# IS COVER CROP SPECIES RICHNESS MORE IMPORTANT AT BUILDING SOIL HEALTH THAN SHOOT BIOMASS IN A SEMI-ARID REGION?

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## ABSTRACT

Cover crop mixtures (CCMs) as partial fallow replacements have the potential to increase soil health, yet long-term studies on CCMs, especially in semi-arid environments are relatively rare. An eight-year study at two locations in semi-arid Montana sought to evaluate the effect of functional group (N fixer, tap roots, fibrous roots, Brassicaceae) and species richness (1, 2, 6, and 8 species) on a range of biological, physical and chemical soil parameters, when cover crops were alternated with wheat. Although several soil health parameters were sometimes higher with covers than fallow, there were few differences in soil health parameters among cover crop treatments. There were, however, significant positive relationships between total shoot biomass returned (covers, weeds, and wheat stubble) and both soil organic carbon (SOC) and potentially mineralizable nitrogen (top 4 inches) biomass at both sites. Specifically, each 1-ton shoot biomass/acre equated to an SOC difference in the top 4 inches of approximately 0.035%. This finding demonstrates why it's challenging to substantially affect SOC in a semi-arid environment by growing cover crops when cover crop-wheat systems only returned about 1-3 ton/acre more residue over the study life than fallow-wheat systems. The combined results demonstrate that selecting cover crop species that result in high amounts of total residue returned (cover crop residue plus cash crop stubble), is likely more important than cover crop species richness for improving soil health.

## 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

The study was begun near Amsterdam and Conrad, MT in 2012 on farm fields with no-till management histories (Table 1). Annual precipitation averaged approximately 14 inches at Amsterdam and 12 inches at Conrad. Study sites had 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 data.

| Site | Amsterdam | Conrad |
|---|---|---|
| **Elevation (ft)** | 4740 | 3410 |
| **Texture** | Silt loam | Clay loam |
| **pH** | 8.2 | 6.5 |
| **SOC (%)** | 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

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)<br>Black lentil (*Lens culinaris* Medik. cv. Indianhead)<br>Oat (*Avena sativa* L.)<br>Canaryseed (*Phalaris canariensis* L.)<br>Turnip (*Brassica rapa* L.)<br>Safflower (*Carthamus tinctorius* L.)<br>Forage radish (*Raphanus sativus* L. var. *longipinnatus)*<br>Winter canola (*Brassica napus* L.) |
| **Brassicas** | BR | Forage radish, Winter canola |
| **Minus Brassicas** | MBR | All but canola, radish and turnip |
| **Fibrous Roots** | FR | Oat, canaryseed |
| **Minus Fibr Roots** | MFR | All but oat and canaryseed |
| **Nfixers** | NF | Forage pea, black lentil |
| **Minus Nfixers** | MNF | All but pea and lentil |
| **Taproot** | TR | Turnip, safflower |
| **Minus Taproots** | MTR | All but turnip and safflower |

(*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 Sampling and Analyses -*** A final comprehensive suite of biological, chemical, and physical soil assays was performed 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 in two locations per subplot with a hydraulic probe from the medium N rate of all 11 cover crop treatments, and also for the low and high N rates for Fallow, Pea, and the Full mix. Only a smaller set of soil parameters was assessed in all treatments, allowing us to answer the question on whether species richness affected soil health.

The surface four inches were analyzed for potentially mineralizable nitrogen (PMN; 2-week anaerobic incubation) and 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.

***Tissue sampling and stubble estimates –*** Cover crops and weeds were cut at the soil surface from a 0.84-$m^2$ area in each cover crop year, dried, and weighed. Wheat stubble was estimated using subplot combine wheat grain yield and typical harvest indices measured in similar Montana environments. Harvest indices were slightly adjusted based on N rate.

## RESULTS AND DISCUSSION

Concentrations of PMN in Pea and Full were greater than in Fallow at Amsterdam in the medium N treatment, whereas there were no PMN differences among any treatments at Conrad (Fig 1). At both sites, there were no PMN differences between each 2-species functional group and the corresponding 6-species mix that did not contain that functional group, which was surprising especially for the N fixers (NF) v. Minus N fixers (MNF).

Pea and Full treatments resulted in higher SOC and STN than fallow, yet there were no differences in either parameter between the single species and 8-species mix (Table 3). While the difference in values might 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. Surprisingly, N fertility rates used in this study did not affect any soil parameter when analyzed across Fallow, Pea, and Full mix.

