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Compost and Cover Crop Effects in Dryland Organic Wheat

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COMPOST AND COVER CROP EFFECTS IN
DRYLAND ORGANIC WHEAT

by

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ABSTRACT

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by

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Utah State University, 2021

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Producers of dryland organic wheat (*Triticum aestivum* L.) in the western USA struggle to maintain adequate soil fertility due to the high cost of organic fertilizers and concerns over moisture use of cover crops. Low soil fertility results in decreased wheat yield and quality, and increased year-to-year variability in yield and quality based on weather. This study was conducted to measure the effects of, and interactions between, cover crop mixes and a one-time compost application on soil health and winter wheat yield and quality. The study was located on three adjacent certified organic wheat farms near Snowville, UT, each with a calcareous silt loam soil under conventional tillage in a wheat-fallow system. Four composted steer manure treatments (0, 12.5, 25, and 50 Mg ha^{-1}) and three cover crop treatments (oat [*Avena sativa*]-pea [*Pisum sativum*] mixture, vetch [*Vicia villosa*]-pea mixture, and a mechanically tilled fallow control) were evaluated from fall 2014 to 2017. Treatments were arranged in a randomized complete block split-split plot with three replications, with each farm hosting a single replicate. In

2015, the oat-pea cover crop treatment decreased grain yield, while compost amendment caused yields to more than double. However, neither compost nor cover crops affected yield in 2017. The 2015 crop year was much drier than 2017, suggesting that grain yield and quality benefits may be dependent on other factors such as the precipitation patterns of a particular year. The vetch-pea cover crop treatment increased total soil N in 2017 only, and compost amendment increased nitrogen fixation in the vetch-pea cover crop in that year. Compost treatments increased soil N, P, K, and organic C, both years without affecting soil EC or pH long-term. Nitrogen fixing cover crops may be a viable option for producers to increase soil N when sufficient soil moisture is present, however may be detrimental in a dry year. Compost amendment was shown to increase soil nutrition for multiple years, although that may only translate into increased grain yield when prerequisite weather conditions are present.

(68 pages)

PUBLIC ABSTRACT

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Michael D. Deakin

Producers of dryland organic wheat (*Triticum aestivum* L.) in the western USA struggle to maintain adequate soil fertility due to the high cost of organic fertilizers and concerns over moisture use of cover crops. Low soil fertility results in decreased wheat yield and quality, and increased year-to-year variability in yield and quality based on weather. This study was conducted to measure the effects of, and interactions between, cover crop mixes and a one-time compost application on soil health and winter wheat yield and quality. The study was located on three adjacent certified organic wheat farms near Snowville, UT, each with a calcareous silt loam soil under conventional tillage in a wheat-fallow system. Four composted steer manure treatments (0, 12.5, 25, and 50 Mg ha^{-1}) and three cover crop treatments (oat [*Avena sativa*]-pea [*Pisum sativum*] mixture, vetch [*Vicia villosa*]-pea mixture, and a mechanically tilled fallow control) were evaluated from fall 2014 to 2017. Treatments were arranged in a randomized complete block split-split plot with three replications, with each farm hosting a single replicate. In 2015, the oat-pea cover crop treatment decreased grain yield, while compost amendment caused yields to more than double. However, neither compost nor cover crops affected yield in 2017. The 2015 crop year was much drier than 2017, suggesting that grain yield and quality benefits may be dependent on other factors such as the precipitation patterns of a particular year. The vetch-pea cover crop treatment increased total soil N in 2017 only, and compost amendment increased nitrogen fixation in the vetch-pea cover crop in that year. Compost treatments increased soil N, P, K, and organic C, both years without affecting soil EC or pH long-term. Nitrogen fixing cover crops may be a viable option for producers to increase soil N when sufficient soil moisture is present, however may be detrimental in a dry year. Compost amendment was shown to increase soil nutrition for multiple years, although that may only translate into increased grain yield when prerequisite weather conditions are present.

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Michael D. Deakin

CONTENTS

Page

LIST OF TABLES

LIST OF FIGURES

CHAPTER I

LITERATURE REVIEW

1 | HISTORY OF DRYLAND WHEAT FARMING

Wheat (*Triticum aestivum* L.) is grown on more land area than any other food crop in the world. This is due to its ability to be cultivated in a variety of soil types and under limited rainfall regimes compared to other crops. In addition, there is a strong demand for wheat-based food products in a variety of cultures around the world (Delcour et al. 2010). Wheat can be considered one of the 'big three' cereal crops; for the 2017-2018 crop year the total world harvest of wheat was about 762 MMT as compared to 494 MMT of rice (Oryza sativa) and 1361 MMT of corn (*Zea mays L.*) (USDA, 2019).

The first cultivation of wheat is thought to have occurred about 10,000 years ago in the south-eastern region of modern-day Turkey (Heun et al. 1997). The earliest forms of wheat were selected from wild populations; presumably chosen based on desirable traits for production and use (Shewry, 2009). Domesticated wheat varieties were spread into Greece as early as 6000 BC and northward to France and Spain around 3000 BC. It was introduced to North America when the Spaniards brought wheat to Mexico in 1529 (Feldman, 2001). It was brought to Utah and was planted by the State's first Anglo-American settlers under irrigation in 1847 (Utah History Encyclopedia, 2017).

Dry-farming, or the non-irrigated production of crops in semiarid and arid regions, has been practiced throughout history out of necessity and lack of available water for irrigation. Dry-farming is distinguishable from rain-fed agriculture in that it refers to crop production in areas receiving less than 20 inches of annual precipitation, necessitating the use of moisture conservation techniques to maintain adequate soil moisture throughout the growing season (California Agricultural Water Stewardship Initiative, 2017).

Large-scale dry-farming in the USA was developed as Anglo-American settlers traveled west and began implementing agricultural farming practices developed in the Great Plains and eastern states. Initially, farming in Utah was limited to irrigated agriculture, but as the population grew, farmers began experimenting with dry-farming as early as the 1860s (Widtsoe, 2006). Formal experimentation began with the formation of the Utah Agricultural Experiment Station in 1887, and, in 1902, a systematic presentation of the principles of dry farming was published (Widtsoe, 2006).

With the advent of motorized farm equipment after the turn of the century, producers were able to cover more ground faster and at a lower cost than previously possible with draft animals, making it a further economically viable option to produce crops on the lower yielding dryland acres. By this time, dry-farming had become firmly established in the western USA, along with adoption of production practices such as summer fallow, wide row spacing, and tillage to control weeds and preserve moisture.

