes had all but one functional group ("minus" treatments). In odd years, the wheat crop was fertilized with either 0, 60 or 120 lb N/acre. In April 2019, after growing cover crops for four seasons as a partial fallow replacement, and wheat for three years, the upper four inches of soil at two locations (Amsterdam and Conrad) were sampled for potentially mineralizable nitrogen (PMN), microbial biomass (MB), soil organic carbon (SOC), and soil total nitrogen (STN), and the upper 3 ft for soil nitrate. In general, soil quality parameters were higher in cover crop treatments than after fallow ($P<0.10$), yet relatively few differences were detected among the cover crop treatments, and surprisingly, no soil quality differences were detected among N rates. Notably, MB, PMN, SOC, and STN were not different between sole pea and the full mix, yet soil in both treatments had higher SOC and STN than summer fallow. In 2019, in the 60 lb N/ac treatment at Amsterdam, wheat yield after the full 8-species mix was higher ($P<0.10$) than after the minus brassica, minus fibrous, and legume treatments, and lower than after the minus tap treatment. At Conrad, wheat yield after the full mix in the 60 lb N/ac treatment was not different than any other treatment, likely due to water limitation. Grain protein was generally higher at both sites in legume treatments. This study demonstrates the power of long term studies to determine whether there are soil quality, wheat yield, and wheat protein differences among cover crop treatments.

INTRODUCTION

Cover crops have become increasingly popular in the U.S. and Canada over the past twenty years, with soil quality often cited as a reason for growing them. In humid climates, high cover crop biomass production coupled with somewhat rare soil water limitations, often lead to improved soil quality and similar subsequent grain yields as controls (McDaniel et al. 2014; Olson et al. 2014; Yost et al. 2016). In the semi-arid northern Great Plains, lower residue returns, and frequent severe water limitation, have often produced relatively modest or no soil quality benefits from pea cover crops (O'Dea et al. 2013) with generally lower profit than recropping or wheat-fallow (Miller et al. 2015a; Miller et al. 2015b). Much of this work has been done with single species pulse cover crops, namely pea or lentil. To determine if multi-species cover crop mixes (CCM) can increase soil quality compared to a sole pea cover crop, and whether certain "functional groups" improve specific soil quality properties more than others, we started a mixed species cover crop study in Montana in 2012.

METHODS

This study was begun near Amsterdam and Conrad, MT in 2012 in farm fields with no-till management histories (Table 1). Study sites have four randomized complete blocks with 11 randomly assigned cover crop treatments that included a fallow and sole pea control (Table 2). Cover crop plots were 24 x 50 ft. During the wheat year, blocks were sown at a right angle to the cover crop seeding and nitrogen (N) fertilizer trisected into three rates; 1) none added, 2) 60 lb N/ac, and 3) 120 lb N/ac.

Table 1.

Site	Amsterdam	Conrad
Elevation (ft)	4740	3410
Texture	Silt loam	Clay loam
pH	8.2	6.5
SOM (%)	2.4	2.4
NO_3-N (mg kg^{-1})	6.0	8.5
Olsen P (mg kg^{-1})	13	28
Exch. K (mg kg^{-1})	359	498

The CCM treatments were designed to include four plant functional groups: **legumes**, included for their N fertility inputs; **fibrous rooted** plants, for their potential to add carbon (C) to the soils; **tap rooted** species, for their effects on soil structure and infiltration; and **brassicas**, due to their unique biochemistry and contribution to ground cover. We selected two species for each functional group. The CCM treatments include four single functional-group treatments, one full treatment mix of all eight species, and four treatments which include all but one functional group (minus fibrous root, minus legume, minus tap root, and minus brassica; Table 2). This addition-subtraction approach allows us to potentially identify the positive, negative, or neutral effects of each functional group. Functional groups have remained the same but some species were replaced because a) they were non-competitive under our management scheme - proso millet (*Panicum miliaceum* L.) and camelina (*Camelina sativa* L.); b) posed an unanticipated weed threat - Italian ryegrass (*Lolium multiflorum* Lam.); or c) could not be terminated with glyphosate - common vetch (*Vicia sativa* L.).

