EFFECTS OF A HIGH RATE OF COMPOSTED CATTLE MANURE AND COVER CROPS IN SEMI-ARID DRYLAND WINTER WHEAT CROPPING

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ABSTRACT

Growing dryland winter wheat (*Triticum aestivum,* L.) in the US Northern High Plains (NHP) region is challenged by inadequate soil organic matter (SOM), limited soil water and nutrients, and frequent droughts. A single application of a high rate of composted cattle manure (compost) may help address these issues. Multiple soil health-associated benefits have been observed in different climates, but are still unexplored in the NHP. In order to conserve compost-associated benefits and to prevent compost-amended soils from weed infestation, spring planting of cover crops has been recommended. The synergy between these two practices could help build up SOM, increase soil water-holding capacity, and reduce greenhouse gas (GHG) emissions. The objective of this study was to evaluate the legacies of a single application of compost (0, 15, 30, and 45 Mg ha^{-1}) and annual fallow cover crop planting on soil moisture, inorganic nitrogen (N), and GHG emissions three years after compost application. Unfortunately, results suggested no lasting benefits of the two factors combined. The highest rate of compost showed elevated, yet statistically insignificant soil moisture and inorganic N concentrations in the fallow not planted to cover crops. Nitrous oxide fluxes were comparable to the lower compost rate and the control, suggesting effective soil N conservation. Cover crops alone were not beneficial: they depleted soil moisture and soil inorganic N from the already water and N limited soils.

INTRODUCTION

Consumer demand for organic food has shown double-digit growth in recent years, encouraging the development of a wider range of organic foods (Curtis and Quarnstrom, 2019). Organically certified winter wheat (*Triticum aestivum,* L.) production is on the rise due to greater consumer demand, higher premiums, and better economic returns from grain sales (Curtis and Quarnstrom, 2019).

There is much to be learned about organically certified production of winter wheat in eco-regions like the NHP. Soils are marginally productive, are low in soil organic matter (SOM), alkaline, and often sodic. The climate can be challenging with low, often unpredictable, precipitation and extended periods of drought during the growing season (Hansen et al., 2012). In order to retain the organic certification status, producers are obligated to come up with a SOM building plan. Composted cattle manure (compost) has been widely utilized worldwide as an effective soil amendment with the purpose of improving numerous biological, chemical, and physical properties associated with increasing SOM (Reeve et al., 2012). Used primarily for their within-season fertilizing contribution, composts and raw manures also play an important role in SOM accumulation and long-term improvements in soil quality (Olsen et al., 2015).

Another practice that is not yet well-explored by organic winter wheat producers in the NHP is the inclusion of cover crops planted for a period of time during the fallow phase. Fallow periods are common throughout the region in order to re-charge the soil water profile, which experiences inconsistent precipitation. Planting cover crops for part of the fallow period (either immediately after crop harvest or early the following spring) has a potential to protect the surface soil from erosion during the non-crop periods (Havlin et al., 2014). Other benefits of cover cropped fallows could include competition with weeds species and, if leguminous, contributing additional N atmospheric dinitrogen (N_2) fixation. However, the idea of adding cover crops to the winter wheat-fallow rotation is met with skepticism in the NHP. This is because cover crops compete with winter wheat for abiotic resources such as soil water and plant-available nutrients during the non-crop season.

Greenhouse gas (GHG) emissions are important measurements that help assess sustainability and health of agroecosystems (Bista et al., 2017). The benefits of cover crops in the fallow may translate to lower GHG emissions through decreased N loss as nitrous oxide (N_2O) and increased SOC from organic matter inputs (Grant et al., 2002).

The main objective of this study was to determine the optimal combination of compost application and cover crops planted in the fallow for long-term benefits in dryland organic winter wheat production in the NHP. It was hypothesized that three years after a single application of a large rate of compost followed by cover crops planted in the fallow in the spring, the legacy of high input SOM would continue in the form of increased plant-available nutrients along with decreased losses to the atmosphere in the form of GHG emissions.

MATERIALS AND METHODS

The study was conducted between September 2018 and August 2019 at the Sustainable Agriculture Research and Extension Center (SAREC) near Lingle, Wyoming. The experiment was a randomized complete block design with four replications. Two sets each of winter wheat and fallow strips were divided into eight field blocks. Each field block contained ten plots. Out of the eight field blocks, four blocks were in the winter wheat growing phase and four blocks were in the fallow phase. Within each strip, four rates of locally sourced compost of 0, 15, 30, and 45 Mg ha^{-1} dry weight (control, low, medium, and high, respectively) were applied to the wheat strips during the fall of 2015 and to the fallow strips during the spring of 2016 and incorporated to a depth of 5 cm. Inorganic fertilizer (IF) consisting of mono-ammonium phosphate and ammonium sulfate was applied to the IF treatment plots in the wheat strips during the fall of 2015 and again to the remaining strips during the fall of 2016. Each spring, a cover crop mix of Austrian winter pea (*Pisum sativum,* L.) and oat (*Avena sativa*) was planted to one half of the fallowed plots and allowed to grow for six weeks. After this time, cover crops were terminated by tillage and those plots remained fallow until wheat planting.