2 | HISTORY OF ORGANIC WHEAT

Although the principles of organic agriculture have been around since the beginning of agriculture itself, organic agriculture as it is known today (farming without the synthetic fertilizers and pesticides increasingly used in conventional farming) began to take shape in the 1920s with the work of Sir Albert Howard in the United Kingdom. Around that same time in Germany, Demeter Association created the first organic-like certification and labeling system, emphasizing "biodynamic farming," a more holistic approach to food production (Barker, 2011). In the 1940s, Howard published a series of books, which advocated the building of soil health using available waste materials to build and maintain soil fertility and humus content. Walter Northbourne later coined the term "organic" to refer to Howard's system of agriculture. Jerome Rodale, an early follower of the organic movement, published a magazine entitled *Organic Farming and Gardening*, which disseminated Howard's organic philosophy throughout the US (Heckman, 2006).

Consumer demand for organic and natural foods began to grow, and by 1990 was recognized when the USDA passed the Federal Organic Foods Production Act, which set out to establish national standards designating which products could be considered "certified organic". In 2002, this effort came to fruition with the publication of the National Organic Program final rules and the USDA Certified Organic labeling program (Heckman, 2006).

As consumer demand for organic products grew, consumers were willing to pay a premium to buy products produced under organic certification, and separate marketing chains began to form. Handlers and processors of organic commodities began paying a premium over conventional production for their certified organic counterparts. Organic price premiums for organic wheat of around 50% were common in the 1990s and early 2000s and have increased sharply in the last five years, where now a premium of 150-200% has been more typical of the current market (USDA NASS, 2017; Dobbs, 1998).

With the allure of organic price premiums, more and more farmers began to experiment with growing organic grains and hubs of organic farms formed in environments best suited to organic production. Surprisingly, in the case of organic winter wheat, the majority of the successful farms were located in dryland areas with low soil fertility (Utah Department of Agriculture and Food, 2017).

The advantages of these dry environments are twofold: first, the low soil moisture means less weed pressure, alleviating one of the largest challenges faced by organic producers. Second, since synthetic fertilizers are less effective at increasing yield in these areas, the opportunity cost for not using them is minimal compared to areas that were more fertile. Because of this, the dry environments of Utah, Wyoming, Colorado, and Montana began to form as the major producers of organic hard red winter wheat (USDA, 2014).

3 | COVER CROPS

Cover crops have been documented to decrease erosion, reduce nitrate leaching, increase soil organic matter, and fix nitrogen for use by a succeeding grain crop (Unger et al. 1998). Other studies have shown that cover crops can be beneficial disease suppression and weed management tools (Carr et al. 2012). In spite of these benefits, the use of cover crops can pose significant challenges, the greatest of which is likely to be managing soil water. Because of this, cover crops have been shown to have inconsistent yield benefits to a following grain crop, depending on region, rainfall regime and cover crop variety.

In the wheat fallow systems of the Intermountain West, water is typically the most limiting factor that determines grain yields. Cover crops have been shown to have either a positive, neutral, or negative effect on the soil water supply among different sites and regions (Unger et al. 1998).

In some areas, cover crops have been shown to contribute to the amount of stored soil water. Positive soil moisture effects have been attributed to decreasing evaporation by shading the ground. This effect is particularly evident in fields under minimum or conservation tillage where the residues of the cover crop can be left undisturbed above ground for an extended period of time following termination. Additional crop residues also provide the added benefits of reducing runoff and increasing soil organic matter content, which in turn can improve soil structure and water infiltration (Carr et al. 2012).

Cover crops can have a neutral effect on soil water when rainfall or timely irrigation can replenish soil water reserves following the growth of the cover crop but before a grain crop is grown. In humid and subhumid regions, precipitation is generally sufficient to recharge soil water reserves prior to the subsequent crop. Soil types predominantly found in these regions are also better suited to storing water than in drier areas, somewhat limiting risk of precipitation timing (Unger et al. 1998).

Cover crops generally have a negative effect on soil moisture due to transpiration. This water usage can be particularly detrimental in semi-arid regions where timely rainfalls may not be sufficient to restore soil moisture, thereby stressing the following crop for moisture. These soils may also have a lower water-holding capacity and compaction issues due to tillage necessary to carry out an organic summer fallow system, thereby exacerbating this problem (Unger et al. 1998).

Although moisture conservation is a significant factor influencing grain yields in semiarid dryland wheat systems, there have been studies demonstrating that in some cases available nitrogen can be even more limiting to crop production (Pikul et al. 1997). Using a legume as a green manure cover crop and reincorporating crop residues into the soil is a viable option for organic dryland wheat producers, to fix nitrogen and increase the available N to the subsequent grain crop. In addition, green manure cover crops may increase the availability of other nutrients by mobilizing them from deeper soil layers and depositing them near the surface in organic form. Conversely, the use of legume crops harvested for grain or forage may have the undesired effect of decreasing desirable plant nutrients other than N, such as phosphorus and potassium (Hoyt, 1990).

4 | COMPOST

Compost and manures can likewise be used to amend soil nutrients and increase soil organic matter, without the risk of drying out soil moisture. Typically, dryland organic wheat producers haven't used these types of amendments due to the inability to recoup application cost over the short term. However, it has been well documented that compost benefits can last for several years, depending on soil type and climate (McAndrews et al. 2006). In semiarid dryland soils, studies have shown that benefits may be evident many years after a one-time application; Ippolito et al. (2010) showed a response 14 years after application in soil organic matter and available nutrients in a semiarid grassland. Reeve et al. (2012) showed higher organic matter, microbial biomass, and P, K and Zn, in plots amended with 50 Mg DM ha^{-1} of composted steer manure, 16 years after the time of application in a dryland organic wheat fallow system. With an increased timeline for the compost benefit decay; this has the potential for improving the economic viability of compost as a soil amendment by allowing producers to amortize the cost of application over several years (Endelman et al. 2010).

Besides the initial addition of nitrogen, phosphorus, and potassium provided by the compost, the way in which these nutrients are delivered may be of particular benefit to the dryland organic wheat system. As discussed above, phosphorus tends to become bound with Ca compounds found in the calcareous soil typical of these farming regions (Reeve et al. 2012). Compost provides a slow mineralization of nutrients that has been shown to improve particularly the uptake of phosphorus in calcareous soils (Braschi et al. 2003).

Due to the high cost associated with organic herbicides, most dryland producers rely on mechanical tillage for weed control during the fallow year. Heavy tillage and erosion tend to reduce levels of soil carbon, which in turn has a detrimental effect on soil health (Sainju et al. 2006). In addition to providing nutrients to the soil, compost has been shown to provide non-nutritive benefits that may be particularly significant for fields under dryland production.