Soil Analyses - A final comprehensive suite of biological, chemical, and physical soil assays were based on samples taken prior to wheat seeding in spring 2019 to measure soil changes after four cycles of cover crops. This sample timing affords a 'read' of potential cover crop effects coincident with wheat at the start of its growing season. Soils were collected from the medium N rate of all 11 cover crop treatments, and in all three N rates for fallow, pea, and the full mix.

Soils were analyzed for nitrate-N (colorimetrically) and soil water to 3 ft. The surface four inches were analyzed for potentially mineralizable nitrogen (PMN; 2-week anaerobic incubation); microbial biomass by substrate-induced respiration over a 4-hour period, analyzed with gas chromatography; total carbon and soil total nitrogen (STN) by combustion. Soil organic C was assumed to equal total C in soils with pH < 7.5 and inorganic C was measured on all others (Sherrod method) and subtracted from total C to obtain SOC.

Table 2. Plant species included in 10 cover crop treatments and a chem fallow control.

Treatment	Abbrv	Plant Species
Fallow	SF	Incidental weeds
Pea	Pea	Forage pea
Full Mix	Full	Forage pea (*Pisum sativum* L. cv. Arvika) Black lentil (*Lens culinaris* Medik. cv. Indianhead) Oat (*Avena sativa* L.) Canaryseed (*Phalaris canariensis* L.) Turnip (*Brassica rapa* L.) Safflower (*Carthamus tinctorius* L.) Forage radish (*Raphanus sativus* L. var. *longipinnatus)* Winter canola (*Brassica napus* L.)
Brassicas	Brass	Forage radish, Winter canola
Minus Brassicas	Mbrass	All but canola, radish and turnip
Fibrous Roots	Fibrous	Oat, canaryseed
Minus Fibr Roots	Mfibr	All but oat and canaryseed
Legumes	Leg	Forage pea, black lentil
Minus Legumes	MLeg	All but pea and lentil
Taproot	Tap	Turnip, safflower
Minus Taproots	MTap	All but turnip and safflower

RESULTS AND DISCUSSION

Soil –Microbial biomass was greater for Full and Pea than Fallow at Conrad, and Pea MB was greater than Fallow at Amsterdam, where N for plant growth was more limiting (Fig. 1). Similar to microbial biomass, PMN of Pea and Full was greater than Fallow at Amsterdam, and PMN of Pea was greater than Fallow at Conrad. These biological parameters are generally in agreement with SOC and STN differences (Table 3). These differences indicate that cover crops increased soil organic matter. While the difference in values do not appear great, they represent an approximate average 2,000 lb/ac difference in soil C, and 200 lb/ac difference in soil N, slightly less at Amsterdam, and slightly more at Conrad, in only the top 4 inches. Soil nitrate-N pool to 3 ft. at Amsterdam was higher after Pea, Legume and Fallow treatments than after the Full mix (data not shown), yet did not differ between the Full mix and any other treatment. Surprisingly, N fertility rates used in this study did not affect any soil parameter when analyzed across Fallow, Pea, and Full mix.

Wheat Yield and Protein

Cover crop effects on wheat yield and protein depended strongly on N rate at both sites, averaging 34, 49, and 52 bu/ac across all cover treatments at Amsterdam, and 29, 37, and 33 bu/ac across all cover treatments at Conrad, for the 0, 60, and 120 lb/ac N rates, respectively. Thus, cover crop treatments were compared within each N rate. Legumes increased yield and protein at the 0 N rate at both locations (Table 4) but our interest was in understanding cover crop treatment effects at the N rate where yield was not N-limited based on protein values ~13.2% (Engel et al. 1999). Thus, we focused on the 60 lb/ac N rate. Sole Pea cover increased wheat grain protein by an average of 1.6 and 3.1 %-units at Amsterdam and Conrad, compared with Fallow and Full (Table 5). At Amsterdam, the presence of legume in the cover crop generally increased wheat grain protein. A similar pattern was observed at Conrad. Thus, we may conclude that legumes were the only cover that exerted an effect on wheat grain protein.

