2012

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Renewable Agriculture and Food Systems: 29(1); 42–47 doi:10.1017/S1742170512000324

Nitrogen fertility in semiarid dryland wheat production is challenging for beginning organic farmers

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Accepted 8 September 2012; First published online 23 October 2012 **Research Paper**

Abstract

Organic farming systems use green and animal manures to supply nitrogen (N) to their fields for crop production. The objective of this study was to evaluate the effect of green manure and composted cattle manure on the subsequent winter wheat (*Triticum aestivum* L.) crop in a semiarid environment. Dry pea (*Pisum sativum* L.) was seeded in early April and terminated at first flower in late June. Composted cattle manure was applied at 0, 11.2 or 22.5 Mg ha^{-1} just prior to pea termination. Winter wheat was planted in mid September following the green manure or tilled summer fallow. No positive wheat response to green manure or composted cattle manure was observed in any of the 3 years of the study. In 2 of the 3 years, wheat yields and grain test weight were reduced following green manure. Green manure reduced grain yields compared with summer fallow by 220 and 1190 kg ha^{-1} in 2009 and 2010, respectively. This may partially be explained by 40 and 47 mm less soil water at wheat planting following peas compared with tilled summer fallow in 2008 and 2009, respectively. Also, in 2008 and 2009, soil nitrate level averaged 45 kg ha^{-1} higher for black fallow compared with green manure fallow when no compost was added. Organic growers in the semiarid Central Great Plains will be challenged to supply N fertility to their winter wheat crop in a rapid and consistent manner as a result of the inherently variable precipitation. Growers may need to allow several years to pass before seeing the benefits of fertility practices in their winter wheat cropping systems.

Key words: organic farming, green manure, composted manure

Introduction

In the semiarid portions of Central Great Plains, dryland agriculture has developed around winter wheat production. A variable climate with unpredictable precipitation has made dryland farming in the region inherently risky[1,2]. Summer fallow, the practice of controlling all plant growth during the non-crop season, was quickly adopted in the region to increase the chances for successful establishment and development of winter wheat and to stabilize winter wheat yields[3]. However, frequent use of summer fallow, especially when mechanical tillage is used, can result in severe soil erosion, reduced soil carbon and quality, and reduced grain yields and protein content in cereal crops[4].

Organic farming systems frequently rely on biological N fixation from *Rhizobium* bacteria in symbiotic association with legume species that are used as green manure[5]. The release of N from plant residues is dependent on several factors that include chemical composition and N concentration, temperature and soil water availability[6]. Optimum temperatures and moisture are required for good decomposition and typically occur when soil moisture content is between 50 and 100% of field capacity and when soil temperatures are between 25 and 32°C[7]. The major challenge to the use of green manure crops in semiarid agriculture is balancing the trade-off between water use by the green manure crop, which will not be available for the following winter wheat crop, and the potential N benefit to the winter wheat crop.

Long-term assessments of lentil (*Lens culinaris* Medikus) green manure as a partial summer fallow replacement in conventional, i.e., non-organic, cropping systems have been conducted in the US Northern Great Plains and Canadian Prairies. In the first half of a 12-year study conducted at Swift Current, Saskatchewan, lentil was planted in May and turned down at full bloom (late July or early August) to maximize N fixation[8]. Subsequent spring wheat yields were reduced compared with traditional summer fallow as a result of soil water depletion by lentil. However, in the second half of the study, lentil was planted in April and turned under in early July to reduce water consumption. Subsequent spring wheat yields in the second half of the study were similar between green manure and traditional fallow, plus there was a gradual increase in wheat grain protein and a gradual decrease in N fertilizer requirement following lentil. In Montana, a similar 12-year study was conducted with lentil as a partial summer fallow replacement[9]. Although the authors did not see a difference in starting soil water for spring wheat following green manure killed at full bloom or fallow, they did see reduced grain yield following green manure in the first 5 years, which they explained by low soil nitrate following green manure. In the last 6 years of the study, grain yields following green manure and fallow were similar and the green manure treatment had 26% greater spring soil nitrate than fallow.