Stukenholtz et al. (2002) showed that a single application of 50 Mg DM ha^{-1} composted steer manure provided yield benefits over and above what could be provided by nutritive benefits alone. It was hypothesized that these benefits were due to increased soil warming, increased soil aeration, increased soil cation exchange capacity, buffering soil pH, and improving soil moisture infiltration and retention. Increased organic matter also has been correlated with increased soil enzyme and microbial activity. In dryland organic wheat systems, limited by the amount of available soil water, using compost to improve soil structure and moisture retention, may provide more benefit over the long term than the nutrient benefit alone (Stukenholtz et al. 2002).

5 | ECONOMIC RETURNS

Due to lower soil fertility and lack of nutrients, yields of organic crops are typically 30% lower than their conventional counterparts (Seufert et al. 2012). In conversations with local producers, this figure was found to be accurate in the organic dryland wheat farms in Northern Utah (R. Grover, Personal Communication, July 27, 2017). This 30% decrease equates to nearly a 10 bu/ac annual loss due to inadequate soil fertility. At market prices present in 2017, lack of adequate soil fertility cost the producer upwards of $60/ac in gross revenue (USDA NASS, 2017; Dobbs, 1998). When looking at net profits per acre, a farming system that could provide adequate plant nutrition has the potential of increasing bottom line profits by 60%, not accounting for nutrient acquisition and application costs. Improving overall soil health also has the potential to decrease quality and yield fluctuations from year to year by improving moisture retention over the long-term, and capitalize on wet years by providing the soil fertility necessary to maximize yields on a year-to-year basis.

6 | SUMMARY AND OBJECTIVES

Because of the high cost associated with organic fertilizers, producers of dryland organic wheat have limited options to increase soil fertility and overall soil health. The typical practice of using mechanical tillage during a fallow year to control weeds only exacerbates this problem. Two options that show promise are the use of cover crops and compost. Cover crops, particularly legumes, have the benefit of being able to fix nitrogen in the field where it is needed, without the cost associated with hauling and spreading. The disadvantage however, is that cover crops have been shown to deplete soil moisture, which is of crucial importance to the dryland producer. Compost does not dry out the soil, and in fact has been shown to increase soil moisture by improving soil structure and aggregates through the addition of organic matter. Although there is a high cost associated with the application of compost, it may be an economically viable option when the long-term carryover effect is taken into consideration. In general, little research has been done investigating the interaction between cover crops and compost, and still less work has been done researching these soil amendments in the calcareous soils typical of dryland winter wheat producing areas of the Intermountain West.

The objectives of this project are to:

1) Measure the effect of a legume cover crop mixture and legume/grass cover crop mixture on soil health, cover crop biomass, weed suppression, and wheat yield and quality.
2) Measure the effect of one-time relatively large compost amendments on soil health, weed growth, wheat yield and quality.
3) Characterize the interaction between the use of cover crops and compost.

CHAPTER II

COMPOST AND COVER CROP EFFECTS IN DRYLAND ORGANIC WHEAT

Abstract

Producers of dryland organic wheat (*Triticum aestivum* L.) in the western USA struggle to maintain adequate soil fertility due to the high cost of organic fertilizers and concerns over moisture use of cover crops, resulting in decreased wheat yield and quality. This study was conducted to measure the effects of, and interactions between, cover crop mixes and a one-time compost application on soil health and winter wheat yield and quality. The study was conducted from 2014 to 2017 on three adjacent certified organic wheat farms near Snowville, UT under conventional tillage, in a wheat-fallow system, whereon four composted steer manure treatments (0, 12.5, 25, and 50 Mg ha^{-1}) and three cover crop treatments (oat [*Avena sativa*]-pea [*Pisum sativum*] mixture, vetch [*Vicia villosa*]-pea mixture, and a mechanically tilled fallow control) were evaluated. In 2015, the oat-pea cover crop treatment decreased grain yield, while compost amendment caused yields to increase 127%. However, neither compost nor cover crops affected yield in 2017. Compost treatments increased soil N, P, K, and organic C, both years without affecting soil EC or pH long-term. The vetch-pea cover crop treatment increased total soil N in 2017 only, and compost amendment increased nitrogen fixation in the vetch-pea cover crop in that year. Compost amendment provided soil health benefits both years, however crop yields were only affected in 2015, suggesting that grain yield and quality benefits, and benefits of cover cropping, may be dependent on factors such as the precipitation patterns of a particular year, in this region.

1 | INTRODUCTION

Wheat (*Triticum aestivum* L.) is one of the main cereal crops grown worldwide. Hard red winter wheat, produced using certified organic practices, is predominantly grown on dryland acres, and centralized in the western states of Utah, Colorado, Wyoming, and Montana (USDA, 2014). Due to lack of rainfall, the majority of the organic wheat grown organically in Utah is produced on dryland acreage in a wheat–fallow system. This system allows the producer to utilize water from two growing seasons to grow a single crop. Typically, no inputs are applied due to the inability to recoup the application costs over the short term. The combination of a homogeneous crop rotation, and the absence of inputs that return nutrients back into the system results in poor soil fertility, which is evidenced by decreased yields and quality (Reeve et al. 2012).

Nitrogen (N) is typically the limiting nutrient in dryland wheat production systems, even in areas with limited rainfall (Pikul et al. 1997). In low input organic systems, producers rely on internal N cycling, mimicking natural ecosystems. However, unlike the natural environment, N is removed from the system each time a crop is harvested, leaving the soil perpetually N depleted (Dawson et al. 2008). In addition, retaining available phosphorus (P) can pose a challenge to dryland organic wheat farms. The semiarid calcareous soils, on which many of these farms are located, typically have high pH and reactive Ca compounds that precipitate phosphorus, making it unavailable to the plant (Reeve et al. 2012).

One option to introduce N back into the system is by the use of a nitrogen fixing green manure cover crop grown during the fallow year. This option has the added benefits of potentially reducing the need for tillage to control weeds, decreasing erosion and nitrate leaching, and increasing soil organic matter (Unger et al. 1998) which may improve soil moisture holding capacity over the long-term. However, cover crops can also use valuable soil moisture through transpiration, depleting reserves needed to produce the subsequent grain crop (Miller et al. 2011). Grain yield benefits have been shown to be inconsistent and dependent on cover crop variety, growing region, and annual precipitation (Nielsen et al. 2016).