The Amsterdam weather year was unusually cool and wet, delaying crop

Table 3. Soil organic carbon (SOC) and soil total nitrogen (STN) measured Apr 2019 in top 4 inches of soil at Amsterdam and Conrad, MT, after eight years and four cycles of cover cropping.

	Amsterdam		Conrad	
Cover	SOC	STN	SOC	STN
	---------- % ----------		---------- % ----------	
Full Mix	1.39 a	0.132 a	1.19 a	0.121 a
Pea	1.35 a	0.133 a	1.22 a	0.127 a
Fallow	1.25 b	0.119 b	1.05 b	0.108 b

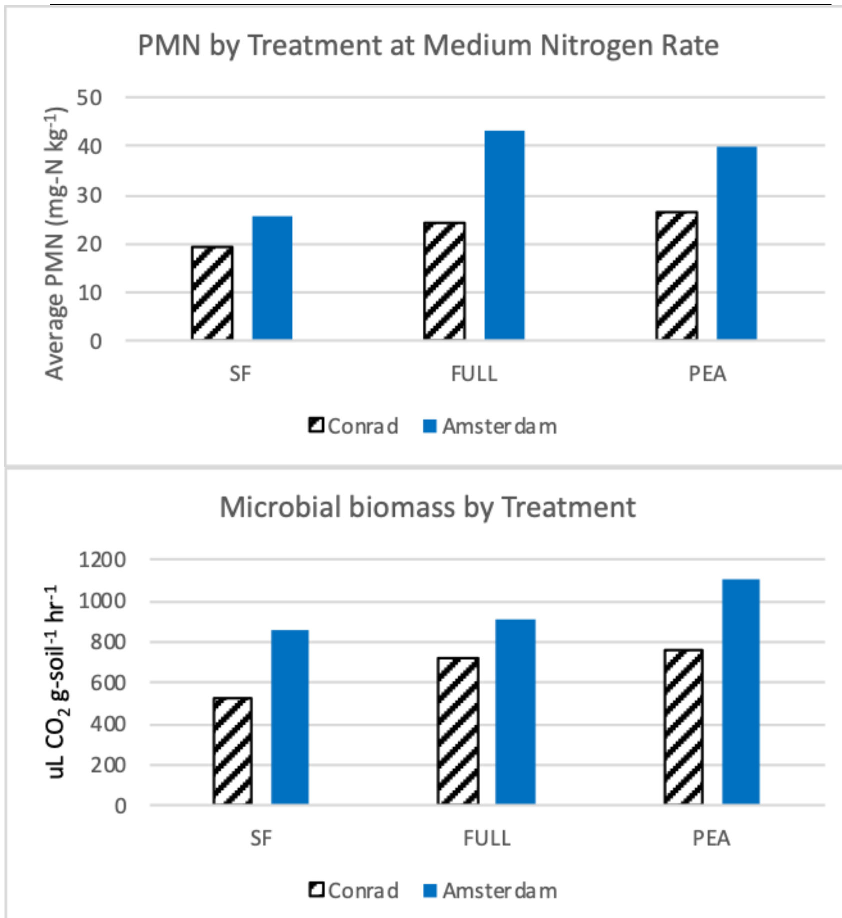

Fig 1. PMN (upper panel) and MB as inferred by CO_2 respiration rate (lower panel) at Conrad and Amsterdam, MT, measured from 4-inch soil samples collected in the medium N rate treatments in April 2019. At Conrad, both covers had greater MB than SF (Summer Fallow) and Pea had higher PMN than SF, but Pea did not differ from Full for MB or PMN. At Amsterdam, only Pea and SF differed statistically for MB and both covers had greater PMN than SF (P<0.10).

development, although no effective rainfall was received after July 30. Possibly wheat growth occurred too quickly on legume-enriched plots, using soil water too quickly, and causing a yield depression. Grain test weight was slightly lower (62.5 vs 62.9; P=0.06) following legumes, adding some credence to this "haying off" argument**.** It is noteworthy that the Brassica functional group increased wheat yield at Amsterdam (Table 4), and at both locations in 2017 (data not shown). Brassica residues are more likely to inhibit wheat disease in cool, wet springs, and this benefit from brassica cover crop merits further investigation. At Conrad, wheat following legume covers yielded 24% greater than the 'minus legume' cover crop mix, indicating that N release from legumes was important to building yield, even in this drier environment.

