COMPOSTED MANURE IMPACTS ON ORGANIC WHEAT PRODUCTION IN THE NORTHERN GREAT PLAINS

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ABSTRACT

Montana leads the nation in organic production of small-grain crops including wheat (*Triticum* spp.). A major challenge faced by dryland farmers when growing wheat organically is supplying adequate N for optimum wheat yield and quality. A onetime application of composted manure at four rates (0, 5.6, 11, and 22 tons/acre) vs. annual applications of urea based on soil test results when growing wheat in wheat/fallow and wheat + biennial sweetclover [(*Melilotus officinalis* (L.) Lam.]/green fallow systems were compared for impacts on grain yield and protein concentration in central Montana, beginning in 2021. Wheat yield differences were not detected in plots where urea was applied vs. check (0 applied N) plots in any year ($P > 0.05$). In contrast, wheat yields were greater in plots receiving a onetime application of composted manure at 22 tons/acre vs. urea-fertilized plots in both 2021 (10 vs. 5 bu/acre) and 2023 (49 vs. 29 bu/acre). Grain yield was lower when wheat was grown with and following a green manure (green fallow) vs fallow. Protein concentration was elevated in wheat grain harvested from plots receiving an application of composted manure at all three rates (average = 19.5%) compared to urea-fertilized or check plots (18.7%) in 2021, but lower in manure-amended (average = 11.8%) and check (11.4%) plots than in urea-fertilized plots (13.4%) in 2023. The threshold for grain protein concentration indicating N sufficiency when growing winter wheat (12.1%) suggests that N limited grain yield in manure amended plots in 2023. Results from this ongoing study suggests that grain yield benefits can result when wheat is grown organically three years after a single application of composted manure in the northern Great Plains, although lack of plant-available N may prevent maximum amounts from being produced.

INTRODUCTION

Montana was the leading domestic producer of organic wheat in 2021, producing just under 704,000 bushels on over 66,000 acres that year, or nearly 18% of the U.S. total (USDA NASS, 2022). Low organic wheat yields (11 bu/acre average) reflect a severe drought that persisted across much of the state in 2021 (Ragar & Monares, 2021), but also the other abiotic as well as biotic stresses that dryland organic farmers encounter when growing wheat. For example, low soil fertility was identified as the second greatest obstacle after weeds to growing wheat profitably when organic farmers were surveyed across Montana (OAEC, 2017).

Soils in fields on organic farms generally are low in one or more plant nutrients in the northern Great Plains (Knight et al., 2010). In a Montana survey, nearly 80% of organic farmers reported that soil nutrient deficiencies were a problem on their farms, with a majority (67%) basing their conclusion on soil test results (OAEC, 2017). Growing green manures, notably pea (*Pisum* spp.) and biennial sweetclover (clover), was the most common practice for remediating low soil fertility on organic farms reported in that survey. Other practices used to improve soil nutrient status included crop rotation, incorporating grazing into the cropping system landscape, and applying livestock manure, but only on a minority of organic farms.

The facts that most organic farmers reported soil nutrient deficiencies occurring in fields on their farms, and that green manuring was a common practice used to maintain soil fertility, suggest that other practices must be used to improve soil fertility for optimum grain yield and quality in Montana. Previous research demonstrated that wheat grain yield was elevated for several years after applications of manure were discontinued in Alberta, CA (Larney and Olson, 2018). Our objective is to determine if a similar legacy impact occurs following a onetime application of composted cattle (*Bos taurus*) manure in Montana, and how the presence or absence of a green manure crop grown during the fallow-phase impacts subsequent wheat yield in a fallow-wheat system.

MATERIALS AND METHODS

The study was established in a field at the Montana State University, Central Agricultural Research Center (47°03´ N, 109°57´ W; 4200 ft elevation), in April 2021. Treatments were arranged in a randomized complete block in a split-plot pattern. Composted manure applied at four rates (0, 5.6, 11, and 22 tons/acre) along with a urea fertilized treatment comprising main plots and cropping system phases comprising subplots: 1. wheat/fallow system, wheat phase; 2. wheat/fallow system, fallow phase; 3. wheat + clover/green fallow system, wheat phase; and 4. wheat + clover/green fallow system, green fallow phase. Fertility and cropping systems phases were established in each of four blocks; subplot dimensions were 20 x 35 ft.

Composted manure was applied once and incorporated using a tandem disk when the study began. Urea (46-0-0) was broadcasted and incorporated in fertilizer main plots annually based on soil test results from samples collected within a few weeks of planting wheat. The original intent was to plant winter wheat during wheat phases in both systems but a delay in project startup forced the substitution of spring wheat (planted in May) for winter wheat (planned for planting the previous September) during the 2020-21 growing season. During the 2021-22 growing season, spring wheat was planted into poorly established winter wheat (<50%) because of persistent drought, resulting in mixed spring and winter wheat subplots. Good growing conditions throughout 2022-23 resulted in excellent establishment and survival of winter wheat so spring wheat was not planted.