Compost amendment is another option for organic producers to replenish soil nutrients and increase overall soil health. Compost provides nutrients essential for plant grown, and, in addition, provides non-nutritive benefits from increased soil organic matter (Stukenholtz et al. 2002). Inputs of organic matter may increase soil moisture infiltration and retention, and have been correlated with greater soil enzyme and microbial activity. This aspect may be particularly important for producers using heavy tillage to control weeds (Sainju et al. 2006). Historically, dryland organic wheat producers in Utah haven't used compost amendments due to the inability to recoup application costs in one growing season, however studies showing the long-lasting effects of one-time compost amendments may improve the economic viability of this option, by allowing growers to amortize the cost over several growing seasons (Reeve et al. 2012).

Little is known about the interaction effect of using cover crops and compost together in dryland cropping systems. However, several studies looking at the environmental impacts of using cover crops and compost together in more humid regions have found significant interactions. Fronning et al. (2008) found that using a rye cover crop reduced N_2O emissions following manure and compost amendments by 95 and 97% respectively in a corn-soybean rotation in Michigan. Boardman et al. (2018) found a significant interaction effect on CO_2 emissions in one year of a study of organic grain in Missouri.

The objectives of this project were to 1) measure the effect of a legume cover crop mixture and legume/grass cover crop mixture on soil health, cover crop biomass, weed suppression, and wheat yield and quality, 2) measure the effect of a one-time relatively large compost addition on soil health, weed growth, wheat yield and quality, and 3) characterize the interaction between the use of cover crops and compost.

2 | MATERIALS AND METHODS

2.1 | Site Description and Experimental Design

This study was conducted on three adjacent certified organic farms located south of Snowville UT. Farm 1 was located approximately 7 miles south of Snowville, UT (N 41° 51’ 55.242”, W 112° 44’ 38.644”, 1414 m elev.), Farm 2 was located approximately 4.7 miles south of Snowville, UT (N 41° 54’ 28.955”, W 112° 45’ 53.452”, 1389 m elev.), and Farm 3 was located approximately 6 miles south of Snowville, UT, (N 41° 53’ 36.024”, W 112° 46’ 11.996”, 1392 m elev.). All farms had been certified organic for 15+ years and followed a wheat-fallow rotation. The soil type on all three farms is listed on the NRCS soil survey as calcareous Thiokol silt loam (ThA) (USDA NRCS). The average annual rainfall for this area is 335 mm (Utah Climate Center). The soil cation exchange capacity was similar across farm sites. Soil texture measured at the sites varied moderately, with soil classifications of silty clay loam, loam, and silt loam, on study sites on Farm 1, Farm 2, and Farm 3, respectively (Table 3).

The study was conducted from 2014-2017, using a completely randomized split-split-plot design. Each farm served as a block for statistical analysis. Within each block or farm site, three subplots were randomly assigned a compost level of 12.5, 25, or 50 Mg ha^{-1}, with a 0 Mg ha^{-1} control between each plot in order to provide a buffer in between compost applications and to prevent drift from one treatment to another. One of the 0 Mg ha^{-1} strips was randomly selected to be harvested as the 0 Mg ha^{-1} compost treatment. Each subplot was then further divided and randomly assigned a cover crop treatment. Cover crop treatments consisted of a spring planted legume mixture, comprised of Austrian winter pea (*Pisum sativum*) and hairy vetch (*Vicia villosa*), and a spring planted legume/grass mixture comprised of Austrian winter pea and oats (*Avena sativa*). Plots were 15.2 m by 22.8 m in size.

This study was funded through the NRCS Conservation Innovation Grant, and was initially designed as an on-farm demonstration of the cover crop and compost treatments used in this experiment. Because of this, the experimental design had a few statistical limitations that need to be taken into account. First, as mentioned earlier, each site was used as a block for statistical analysis, with one rep per site. Using each farm site as block, we could account for variation between sites, however this design resulted in less statistical power by failing to account for variations within each farm site due to the lack of replication on each farm site individually. In addition, the 15.2 m compost treatment strips were assigning randomly with a 0 Mg ha^{-1} compost rate buffer in between, one of the buffer strips was selected randomly and data was collected from that strip as the 0-rep rate. In essence, data had to be collected from a buffer strip in order to complete the study. In order to mitigate this, data was collected from the center of the relatively wide strips.

This study was part of a larger "mother" project led by Utah State University, which was fully replicated and conducted near this project. The satellite trials used in this study, were therefore not replicated at the site level in order to simplify the overall project and increase grower collaboration and feedback. This type of design has been shown to increase farmer participation in university research and increase adoption of new technologies after research has been completed (Snapp, 2002).

2.2 | Cultural Practices

The two-year management cycle for these farms includes three non-inversion tillage operations during the fallow year to prepare the seedbed and control weeds, these tillage operations are carried out using a chisel plow with sweeps, followed by either tine or spike tooth harrows. The first tillage after the prior year's harvest occurred in the spring around April 1, 2014, and March 15, 2016, at a depth of approximately 12-19 cm. Succeeding tillage was performed over the summer as needed to control weeds and at a depth of 8-12 cm, at the discretion of the farmer cooperators. Winter wheat planting dates in this area range from late August to early October depending on soil moisture and rainfall. Wheat plating on the study sites occurred between August 6 and August 29 in 2014, and on September 15 in 2016. Wheat was planted in rows spaced 30 cm apart using a deep furrow hoe drill with wheat seeding rates ranging from 62-73 kg ha^{-1}. Two different hard red winter wheat varieties were used in the study at the discretion of the farmer cooperators. Deloris (Reg. No. CV-934, PI 631447) developed by the Utah

Agricultural Experiment Station (UAES), was planted on the Farm 1 site in 2015. Juniper (Reg. No. CV-1021, PI 639951), developed by the Idaho Agricultural Experiment Station, was planted on the Farm 2 and Farm 3 sites both years, and on the Farm 1 site in 2017. Harvest typically occurs mid-July and residues are allowed to stand in the field until the following spring.

Compost was prepared from steer manure and bedding material obtained from a feedlot in Declo, ID, and composted by Magic Valley Compost. It was then transported and delivered to the site, where it was spread using commercial scale applicator trucks prior to wheat planting in the fall of 2014. The compost contained 0.78 % total N, 0.29% P, 1.09% K, 2.96% S, and had an EC of 15.1 dS m^{-1}. Compost was applied as a one-time amendment and never re-applied for the life of the study.

Cover crop mixes were planted in the spring of the typical fallow year, shortly after the first tillage operation of over-wintered wheat stubble on April 9, 2014, and March 21, 2016. The cover crop mixes were planted using a disc drill with 19 cm row spacing and allowed to grow for approximately two months. The cover crop mixes were terminated and incorporated as a green manure, using a chisel plow with sweeps, and at a depth of 8-12 cm, on June 16, 2014, and May 22, 2016. This tillage happened in conjunction with the second tillage pass in the typical wheat-fallow rotation.