Concentrations of PMN in the upper 4 in. were 20 to 30% higher for the 6-species mixes than the 2-species mixes in the medium N treatment at both sites, although the absolute differences (~7 mg N/kg) equated to only about 10 lb N/ac. Concentrations of SOC and STN in the medium N treatments were not different between the 6-species and 2-species mixes at either site.

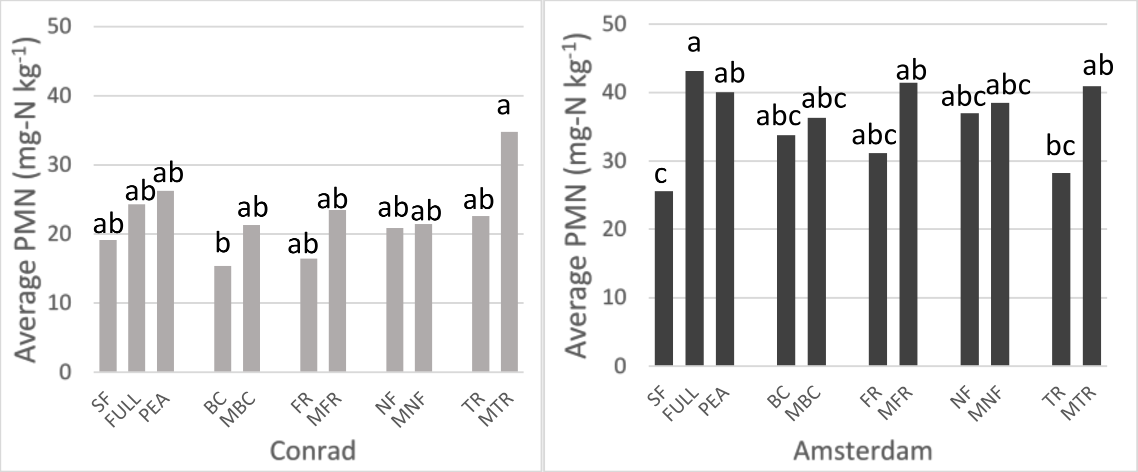

Figure 1. Potentially mineralizable nitrogen for 11 treatments at the medium nitrogen rate, following four rotations of cover crops at two field sites. See Table 2 for treatment descriptions. Letters show significant differences ($p < 0.1$).

There were positive relationships between total cover crop plus wheat stubble biomass (6-yr Amsterdam, 7-yr Conrad) and PMN at both sites (data not shown). In addition, total biomass was correlated with SOC somewhat weakly at Conrad (P=0.09) and strongly at Amsterdam (P=0.002), but with similar slopes (Fig 2). Specifically, each 1-ton shoot biomass/acre equated to an SOC difference in the top 4 inches of approximately 0.035%. The full range in biomass returned was less than 5 ton/ac at both sites (equating to an SOC difference of about 0.18%) and far less among the cover crop treatments (meaning without fallow). The large amount of biomass needed to affect SOC meaningfully demonstrates the challenge of increasing SOC in a semi-arid environment, even with cover crops.

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 |

Strong relationships between residue returned and SOC differences have previously been documented in somewhat wetter areas of the northern Great Plains (Shrestha et al. 2013; Engel et al. 2017). Due to the challenge in finding SOC differences among crop and fertility treatments, especially in short term studies, positive SOC v. biomass relationships suggest that biomass returned could be a surrogate for SOC. Even in our 7-year study, we found SOC was not different among our 11 cover crop treatments at Amsterdam at the medium N rate; however, there were several differences among total study biomass at this same site (Fig 3). Combined with the very strong relationship at Amsterdam between total biomass returned and SOC, it's likely that SOC differences existed, yet could not be detected due to high variability in SOC. The much larger area sampled for biomass (~ 3.3 $m^2$ over four cover crop years and ~10 $m^2$ per year for grain yield conversions to wheat stubble) than for soil (~ 0.0016 $m^2$) in each subplot, might partly explain why biomass differences were easier to detect than SOC differences.