In a conventional production system in Colorado, winter wheat yield following annual legume green manures [Austrian winter pea (*Pisum sativum* L. subsp. *sativum* var. *arvense* (L.) Poir.), spring field pea and black lentil] was reduced from 400 to 1050 $kg\,ha^{-1}$ compared with summer fallow depending on the termination date of the green manure[10]. Water use by the green manure explained 88% of the variability in winter wheat yield. The benefits of green manure fallow were highly weather-dependent and inconsistent. The impact of replacing summer fallow in a no-till production system with various spring-planted crops prior to winter wheat seeding was studied in western Nebraska[11]. Winter wheat yields following summer fallow replacement crops were reduced from 22 to 58% following oat (*Avena sativa* L.) + pea for forage and corn (*Zea mays* L.), respectively, compared with wheat following summer fallow. This was largely explained by a 27–41% reduction in soil water at wheat planting following these two crops compared with following summer fallow. Winter wheat yield has been reported to be strongly correlated with the available soil water at wheat planting[12].

In a dryland organic wheat system in Montana, winter wheat yield and quality were higher following winter pea green manure than spring pea green manure[13]. Winter pea had greater shoot N content when terminated at the pod stage, contributed greater soil nitrate-N, and used less soil water than spring pea. Termination timing, either at bloom or pod stages, was of secondary importance to pea type.

Animal manures are widely used to fertilize crops and increase soil organic matter content. Nitrogen content of manure is affected by animal species, feed, bedding, and manure storage and handling. The average apparent first-year N availability for corn was 57, 53, 14 and 4% for fresh poultry, dried poultry, composted poultry and composted cattle (*Bos taurus*) manure, respectively[14]. Corn yield following composted cattle manure was no different than the no N control treatment. Apparent N and phosphorus recovery in barley (*Hordeum vulgare* L.) was lower for fresh and composted beef cattle manure (5–9%) than for inorganic fertilizer (22–47%)[15]. The gradual N release from fresh and composted manures, as opposed to the quick release of inorganic N fertilizer, over several years benefitted weed growth more than spring wheat[16].

Organic growers are restricted to using organic certified N sources. In a semiarid environment such as Sidney, NE, conversion of these organic N sources to nitrate–N may be slower than in a more humid environment. The objective of this study was to ascertain the impact that green manure pea and composted cattle manure had on winter wheat yield and grain quality characteristics in a certified organic production system in the semiarid Central Great Plains.

Materials and Methods

Studies were conducted in fields certified through the Organic Crop Improvement Association in 2006 at the University of Nebraska–Lincoln High Plains Agricultural Laboratory (41°12′N, 103°0′W, 1315 m elevation above sea level) located near Sidney, NE. The certified organic land is divided into three 10-ha fields managed in a 3-year rotation of winter wheat–proso millet (*Panicum miliaceum* L.)–green manure fallow. Each year, a new study was established in the field with green manure fallow. Soils were an Alliance silt loam (fine-silty, mixed, superactive, mesic Aridic Argiustolls) in 2008/2009 and a Duroc loam (fine-silty, mixed, superactive, mesic Pachic Haplustolls) in 2009/2010 and 2010/2011. Soil pH in the surface 20 cm was 7.3, 6.6 and 7.0 for 2008/2009, 2009/2010 and 2010/2011, respectively. Soil organic matter content in the surface 20 cm was 23, 27 and 27 $g\,kg^{-1}$, respectively.