2.4 | Measurements

Wheat yield was determined at crop maturity, on July 10, 2015, and July 26, 2017, by harvesting a 3.05 m swath from the center of each plot using a plot combine and weighing the harvested grain using an electronic balance. Grain moisture was determined using the HarvestMaster GrainGauge H2. Test weight was determined by cleaning grain samples from each plot, and measuring test weight using AACCI method 55-10.01. Protein was determined by using a near infrared spectrometer (Bran+Luebbe InfraAlyzer 2000), calibrated for winter wheat flour using AACCI Method 39.11.01. Dough quality was determined using a 2-gram mixograph (National Manufacturing Division of TMCO, Lincoln, NE) according to AACCI Method 54-40.02 (AACC International).

Soil samples were taken in the spring of the crop years, on April 23, 2015, and May 2, 2017. Five subsample soil cores were taken at depths of 0-10 cm, and 0-30 cm, and combined into one representative soil sample per depth. In addition, in 2017, samples were taken at depths of 30-60 cm and 60-90 cm. Soil properties were measured using approved soil reference methods for the western region (Gavlak 2005). Soil ammonium and nitrate were extracted immediately after sampling using 1 M KCl (1:5 of soil:solution by mass). Soil ammonium and nitrate were then measured using a flow injection analyzer (QuikChem 8500, methods 12-107-06-1-A, 12-107-04-1-J Lachat Instrument, Loveland CO). Extractable P and K were measured using the Olsen method (Method S4.10); soil pH and EC using the DI water ratio method (Method S2.20 and Method S2.30). The DTPA extraction method was used to measure Fe, Zn, Cu, and Mn (Method S6.10). Gravimetric soil moisture content at the 0-10 cm and 0-30 cm depths in 2015 and all depths in 2017, was determined by measuring the weight lost after drying samples (105°C for 24 h). In addition, in 2015 from April 09 to May 21, a 503 DR Hydroprobe Neutron Scattering Device (CPN International, Concord CA) was used every two weeks to measure soil moisture on all the 0 and 77 Mg ha^{-1} plots at depths of 30 cm, 60 cm, 120 cm, 150 cm, and 180 cm. To facilitate soil moisture measurement at depth aluminum access tubes were placed in the soil using a Giddings probe. The tubes contained collapsible sleaves that could be raised and lowered to a depth of 30cm to enable tillage operations. Total N was measured by combustion (Skalar Primacs^{TN} analyzer, Skalar, Inc., Breda, The Netherlands); total and inorganic C were measured on a multi-carbon Skalar Primacs^{SLC} analyzer (Skalar, Inc., Breda, The Netherlands) and organic C determined by the difference as described in the operating manual.

Readily mineralizable carbon (RMC), basal microbial respiration (BR) and active microbial biomass by substrate-induced respiration (SIR) were measured using the Anderson and Domsch (1978) method, by bringing ten grams of wet weight soil to 22% moisture content (-0.033 Mpa). The soil was then incubated for 14 days at 24°C and total CO_2 measured indicating RMC microbial biomass. The vials were recapped for 2 hours and the hourly CO_2 rate was measured indicating BR microbial biomass. Afterwards, 0.5 mL of 60 g L^{-1} aqueous solution of glucose was added to the vials and rested for 1 hour, before being recapped for 2 hours. Finally, CO_2 was measured in the headspace using an infrared gas analyzer (model 6251, LICOR Biosciences, Lincoln, NE), indicating SIR microbial biomass (Reeve et al. 2012).

Dehydrogenase enzyme activity was measured by taking a 2.5 g soil sample (Tabatabai, 1994) and adding DI water to achieve a 22% moisture soil solution by weight. Samples were then incubated overnight at 25° C. The following day, a solution of 0.5 ml of 3% triphenyl tetrazolium chloride (TTC) and 1.0 ml 2% $CaCO_3$ was added to each sample and incubated at 37° C for 24 hours. After 24 h, 10 ml methanol was used to extract the resulting triphenylformazan (TPF), which was measured at 490 nm using a microplate reader (Spectramax M2, Molecular Devices, Sunnyvale, CA). Finally, µg TPF

g^{-1} dry weight soil was determined by subtracting control readings from each sample and comparing to the standard curve. Acid and alkaline phosphatase enzyme were measured using a 1 g soil sample (Tabatabai, 1994), and adding 4.0 ml of modified universal buffer (MUB) at a pH of 6.5 for acid phosphatase and 11 for alkaline phosphatase, and 1.0 ml disodium p-nitrophenyl hexahydrate solution. Control samples were included to account for color exuded by humic materials, and MUB was not added to these tubes. The samples were then incubated for one hour at 37° C, then 1.0 ml 0.5 M $CaCl_2$ and 4.0 ml 0.5 NaOH was added to the samples and controls. In addition, p-nitrophenyl phosphate was added to the control tubes only. All samples and controls were then placed in a centrifuge at 4,000 rpm for 5 minutes, and measured at 405 nm using a microplate reader (Spectramax M2, Molecular Devices, Sunnyvale, CA). The µg p-nitrophenol g-1 dry weight soil was determined by subtracting control readings and comparing to a standard curve.

2.5 | Statistical Analysis

The results were analyzed in SAS Studio University Edition/ SAS 14.2 (SAS Institute, Cary, NC), using a mixed model following the PROC GLIMMIX procedure. All data was analyzed by year, after year was determined to be significant due to significant weather variations. Compost treatment and cover crop treatment were set as fixed factors and farm site was set as a random factor. Means separations were conducted using the least significant difference method (LSD) with the significance level set at alpha = 0.10.

3 | RESULTS AND DISCUSSION

3.1 | Growing Conditions

The August of 2014 was unusually wet (Table 1) and led all three of our farmer cooperators to plant winter wheat abnormally early (from Aug 6- Aug 29). This early planting resulted in above average fall wheat growth. Following this early planting the winter of 2014-2015 was abnormally dry (Table 2). No snow cover was present and wheat seedlings were left in relatively dry ground. These conditions resulted in spotty stands due to winter kill and cold related plant desiccation. In addition, possibly due to the weakened stand and early planting, an outbreak of Russian wheat aphid further stunted the crop. The crop matured earlier than normal in the spring, and by the time rain arrived in May, the crop was too far behind to catch up and extremely low yields were harvested in 2015.

In the 2016-2017 crop year, wet conditions coincided perfectly with the optimum planting window and wheat was planted into ideal soil moisture on September 15. Snow cover protected the crop over the winter and a wet spring led to a bumper harvest in 2017.