Austrian winter pea [*Pisum sativum* L. subsp. *sativum* var. *arvense* (L.) Poir] was planted in May 2021 as a substitute for “second-year” clover in green fallow plots in the 2020-21 growing season. Clover was planted with spring wheat in wheat + clover plots in 2021 with the clover becoming the green manure in the green fallow plots in 2022 (i.e., 2021-22 growing season). Clover planted in May 2022 into winter wheat planted the previous September became the green manure crop in green fallow plots in 2023. Fallow (i.e., not green fallow) plots were tilled from spring through summer to control weed growth, as needed.

Above-ground plant biomass (crops and weeds) was determined within a 5.4-ft^2 area in each subplot when wheat was at the watery ripe to early milk stages of kernel development (Zadoks growth stage 71-73, Zadoks et al., 1974). Plants were clipped at the soil surface, separated by type (weeds, wheat, and green manure), dried at 125-130^o F and then weighed once a constant weight was reached (roughly 7 to 10 d after clipping). Leaf area index (LAI) was calculated from photosynthetic active radiation measurements made at three locations within each subplot using an Accupar LP 80 ceptometer just prior to harvesting plant biomass samples. Wheat grain was harvested from the center of each subplot using a small-plot combine after wheat reached physiological maturity and kernel moisture content was <16%. Grain yield is reported as bu/acre adjusted to a 12% moisture concentration. Grain protein concentration was determined by NIRS for a subsample from each subplot using a CropScan 3000B Whole Grain Analyzer in 2001 and a Foss Infratec Analyzer in 2023. Grain was mixed (spring and winter wheat) in 2022 so grain protein concentration was not determined that year. Grain test weight was determined from a subsample in each year.

Treatment effects were analyzed separately across years because of differences in wheat (spring wheat in 2021, mixed wheat in 2022, and winter wheat in 2023). A split plot analysis was conducted using the ‘splitplot’ function in the ‘doebioresearch’ package for R statistical software, with rep as block, composted manure and urea treatments as main plots, and wheat production method (± sweetclover) as subplots. Treatment means were separated using a protected LSD at $P < 0.05$. The ‘agricolae’ package for R statistical sofware’s ‘aov’ and ‘LSD.test’ functions were used to compare sweetclover biomass across wheat whole plots in the +sweetclover plots.

RESULTS AND DISCUSSION

The LAI of plant canopies receiving 11 or 22 tons/acre of composted manure was larger than canopies receiving ≤6.5 ton/ac in 2021, including the urea-fertilized plots (Table 1). In 2022, differences in plant canopy LAI were only detected between plots which had received the heaviest composted manure rate previously (larger) and the urea- fertilized plots (smaller; Table 2). In 2023, plant canopy LAI was greater in plots that received composted manure at 22 tons/acre previously than urea-fertilized plots and in 0 check (i.e., non-manure-amended or urea-fertilized) plots (Table 3). Plant canopy LAI was lower when wheat was planted following and with green manures than in wheat monoculture in each of the three years (Tables 1-3).

Above-ground biomass produced by weeds, wheat, and green manures generally was nonresponsive to composted manure and urea applications, with two exceptions. In 2023, biomass production by weeds was greater in plots where composted manure was applied at 11 and 22 tons/acre back in 2021, or urea was applied annually, then in 0 check plots (Table 3). In 2021, wheat produced more above-ground biomass in plots that

Table 1. Leaf area index (LAI), aboveground weed and crop biomass, and wheat grain yield and quality across four composted manure rates, a urea fertility application, and a 0 (check) treatment in wheat ± Austrian winter pea (AWP) plots in central Montana during 2021.

		Above-ground biomass			Wheat grain		
Treatment	LAI	Weeds	Wheat	AWP	Yield	Protein	Test weight
		-----------lbs/acre------------			-bu/acre-	--%--	-lbs/bu-
Main plot							
0	0.51b[†]	233	917b	22	6.3ab	18.7b	57.9
5.6	0.61b	338	1104ab	2	7.0ab	19.4a	57.7
11	0.84a	308	1210a	1	9.6a	19.6a	57.7
22	0.93a	187	1214a	7	9.5a	19.5a	58.2
Urea	0.45b	128	849b	10	5.1b	18.7b	57.5
Subplot							
+AWP	0.68b	204	1032	--	7.1	19.1	57.4b
-AWP	0.74a	273	1089	--	7.9	19.2	58.2a
	P-values						
Main plot (MP)	<0.01	0.760	0.0367	0.4	0.04	0.011	0.515
Subplot (SP)	0.04	0.076	0.4516	--	0.31	0.494	0.006
MP x SP	0.07	0.311	0.0460	--	0.22	0.568	0.445

[†]Differences in a letter within a column and heading (e.g,, Main plot) indicate differences in treatments at $P < 0.05$.

Table 2. Leaf area index (LAI), aboveground weed and crop biomass, and wheat grain yield and quality across four composted manure rates, a urea fertility application, and a 0 (check) treatment in wheat ± sweetclover (clover) plots in central Montana during 2022.