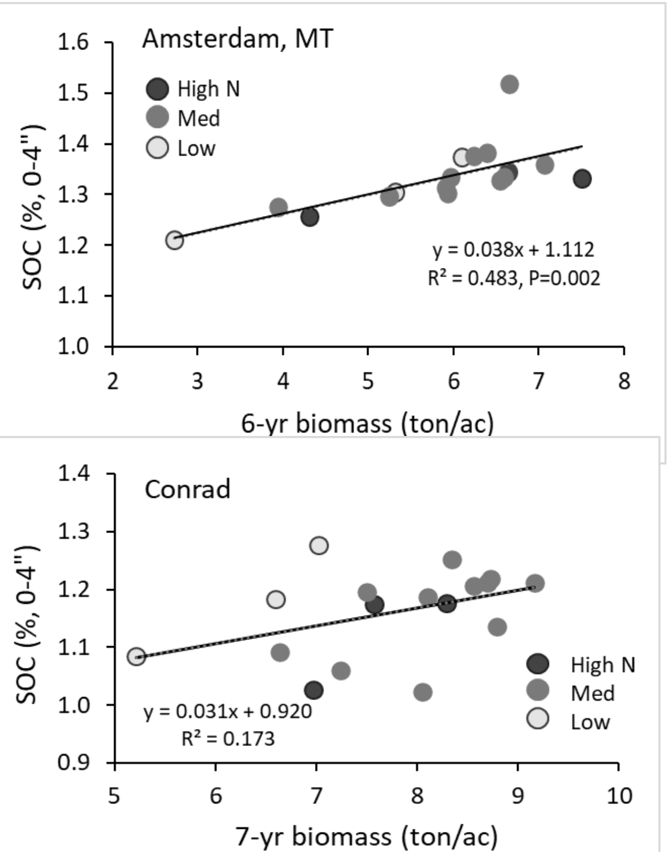

Fig. 2. Relationship between soil organic carbon (SOC) collected in April of final study year and total study biomass (covers plus wheat stubble) at Amsterdam and Conrad. Amsterdam wheat was hailed out in 2013, and hence had one less year of biomass. Soil was collected from low and high fertilizer N rate treatments for Fallow, Pea, and Full only, and in medium N treatments for all cover crop treatments.

Given that shoot biomass was correlated with some soil health parameters, notably SOC, we investigated whether species richness or perhaps legume presence was correlated with total biomass. At Amsterdam, 6-species mixes produced 4% more total biomass (cover plus wheat stubble) than the 2-species mixes (P=0.01) in the medium N treatment, whereas there was no difference between 6- and 2-species biomass at Conrad. In a semi-arid region, where low precipitation invariably limits crop yield, it's likely that species richness affects biomass less than in a more humid region.

Inclusion of legumes almost always resulted in higher total biomass returned. Notably, total biomass returned at both sites for the medium N rate was approximately 11 to 14% higher for the 2-species N fixer mix than for the other three 2-species mixes without N fixers, the Full mix produced 8 to 12% more biomass than the 6 species mix without N fixers (MNF), and Pea out-produced more treatments than any other cover.

## SUMMARY

In conclusion, by growing cover crops more frequently than most producers grow them, we were able to detect soil health differences among cover crop treatments after four cycles. The largest soil health differences were generally between fallow and cover crops, rather than among cover crops. The amount of residue returned is more important at affecting soil properties, than the number of species in the mix, and the inclusion of legumes consistently increased biomass.

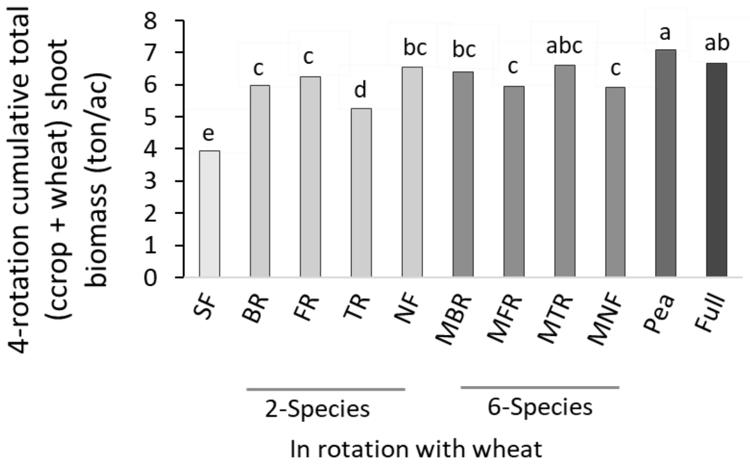

Fig. 3. Total 6-yr biomass (4 cover crop years + 2 stubble years) at Amsterdam. Different letters above bars indicate significantly different (P<0.10) biomass amounts. See Table 2 for descriptions of each treatment.

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