Table 4. Spring wheat yield (bu/ac @ 12% moisture) for 11 cover crop treatments x 3 N application rates (0, 60, and 120 lb N/ac) at Amsterdam and Conrad, MT, 2019.

	Amsterdam			Conrad		
Treatment	0	60	120	0	60	120
Fallow	32.2 B	53.3 A	53.6 A	24.2 C	38.6	33.9
Full mix	36.7 AB	49.7 B	50.3 AB	28.3 B	38.4	35.3
Pea	41.5 A	47.2 B	48.1 B	36.0 A	35.6	34.1
Brassica	32.5	**52.0**	**56.7**	25.7	34.6	**30.8**
M Brass	36.2	**44.8**	**51.7**	28.1	38.5	**37.1**
Fibrous	**26.9**	46.6	49.2	**23.4**	40.1	32.6
M Fibr	**37.3**	45.4	52.2	**31.9**	36.3	32.7
Legume	**37.7**	44.3	**46.0**	**40.0**	**39.4**	**35.7**
M Legu	**28.8**	47.0	**55.7**	**22.2**	**31.7**	**27.5**
Tap	29.0	51.2	56.5	27.4	**40.9**	33.2
M Tap	33.9	54.3	51.6	29.1	**33.6**	31.5
$LSD_{0.10}$	*5.8*	*3.1*	*5.0*	*3.1*	*7.1*	*5.7*

When means in the top tier of table are followed by the same or no letter, they do not differ ($P > 0.10$). For each paired comparison of presence and absence of each functional group, bolded values differ ($P < 0.10$).

The differential response for Tap vs Minus Tap at Conrad is likely because very little biomass was present in the Tap treatment in 2018 due to drought and N stress on turnip and preferential grazing of safflower by antelope, likely leaving more soil water for the following wheat crop.

In conclusion, by growing cover crops more frequently than most producers grow them, we were able to detect soil quality and wheat production differences among cover crop treatments after four cycles. The largest soil quality differences were generally between fallow and cover crops, rather than among cover crops. Perhaps the amount of residue returned is more important at affecting soil quality properties, rather than the specific functional group.

Table 5. Spring wheat grain protein (@ 12% moisture) for 11 cover crop treatments x 3 N rates (0, 60, 120 lb N/ac) at Amsterdam and Conrad, MT, 2019.

	Amsterdam			Conrad		
Treatment	0	60	120	0	60	120
Fallow	10.6 B	12.8 B	14.5 B	11.0 A	13.2 B	15.8 B
Full mix	10.7 B	12.4 C	14.4 B	9.5 B	13.1 B	16.1 B
Pea	11.8 A	14.2 A	14.9 A	11.1 A	16.2 A	16.8 A
Brassica	10.6	**12.3**	**14.1**	9.5	13.5	16.3
M Brass	10.6	**13.2**	**14.6**	9.5	14.4	16.3
Fibrous	10.3	**12.1**	14.4	11.4	**13.5**	**16.3**
M Fibr	10.5	**12.9**	14.4	11.1	**14.9**	**16.7**
Legume	**11.9**	**14.3**	**14.9**	11.0	**15.3**	16.7
M Legu	**10.1**	**12.0**	**14.1**	9.8	**12.9**	16.7
Tap	**10.0**	**11.8**	**14.2**	**11.1**	13.2	**15.9**
M Tap	**10.9**	**12.9**	**14.5**	**9.5**	13.4	**16.5**
$LSD_{0.10}$	*0.47*	*0.34*	*0.20*	*1.35*	*1.08*	*0.38*

Means in top tier followed by the same letter do not differ (P > 0.10). For each paired presence/absence of each functional group, bolded values differ (P < 0.10).

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