Three years after the establishment of the experiment, field soil samples were collected once per month during the non-active growing season (September through

April) and every 2 weeks during the active growing season (May through August) using a soil probe to a depth of 10 cm. Soil was collected out of plots in both the wheat and fallow phases. Soil samples were transported to the lab and processed within 24 hours. Gravimetric water content was determined for each sample by removing a 10-11 g subsample and measuring the difference in mass before and after drying at 105ºC for 48 hours (Gardner, 1986). Samples were sieved through a 2 mm sieve post-drying to assess gravel content. Soil NH_4-N and NO_3-N were determined from 1:2.5 soil KCl (2 M) extracts. Soil KCl extracts were shaken for 30 minutes, stored at 4ºC overnight, and filtered through ashless filter paper (Q5 Fisher Scientific, USA). Soil remaining in specimen cups after extraction was wet sieved to pass a 2.0 mm sieve to determine the gravel weight needed to correct the final gravimetric soil water content. Soil NH_4-N was determined with the Weatherburn method (1967) and sodium salicylate reaction and soil NO_3-N was determined with the Doane-Horwath method (2003) and vanadium chloride reaction. All NH_4-N and NO_3-N samples were analyzed using a microplate spectrophotometer (Bio-tek PowerWave HT: RPRWI, Bio-tek Inc., Winooski, Vermont, USA).

Greenhouse gas (GHG) samples were collected using static closed chambers based on the enclosure technique as outlined by Hutchinson and Mosier (1981). Greenhouse gas samples were analyzed on an automated gas chromatograph (Varian 38001) equipped with a thermo-conductivity detector for CO_2, flame ionization detector for CH_4, and electron capture detector for N_2O analyses (Mosier et al., 1991). The best GHG flux was determined based on four independent linear or logarithmic estimates of the concentration change over time (Hutchinson and Mosier, 1981).

RESULTS AND DISCUSSION

The goal of this study was to assess the potential synergy and determine the optimal combination of compost application and cover crops planted in the fallow for long-term benefits to dryland organic winter wheat production in the NHP. Specifically, if a single application of a high rate of compost would have long-lasting effects on soil parameters and to determine if cover crops planted in the fallow phase of the organic winter wheat-fallow rotation would create any synergistic benefits with compost. Although there were multiple instances where compost and cover crops acted as significant factors alone, there were very few interactions between the two, suggesting that cover crops did not result in a synergy with compost in the third year after compost application (Table 1).

Table 1: Comparisons of compost and cover crop treatments using t-tests among the parameters of gravimetric soil moisture (moisture), inorganic nitrogen (InN), carbon dioxide (CO_2), and nitrous oxide (N_2O). Values in bold with asterisk indicate a significant difference compared with the control/bare treatment at $\alpha < 0.10$.

	Moisture		InN		CO2		N2O	
	cc	bare	cc	bare	cc	bare	cc	bare
	g/g		*ug/g OD soil*		*ugC/m2/hr*		*ugN/m2/hr*	
Control	0.200	0.203	6.03	7.29	39.51	44.39	2.39	3.02

IF	**0.190 ***	0.194	6.33	8.48	35.00	42.68	2.33	3.11
Low	0.195	0.206	5.04	9.29	39.99	30.79	2.17	2.35
Medium	0.193	0.200	**4.19 ***	7.78	44.38	41.73	2.64	2.89
High	0.200	0.210	6.47	7.64	46.23	53.25	2.35	2.71

In general, the wheat phase of the growing cycle resulted in lower soil water content than the fallow phase by 3% (Figure 1A). One of the biggest concerns of dryland winter wheat production is soil water availability during the most critical periods of crop growth.

Inorganic nitrogen (sum of soil NH_4-N and NO_3-N) was also significantly impacted by the phase during the growing cycle (Figure 1B). After planting in the fall and throughout the winter, inorganic nitrogen in the wheat phase was on average 5 times higher than the fallow phase. However, after active wheat growth began in the spring, inorganic nitrogen levels were on average 1.7 times higher in the fallow phase compared to the wheat phase. Fallowing is considered an important management strategy for the restoration of soil productivity due to the replenishment of nutrients removed by crops (Adekiya et al., 2021).

In general, CO_2 fluxes from dryland winter wheat are low compared with other dryland crops (Hurisso et al., 2016). Carbon dioxide emission increased in the spring and summer months when temperatures increased (Figure 1C). This increase could have been a result of wheat root respiration (Larinova et al., 2006). The CO_2 flux in the wheat phase remained relatively constant during the active growing season. The CO_2 flux in the fallow phase experienced a sharp increase after cover crop termination. Vegetated land surfaces play a significant role in controlling carbon dynamics in the global carbon cycle so removal of cover crop residue from tillage can increase CO_2 emissions (Ray et al., 2020).