3.2 | Agronomic Effects

Both compost amendment and cover crop significantly affected yield in 2015, however the cover crop x compost interaction was not significant (Table 4). In 2015, wheat yield showed an upward trend with increasing compost rate. The highest rate of compost (50 Mg ha^{-1}) increased yield in 2015 by 127% over the control. This result is consistent with Stukenholtz et al. (2002), who showed similar yield increases relative to the control, the first year after application of 50 Mg ha^{-1} of compost in a nearby field. In

2017, the highest compost rate increased yield by only 17% and was not statistically significant. The oat-pea cover crop treatment significantly reduced yield in 2015, but had no effect on yield in 2017 (Figure 1).

These findings suggest that the efficacy of cover cropping and compost treatments may be conditional on rainfall and other weather conditions that vary from year to year. In an extremely dry year such as 2015, cover crops may increase transpiration as shown in previous studies (Unger et al. 1998). This increase in transpiration may be detrimental to grain yield. Nielsen et al. (1996) showed that as annual precipitation decreased, wheat yields following cover crops also decreased. Soil moisture measurements in this study, however, were unable to detect decreased stored soil moisture in cover crop treatments (Table 13). This was likely due to the presence of a cemented caliche layer 0.5 – 1 m below the soil surface which was fractured during installation of the soil moisture access tubes leading to preferenial flow.

In 2016, weeds were not controlled in the fallow plots in order to measure the amount of weed suppression relative to untilled fallow. In 2017, no significant yield differences were observed between cover crop treatments. This may have indicated that in 2017 adequate precipitation was recieved to replenish stored soil moisture following the growth of the cover crop, as found by Unger et al. (1998). Contrarily, since fallow plots contained significant weed biomass in 2016 (Figure 3), this effect could also be attributed to equal transpiration by weeds in the fallow treatments and cover crops in the cover crop treatments. Therefore, furthur reaserch would be needed to understand the relationship between precipitation and yield of a grain crop following a cover crop in this region.

Grain test weight and protein did not show any significant differences from the main effects of compost and cover crops or the compost x cover crop interaction (Table 4). Similarly, Miller et al. (2011) found that spring planted pea green manure did not significantly affect protein or yield of the subsequent organic wheat crop, however, fall planted pea increased both wheat yield and protein in fields with similar precipitation, indicating fall planted covers may be an area for future study for this region.

Test weight was unaffected by any treatment. Mixograph baking quality results were slightly affected in 2015, with somewhat lower baking quality on the higher compost rates, although there were no statistically significant differences between the lowest and highest compost treatments (Table 4,5). The differences in mixograph results were unlikely to translate into real differences in baking quality caused by cover crop and compost treatments.

3.4 | Cover Crop Biomass

Both cover crop mixes were successfully established, however neither cover crop was completely canopied at the time of termination (Figure 3). In 2014, cover crop type had no effect on total biomass. Cover crop type significantly affected cover crop biomass in 2016 (Table 4), with the oat-pea treatment having approximately 51% higher biomass than the vetch-pea treatment. In addition to increased biomass, the oat-pea cover crop significantly reduced weed biomass relative to untilled fallow in 2016. The vetch-pea cover crop also reduced weed biomass relative to untilled fallow, however this result was not significant (Figure 3). Similarly, Carr, et al. (2012) found that cover crop mixes containing hairy vetch plus winter wheat or winter rye suppressed weeds significantly more than hairy vetch alone.

Because compost was only applied after cover crops were terminated in 2014, due to persistent windy conditions which led to challenges in scheduling the operator, there is only one year of data (2016) measuring the effect of compost on cover crop biomass. In 2016, compost treatments had a significant effect on cover crop biomass (Table 4), showing an upward trend in biomass as the compost rate increased. The highest compost rate (50 Mg ha^{-1}) increased cover crop biomass by 126% over the control. Although compost positively increased the cover crop biomass, it also negatively affected the composition of the cover crop stand by increasing the percentage of weeds and volunteer wheat present (Figure 4). At the 0 Mg ha^{-1} rate weeds and volunteer wheat represented 16% and 26% of the total biomass, however at the 50 Mg ha^{-1} compost rate, weeds and volunteer wheat represented 42% and 17% of the total biomass (Figure 5). Increased weeds and volunteer wheat in a cover may not be an issue for some producers, as when the goal of the cover crop is to increase soil organic matter by incorporating as much organic carbon as possible, because the cover crop will likely be terminated before seed set. However, if nitrogen fixation with the least amount of water usage is the goal, these higher populations of weeds and volunteer wheat would likely decrease the likelihood of the cover crop resulting in a profitable outcome for the producer.

3.5 | Soil Effects

Soil nitrate and total N were increased significantly in the compost treatments in 2015, and total N was significantly greater in 2017 (Figure 6). The highest compost rate increased soil nitrate 82% over the control in 2015, showing an upward trend. In 2017, at the highest compost rate, soil total N showed an increase of 23% over the control. Nitrogen is typically thought of as a relatively short-lived nutrient within the soil due to its high mobility within the soil profile and propensity to leaching. In this study increased levels of total soil N were seen three years after comopost application, perhaps indicating that in a semi arid environment, addition of compost may provide longer term soil nitrogen benefits than one year only. In addition, in 2015, the vetch-pea cover crop mix had significantly more soil nitrate than the oat-pea cover crop, though not significantly more than fallow. However, in 2017, the vetch-pea cover crop treatments did have significantly higher soil total N than the fallow treatments. These findings indicate that if nitrogen fixation is the goal, a cover crop mix containing only legumes will likely outperform a mix of legumes and cereal grains.

The cover crop x compost interaction was also significant for soil nitrate in 2017 only (Table 7). In 2017 compost amendment increased soil nitrate more in the vetch-pea treatment than in the other two treatments (Table 9). This may be due to increased soil fertility from the compost amendment allowing the vetch-pea cover crop mix to fix more atmospheric nitrogen than the oat-pea or fallow treatments. In 2014, compost was not applied until after cover crop termination, making it unlikely that an interaction would be observed. Further research would be needed to reinforce this claim, since the result was observed in one year only, and soil total N and NH_4 did not follow a similar trend.

As shown in previous studies (Reeve et al. 2012), soil P was shown to increase significantly with compost addition (Figure 7). Soil P levels were increased from very low, 6.02 ppm in 2015, and 5.55 in 2017 to sufficient, 18.9 ppm in 2015, and 15.0 ppm in

2017 (James et al. 1993). This may be of especially beneficial to growers in calcareous soils as Braschi et al. (2003), demonstrated that the slow mineralization of compost in calcareous soils increased plant uptake of P. It was also shown that elevated soil P levels were still significant both 1 and 3 years after compost application, reinforcing the findings of Reeve et al. (2012) which demonstrated that compost addition can have a long-lived effect on phosphorus availability in this region.