A split-plot experimental design was used. Whole plot treatments were replicated four times in a randomized complete block design and consisted of green manure fallow and conventional tilled fallow (black fallow), and subplots consisted of one of three levels of composted cattle manure (0, 11.2 or 22.5 $Mg\,ha^{-1}$). Whole plots were 9 m × 9 m and subplots were 3 m × 9 m. Forage pea '4010' was used as the green manure crop. Peas were treated with the peat formulation of Cell-Tech pea and lentil (Novozymes BioAg, Inc., Brookfield, WI) and planted in early April at a depth of 7.5 cm in 25-cm rows and at a seeding rate of 67 $kg\,ha^{-1}$. Peas were allowed to grow until first flower, which occurred during the last 2 weeks of June, and then terminated with a tandem disc operated to a 10-cm depth. This was followed by a chisel plow with small sweep points and then a rod weeder for the remainder of the fallow period. Immediately prior to pea termination, pea biomass was randomly collected from 1 m^2 per replication to estimate pea biomass. Pea biomass was dried at 50°C until a constant weight was achieved. Also, at this time, composted manure

Table 1. Precipitation during the pea, fallow and winter wheat phases of the field study conducted at Sidney, NE from 2008 to 2011.

Crop phase	2008–2009	2009–2010	2010–2011
		mm	
Peas	112	313	205
Fallow	159	115	108
Winter wheat	412	406	440
Total	683	834	753

Table 2. Winter wheat grain yield and soil water in surface 122 cm of soil at wheat planting following green manure and black fallow at Sidney, NE from 2008 to 2011.

	Grain yield			Soil water		
Treatment	2009	2010	2011	2008	2009	2010
	$kg\,ha^{-1}$			mm		
Green manure fallow	2990	4020	4570	143	178	277
Black fallow	3210	5210	4530	183	225	264
P-value	0.021	0.044	0.776	0.008	0.017	0.063

treatments were applied to designated plots. Black fallow plots were tilled twice with a tandem disc and then once or twice with a chisel plow with small sweeps and then a rod weeder.

Composted cattle manure was stockpiled to provide fertilizer to the experiment for 3 years. The compost contained $9.5\,g\,N\,kg^{-1}$, $6.7\,g\,P\,kg^{-1}$, and $11.8\,g\,K\,kg^{-1}$ on a dry matter basis. The compost application rates provided a total of 94 and $188\,kg\,N\,ha^{-1}$ each year on an as-applied basis (12% moisture content), but only 10–20% of this would mineralize during the crop growth cycle[17].

Immediately prior to winter wheat planting, a soil sample was taken from the middle of each plot with a hydraulic soil probe using a 5-cm diameter sampling tube. Soil depth increments were: 0–20, 20–60 and 60–120 cm. A portion of each sample from every plot was used to determine gravimetric soil water content, while a second portion was air dried and analyzed for soil nitrate concentration. Gravimetric soil water content was converted to volumetric water content by multiplying by the soil bulk density for each depth layer.

Winter wheat 'Goodstreak' (2008) and 'Hatcher' (2009 and 2010) were planted at a rate of $56\,kg\,ha^{-1}$ in mid September at a depth of 5 cm and a row spacing of 30 cm. Immediately prior to wheat harvest in mid July, 2 m of row were clipped at ground level and removed from each plot to determine harvest index. Wheat straw from these samples were subsequently ground and analyzed for total N. Plots were mechanically harvested with a plot combine and yield determined from an area 2.0 m wide × 7.6 m long. Grain moisture and test weight were determined and

Table 3. Soil nitrate–N in the surface 120 cm of soil before winter wheat planting and following green manure and black fallow at Sidney, NE from fall 2008 through 2010.

Treatment	2008[1]	2009	2010
		$kg\,N\,ha^{-1}$	
Green manure fallow			
No compost	80a	121c	121b
$11\,Mg\,ha^{-1}$ compost	78a	253a	167a
$22\,Mg\,ha^{-1}$ compost	104a	219ab	146ab
Black fallow			
No compost	111a	179b	122b
$11\,Mg\,ha^{-1}$ compost	110a	194b	125b
$22\,Mg\,ha^{-1}$ compost	102a	223ab	144ab

[1] Means within a column followed by the same letter are not significantly different at the 5% probability level.

Table 4. Winter wheat grain moisture and test weight following green manure and black fallow at Sidney, NE from 2009 to 2011.