Since the soil water content never exceeded 0.55 g g^{-1} dry soil in this study, denitrification was not the dominant process that influenced N_2O emission (Bista et al., 2017). Rather, N_2O emission in drylands have been reported to be the product of nitrification of available labile N substrates and dryland soils are reported to have high nitrification potential (Bista et al., 2017 and Norton et al., 2008). Nitrous oxide fluxes in the fallow phase were 1.2 times higher than the wheat phase (Figure 1D).

Cover crop growth in the fallow phase during the active growing cycle (April-August) produced significant differences compared to bare fallow for soil gravimetric moisture and inorganic nitrogen (Table 2). Cover crops decreased soil moisture by 1% compared to the bare fallow. Cover crops increased soil inorganic nitrogen 1.4 times compared to the bare fallow. However, cover crops did not have a significant impact on CO_2 nor N_2O emissions, suggesting nutrient conservation due to higher levels of soil inorganic nitrogen.

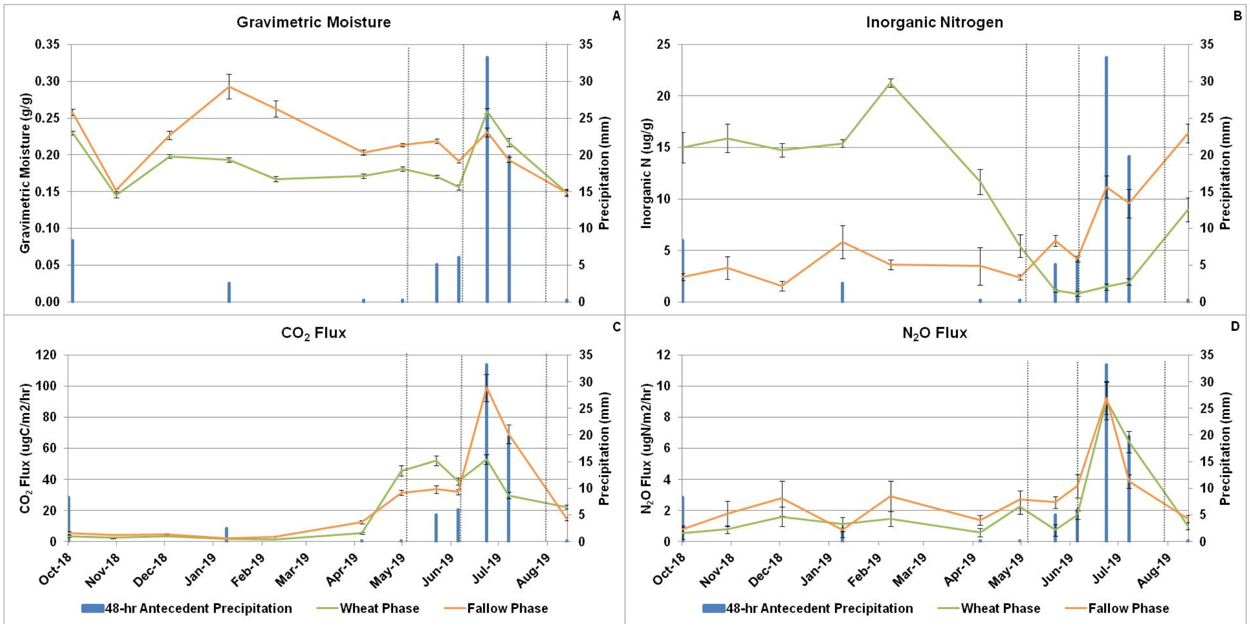

Figure 1: Gravimetric soil moisture (A), soil inorganic nitrogen (sum of soil NH_4-N and NO_3-N) (B), carbon dioxide flux (C), and nitrous oxide flux (D) in the wheat and fallow phases of the growing cycle. 48-hour antecedent precipitation is included on the second axis. Dashed lines indicate tillage events that affected the fallow phase (orange line) only.

Table 2: Cover crop impacts to parameters measured (gravimetric soil moisture (moisture), inorganic nitrogen (InN), carbon dioxide (CO_2), and nitrous oxide (N_2O) during the active growing cycle (April-August). Values in bold with lowercase letter indicate a significant difference within the row at α=0.10.

	Moisture			InN			CO2			N2O		
	Avg	Test Stat	P-Value	Avg	Test Stat	P-Value	Avg	Test Stat	P-Value	Avg	Test Stat	P-Value
	(g/g)			*(ug/g OD soil)*			*(ugC/m2/hr)*			*(ugN/m2/hr)*		
Bare	**0.203 a**	5.770	0.02	**5.62 b**	6.41	0.01	41.02	0.16	0.69	2.38	1.50	0.22
Cover Crop	**0.196 b**			**8.10 a**			42.57			2.81		

CONCLUSIONS

A single application of a high rate (45 Mg ha^{-1}) of compost was shown to have minimal long-lasting benefits in dryland organic winter wheat-fallow rotations in the NHP. However, annual planting of cover crops in the fallow can have the potential to increase carbon and nitrogen conservation due to the absence of increases to CO_2 and N_2O emissions.

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