Similar to P, K was shown to be significantly increased by the addition of compost (Figure 7). However, unlike P, soil levels of K were extremely high even for the control treatments, indicating that although compost increased K significantly, it may not translate to crop benefits, as N and P will likely be the limiting factor nutritionally.

In 2015 iron and manganese were significantly increased due to compost amendment (Table 7, 10). DTPA iron increased modestly from 4.4 mg kg^{-1} at the 0-compost rate, up to 4.99 mg kg^{-1} at the highest rate. DTPA Manganese increased significantly from 6.91 mg kg^{-1} to 8.66 mg kg^{-1} at the highest rate. These results however, were not seen in 2017, indicating that compost amendment did not offer long term increases in soil micronutrients in this study.

In addition, soil organic carbon increased significantly due to compost amendment (Table 7). In 2015 soil organic carbon at the high compost rate was increased 21 % from the 0 rate, from 1.14 % to 1.38 % (Figure 8). In 2017, soil organic carbon showed an increase of 29 % from 1.25 % to 1.62 %. Dissolved organic carbon (DOC) also showed significant increases in both years. Increases in DOC however, were only apparent in the top 30 cm of soil, with 30-60 cm and 60-90 cm showing no significant difference (Table 8).

Compost amendment may be a viable option for dryland organic producers to rapidly increase soil organic carbon, even in the presence of a fallow year using mechanical tillage, thereby decreasing the negative effects caused by mechanical tillage (Sainju et al. 2006). Stukenholtz et al. (2002) showed that addition of compost provided increases to yield over and above the nutrient benefit alone. A host of soil health benefits have been shown due to small increases in organic matter, including increased water holding capacity and increased soil microbial biomass (Blanco et al. 2013). In this study significant differences in organic carbon were shown, however yield benefits were limited to the 2015 harvest, a dry year, with no significant differences in yield in 2017, a wet year. This supports the findings reported by Stukenholtz et al. (2002) that yield responses to compost are more pronounced in dry years, likely due to infiltration and moisture holding benefits provided by the increased soil organic matter. Increased soil organic carbon over time may indicate that although a yield carryover effect was not seen in 2017, increased organic carbon may benefit subsequent crop years in addition to the year of application.

Compost amendment had only a slight effect on soil pH in 2015, which was higher at the 0 compost rate than any of the other rates (Table 10). EC was significanly affected in 2015 as well, with increases from 311 µs cm^{-1} to 426 µs cm^{-1} at the highest compost level. In 2017 no significant differences were seen. Similarly Reeve et al. (2012), found that 50 Mg ha^{-1} of compost had no effect on soil pH and EC 16 years after application.

Soil microbial activity as measured by dehydrogenase, acid and alkaline phosphatase, and SIR, RMC, and BR, soil respiration all increased significantly but only in the 2017 harvest year, due to compost amendment (Table 11). No significant differences were observed in 2015. Enhanced soil enzyme and microbial biomass and activity are associated with increased nutrient cycling as well as non-nutritive effects such as soil aggregation (Flieβbach & Mäder, 2000).

3.6 | Soil Moisture

No differences in soil moisture were measured at any depth in either year with one exception (Table 13). The April 23, 2015, 0-10 cm depth sample showed a slight, but significant moisture increase in the cover crop treatments than in fallow, however all treatments were extremely dry (8-9% water by mass) at this sampling, and all subsequent samples in 2015 and 2017 showed no difference between treatments. Unger et al. (1998) showed that cover crops can have either a positive, negative, or neutral effect on soil moisture, it was shown that a neutral soil moisture condition can occur when sufficient rain is received after a cover crop is grown in order to replenish soil moisture resurves. This may have been the case during the measurement period in 2015 and 2017. In 2015 yields were much below average due to drought conditions in the spring prior to May, however much higher than average precipitation was received in August and Sepember of the previous year, after the cover crop was terminated but while the winter wheat crop was in a growth stage that didn't require much water for transpiration. In 2017, adequate rainfall throughout the growing season provided higher than average yields and could have offset water used by the cover crop. It is also possible that the presence of a cemented layer which we had to drill through in order to install the soil moisture accesss tubes may have caused areas of preferential flow and reducing the reliability of our readings.

4 | CONCLUSIONS

Organic wheat grown on dryland acreage plays a significant role in the organic grain and flour market in the United States. Producers, however, struggle to maintain adequate soil fertility, due to the high cost of organic soil amendments. Low soil fertility results in decreased yields compared to conventional growers, and a high amount of weather dependent variability in both yield and quality.

Cover crops are perceived as an option for improving soil organic matter and available nitrogen. In this study no cover crops had any effect on soil carbon, however the spring planted vetch-pea cover crop mix was found to increase total soil N over fallow in one year of the two harvest years observed. The oat-pea cover crop mix either decreased or had no effect on soil N depending on the year. For producers for which compost is unavailable, growing a legume-only cover crop may be the only viable source of N available, and was shown to be effective in at least some growing years. In 2015, a very dry year, the oat-pea cover crop treatment significantly decreased grain yield, the vetch-pea cover crop mix also decreased yield slightly, though this was not statistically significant. Neither cover crop had any effect on grain yield in 2017, a wet year. If adequate precipitation was present, growers could increase soil N without any wheat yield decrease, which may eventually translate into yield or protein increases. However, in a dry year, cover crops, specifically those containing cereal grains, may significantly reduce the wheat yield of the successive grain crop, without contributing to soil N.

Amending the soil with compost is another option for organic producers, and was found to significantly increase soil macronutrients N, P, and K. Compost amendment also increased soil organic carbon, without increasing EC or pH over the long-term. Additionally, these and other improvements to the soil caused a more than double yield increase in the case of the 50 Mg ha^{-1} treatment in 2015. However, the yield was increased by only 17% in 2017, an amount not statistically significant. This indicates that the grain yield benefits shown in this and other studies may be dependent on other factors such as the weather and rainfall patterns of a particular year.

Although significant increases in yield were not observed in both crop years, soil health benefits were observed in both years which supports findings of other studies documenting the long-lasting compost carryover effect, or instances where the soil health benefits of a one-time addition of compost last for multiple years. Producers may be willing to bear the upfront costs of compost amendments, with the assumption that the long-lasting soil health benefits will eventually translate into increased grain yields and quality on a year when the prerequisite conditions are present.