	Grain moisture			Grain test weight		
Treatment	2009	2010	2011	2009	2010	2011
	$g\,kg^{-1}$			$kg\,m^{-3}$		
Green manure fallow	131	96.9	106	723	767	762
Black fallow	108	99.3	107	779	779	767
P-value	0.014	0.037	0.660	0.014	0.024	0.255

a portion of the grain was analyzed for N content. Grain protein was calculated from grain N content using 5.7 as the multiplier. Total N removal was calculated by adding the N content of the grain and straw.

Data were analyzed using the General Linear Model (GLM) procedure in SAS[18]. Replications were treated as random effects. All other factors in the model were treated as fixed effects. Significant year by treatment interactions were observed, so data were analyzed separately by year. Treatment means were separated using Fishers' protected LSD at the 0.05 probability level.

Results and Discussion

Growing season precipitation, from pea planting through winter wheat harvest, varied from a low of 683 mm in 2008/2009 to a high of 834 mm in 2009/2010 (Table 1). The 30-year average total precipitation for Sidney from 1 April (pea planting) through June of the following year (winter wheat harvest) is 522 mm.

Fallow treatments

Winter wheat yields were higher following black fallow than green manure fallow in 2 of the 3 years (Table 2).

Table 5. Winter wheat grain N removal and total N removal (grain and straw) following green manure and black fallow at Sidney, NE from 2009 to 2011.

	Grain N removal			Total N removal		
Treatment	**2009**	**2010**	**2011**	**2009**	**2010**	**2011**
	---------------$kg\,N\,ha^{-1}$---------------			---------------$kg\,N\,ha^{-1}$---------------		
Green manure fallow	63.5	81.3	97.5	87.8	120	145
Black fallow	68.4	104	92.9	94.8	154	136
P-value	0.086	0.057	0.126	0.094	0.082	0.135

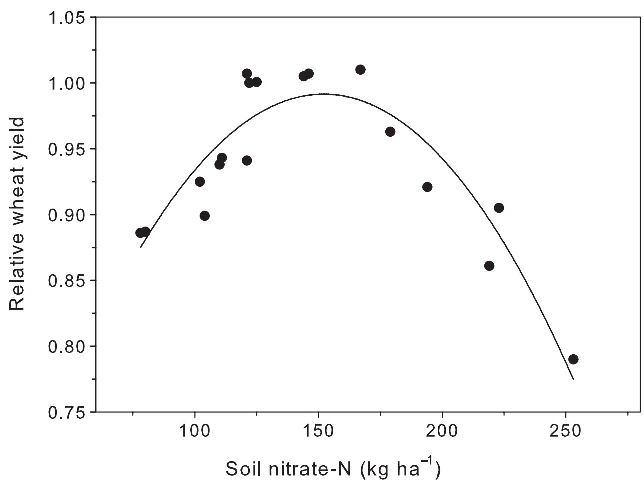

Figure 1. Predicted relative winter wheat yield versus soil nitrate–N (SN) and pre-plant soil water (SW) in the upper 1.2 m of soil. Equation: $Y = 0.64 + 0.00254SN - 0.000094SN^2 + 0.00077SW$, $R^2 = 0.47$.

There was no difference in winter wheat yield between black fallow and green manure fallow in 2011. Soil water prior to winter wheat seeding was at least 40 mm higher after black fallow than after green manure fallow in the first 2 years of the study when winter wheat yields were best following summer fallow. This is in agreement with the findings of Nielsen et al., who found that winter wheat yields were correlated with water at planting and that the elimination of summer fallow reduced soil water at planting and subsequent wheat yield[12]. In 2010/2011, there was less than 20 mm difference in soil water between the two fallow treatments and there was no significant yield difference (Table 2).

Soil nitrate levels were also different between black fallow and green manure fallow treatments receiving no manure (Table 3). Soil nitrate in the fall of 2008 and 2009, on average, was 45 kg ha^{-1} higher for black fallow compared with green manure fallow. The green manure crop not only reduced soil water but also soil nitrate. The N was not lost, but taken into the pea biomass. The dry matter accumulation averaged 1920, 1190 and 1420 kg ha^{-1} for 2008, 2009 and 2010, respectively. The above-ground N content averaged 60, 42 and 44 kg ha^{-1}, which varied due to available soil water. This N would be available later, but the delay in N release in addition to less soil water contributed to reduced grain yield.