		Above-ground biomass			Wheat grain		
Treatment	LAI	Weeds	Wheat	Clover	Yield	Protein	Test weight
		---------- lbs/acre ------------			bu/acre	-- % --	- lbs/bu -
Main plot							
0	1.37	402	1517	8	25.9	--	51.7
5.6	1.48	885	882	75	21.2	--	58.1
11	1.54	545	2391	173	28.2	--	51.8
22	1.62	651	1199	76	30.4	--	59.2
Urea	1.19	283	2047	84	25.4	--	59.1
Subplot							
+clover	1.15b[†]	628	1042b	--	15.1b	--	52.8
-clover	1.73a	478	2172a	--	37.3a	--	59.1
	P-values						
Main plot (MP)	0.18	0.278	0.0620	0.177	0.725	--	0.621
Subplot (SP)	<0.01	0.415	0.0003		<0.001	--	0.159
MP x SP	0.83	0.959	0.1049		0.269	--	0.549

[†]Differences in a letter within a column and heading (e.g,, Main plot) indicate differences in treatments at $P < 0.05$.

received 11 and 22 tons/acre of composted manure than in urea-fertilized or 0 check plots (Table 1). In contrast, wheat grain yield was equal or greater in plots that received a

Table 3. Leaf area index (LAI), aboveground weed and crop biomass, and wheat grain yield and quality across four composted manure rates, a urea fertility application, and a 0 (check) treatment in wheat ± sweetclover (clover) plots in central Montana during 2023.

		Above-ground biomass			Wheat grain		
Treatment	LAI	Weeds	Wheat	Clover	Yield	Protein	Test weight
		----------- lbs/acre -----------			- bu/acre -	-- % --	- lbs/bu -
Main plot (MP)							
0	0.72c†	668b	2751	8.9	33.4b	11.4bc	60.9a
5.6	1.07abc	1552ab	2154	59.9	30.4b	11.2c	60.5ab
11	1.23ab	2464a	2806	55.5	37.6ab	12.2b	59.7c
22	1.43a	2422a	3716	10.0	48.6a	11.9bc	59.8c
Urea	0.94bc	2007a	1950	8.9	29.3b	13.4a	60.0bc
Subplot							
+clover	0.78b	1574	1584b	--	17.4b	12.2a	59.6b
-clover	1.37a	2076	3766a	--	54.2a	11.9b	60.7a
	P-values						
Main plot	0.024	0.0369	0.1571	0.61	0.022	<0.001	0.007
Subplot (SP)	<0.001	0.3103	0.0001	--	<0.001	<0.001	<0.001
MP x SP	0.717	0.5675	0.2152	--	0.069	0.054	0.171

†Differences in a letter within a column and heading (e.g., Main plot) indicate differences in treatments at $P < 0.05$.

onetime application of composted manure at 22 tons/acre than at other rates, in urea fertilized plots, and in 0 check plots in both 2021 and 2023 (Tables 1 and 3). No differences in wheat grain yield were detected across plots receiving composted manure, urea fertilizer, and 0 check plots in 2022 ($P = 0.062$; Table 2). Grain yield was greater in wheat monoculture than wheat + clover subplots in both 2022 (37 vs 15 bu/ac; Table 2) and 2023 (54 vs. 17 bu/ac; Table 3).

Protein concentration of wheat grain was greater when composted manure was applied at any rate than following an application of urea or in 0 check plots in 2021 (Table 1). In contrast, grain protein concentration of wheat was higher in urea-fertilized plots in 2023 than in 0 check plots or plots that received the onetime composted manure applications back in 2021 (Table 3). Protein was more concentrated in grain when wheat was intercropped with the green manure crop than grown in monoculture in 2023 (Table 3), but not in 2021 (Table 1). Protein concentration was not determined for wheat grain harvested in 2022, as noted previously. In 2023, wheat grain test weight was responsive to a urea fertilizer application or previous composted manure applications (Table 3), but not in 2021 or 2022 (Tables 1 and 2). Wheat grain test weight was nonresponsive to manure or urea-fertilizer amended soil in 2021 and 2022 (Table 1-2). In 2023, grain with heavier test weight was harvested in 0 check plots than plots that received 11 or 22 tons/ac of composted manure previously or in urea-fertilized plots (Table 3).

Results indicate that plant canopy LAI, above-ground biomass, and wheat grain yield are comparable or elevated when composted manure is applied once at 22 tons/acre compared with annual urea applications during the first three years in this ongoing study. Interestingly, grain yield differences were not detected between 0 check plots and plots where urea was applied annually each year, suggesting that an early spring application of urea is not an efficient N-delivery system in shallow soils such as those that occur at this location, since these soils are prone to nitrate leaching (Sigler et al.2020). Grain protein was more concentrated in wheat when urea was applied than a previous heavy application of composted manure in 2023, which was less than the 12.1% threshold indicating N sufficiency when growing winter wheat (Engel et al.., 2006) under dryland management, suggesting that the legacy impact of a one-time heavy application of composted manure may be insufficient to maintain adequate N for optimum wheat grain yield and quality. This study will be continued through 2024.

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