Winter wheat grain moisture also varied by year (Table 4). In 2009, grain moisture was less after black fallow than green manure fallow. This was likely the result of wheat plants having less drought stress following black fallow than green manure fallow, which allowed the crop to mature more quickly following black fallow than after green manure fallow. Although the difference in grain moisture levels was statistically significant in 2010, from a practical standpoint, the small difference between treatments was of no significance. In 2011, no difference in grain moisture content was observed.

Grain test weight was higher following black fallow than green manure fallow in 2009 and 2010 (Table 4). In 2011, there was no difference in grain test weight. Test weight is an important quality trait used in the wheat industry and low test weights can result in significant price reductions for grain.

Grain protein averaged 138, 127 and 133 g kg^{-1} in 2009, 2010 and 2011, respectively. Although there were no differences in grain protein content between fallow treatments (data not shown), grain N and total N removal were higher following black fallow than green manure fallow in 2 out of 3 years (Table 5). This was likely the result of greater grain yields following black fallow in the first 2 years of the study.

Manure applications

There were no differences observed between manure treatments in this study. This was likely the result of a short time between manure application and winter wheat planting, and the relatively dry conditions during this time (Table 1), which prevented sufficient release of N from the composted cattle manure. Apparent N recovery in barley was only 5–9% following fresh and composted beef cattle manure[15]. This low recovery rate, combined with adequate soil N from the mineralization of soil organic matter, particularly following black fallow, resulted in no effect of composted cattle manure on the following winter wheat crop.

We saw no benefit from either green manure or composted beef cattle manure on the following winter wheat crop. In fact, in 2 out of 3 years, green manure fallow decreased winter wheat grain yield, at least in part, as a result of soil water depletion prior to winter wheat planting. This agrees with the findings of Vigil and Nielsen from their work in eastern Colorado[10]. The other factor related to reduced grain yield and N removal was diminished nitrate in the fall of 2008 and 2009 after green manure fallow. The relationship between winter wheat yield and N application depends on the availability of both N and soil water. In soils with adequate N but insufficient water, yields are depressed, as in 2009. If N fertility is great enough, especially with limited water, the N response curve is curvilinear[19]. Figure 1 shows this relationship clearly for this experiment. Yields of each year were normalized to relative yield and compared with soil nitrate before wheat planting. Yield was maximized near 150 kg ha^{-1} and higher nitrate levels tended to suppress yield, which was similar to results from Halvorson et al.[19]. A multiple regression equation relating relative yield to soil nitrate and preplant soil moisture had an R^2 of 0.47. The equation is

$$Y = 0.64 + 0.00245\text{SN} - 0.0000094\text{SN2} + 0.00077\text{SW},$$

where SN is kg soil nitrate–N in 1.2 m (Table 3) and SW is mm of preplant soil water (Table 2). The comparison of actual and predicted relative yield is shown in Figure 1.

Zentner et al. and Allen et al. did not see the benefits of green manure in their long-term field experiments during the first 5 or 6 years[8,9]. Our study suggests that growers in the semiarid Central Great Plains are unlikely to see the benefits of green manure or composted cattle manure on the immediately following winter wheat crop. In fact, as a result of the soil water used by green manure crops, winter wheat yields will often be negatively impacted by the use of green manure crops used as a partial summer fallow replacement. This is supported by the work of Nielsen et al.[12]. Organic wheat growers in the semiarid Central Great Plains may prefer the use of fresh manure, with its higher N content relative to composted manure. The use of green manures, which use valuable soil water, may be too risky in semiarid winter wheat production. As is often the case in organic production systems, semiarid winter wheat growers may need to be patient and be willing to accept some negative results in the early years of their production systems in order to see the benefits of these practices in their cropping systems.

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