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TABLES

TABLE 1 Total monthly precipitation amounts for Snowville, UT, for the crop years 2013-2017 with the long-term monthly average for precipitation.

	Precipitation †				
Month	**2013-2014**	**2014-2015**	**2015-2016**	**2016-2017**	**10 Yr. Mean ('08-'17)**
	------------------------------------- mm--				
July	8.9	6.6	31.7	0	7.8
August	0.2	88.6	9.5	0.2	16.5
September	27.9	54.4	41.5	63.3	27.7
October	10.2	0.4	37.2	56.4	27.5
November	12.8	17.6	12.2	18.3	18.4
December	29.8	27.8	34.4	70	36.9
January	18.7	19.3	42.7	98.8	40.1
February	34.3	6.5	11.5	79.3	31.0
March	65.2	12	56.6	41.2	35.0
April	41.6	19.6	49.4	63.7	36.6
May	24.7	113.3	48.7	21	47.3
June	7.2	5.8	6.8	7.1	16.5
Annual	281.5	371.9	382.2	519.3	341.37

† Weather Data was obtained from the nearest Utah Climate Center weather station equipped to measure both rain and snow. Station Name: Brigham City 28 WNW, Location: 41.6163', -112.5437', Promontory UT

TABLE 2 Average monthly temperature for Snowville, UT, for the crop years 2013-2017 with the long-term monthly average temperature.

	Temperature †				
Month	**2013-2014**	**2014-2015**	**2015-2016**	**2016-2017**	**10 Yr Mean ('08-'17)**
	---°C---				
July	24.7	24.5	21.2	23.5	23.37
August	23.3	20.1	21.8	21.7	21.94
September	16.4	17.5	17.7	15.2	16.66
October	6.9	10.4	12.1	10.2	8.91
November	2.7	1.4	0.3	4.3	2.19
December	-7.5	0	-4.1	-5.2	-4.25
January	-4.3	-1.3	-5.1	-7.8	5.50
February	0.5	3.1	-1.2	-0.8	-1.85
March	4.1	6	4.8	6	3.68
April	7.2	8	9.2	6.4	6.72
May	13.6	12.4	11.9	12.5	11.78
June	17.6	21.6	20.6	19.5	18.27
Annual	8.8	10.3	9.1	8.8	8.49

† Weather Data was obtained from the nearest Utah Climate Center weather station equipped to measure both rain and snow. Station Name: Brigham City 28 WNW, Location: 41.6163', -112.5437', Promontory UT

TABLE 3 Soil Classification and cation exchange capacity on dryland organic wheat farms near Snowville, UT in 2015, 0-30 cm depth.

Site	CEC	Sand	Silt	Clay	Soil Classification
	--- cmol kg^{-1}---	----%----	----%----	----%----	
Farm 1	25.5	16.8	54.8	28.4	Silty Clay Loam
Farm 2	21.4	33.3	45.1	53.3	Loam
Farm 3	25.5	25.5	53.3	21.2	Silt Loam

TABLE 4 Significance of F values for wheat yield and wheat grain quality parameters on dryland organic wheat farms near Snowville, UT in 2015 and 2017.

	2015			2017		
Dependent Variable	**Cover Crop**	**Compost**	**Cover Crop x Compost**	**Cover Crop**	**Compost**	**Cover Crop x Compost**
	--------------------	--------------------	--------- **P > F**	---------	--------------------	--------------------
Yield	**0.0013**	**0.0236**	0.8983	0.6740	0.3504	0.5842
Test Weight	0.8833	0.2810	0.7022	0.1222	0.1419	0.8966
Protein	0.1654	0.4220	0.9296	0.2714	0.2488	0.9493
Envelope peak width	0.5150	**0.0922**	0.6879	0.1864	0.8309	0.5817
Envelope tail width	0.5861	0.2429	0.4823	0.7474	0.3155	0.5647
Mid-line left slope	0.7785	**0.0128**	0.9056	0.3602	0.9706	0.6493
Mid line peak time	0.1475	0.4127	0.7535	0.5952	0.3512	0.3905
Mid line peak value	0.9408	**0.0138**	0.2402	0.1913	0.3578	0.9564
Mid line right slope	0.3042	**0.0209**	0.3658	0.2118	**0.0580**	0.6168

TABLE 5 Effect and significance of compost on mixograph bake quality parameters on dryland organic wheat farms near Snowville, UT in 2015. Means ($n = 9$) designated by different letters are significant within year at $p < 0.10$.

	2015			
Compost	**Envelope Peak Width**	**Mid-Line Left Slope**	**Mid-Line Peak Value**	**Mid-Line Right Slope**
------ Mg ha^{-1} ------	**------ % ------**	**----- % min.$^{-1}$ -----**	**------ % ------**	**----- % min.$^{-1}$ -----**
0	26.79 B	13.37 A	52.28 A	-6.80 A
12.5	27.09 B	20.35 B	55.64 B	-9.03 B
25	24.88 A	15.91 A	49.92 A	-6.49 A
50	21.98 A	10.31 A	45.19 A	-6.59 A

TABLE 6 Significance of F values for cover crop biomass and weed biomass on dryland organic wheat farms near Snowville, UT in 2014 and 2016.

Dependent Variable	2014			2016		
	Cover Crop	**Compost †**	**Cover Crop x Compost**	**Cover Crop**	**Compost †**	**Cover Crop x Compost**
			P > F			
Cover Crop Biomass	0.8649	-	-	**<0.0001**	**0.0002**	0.1137
Weed Biomass ‡	0.1134	-	-	**0.0257**	**0.0036**	0.2894
Volunteer Wheat Biomass				**0.0981**	0.1052	0.5417

† Compost was not applied until after the cover crops were terminated in 2014

‡ Fallow treatments were not included in the analysis in 2014 because weeds were controlled by cultivation in those plots that year.

TABLE 7 Significance of F values for soil quality parameters on dryland organic wheat farms near Snowville, UT in 2015 and 2017.

		2015			2017		
Dependent Variable	**Sample Depth**	**Cover Crop**	**Compost**	**Cover Crop x Compost**	**Cover Crop**	**Compost**	**Cover Crop x Compost**
		------ P > F ------					
NH_4	0-30 cm	0.1936	0.2804	0.8772	0.9306	0.3469	0.6235
NO_3	0-30 cm	0.2171	**0.0309**	0.5717	0.9110	**0.0539**	**0.0043**
Total Nitrogen	0-30 cm	0.1764	**0.0725**	0.9353	**0.0367**	**<0.0001**	**0.0880**
Olsen P	0-30 cm	0.5691	**<0.0001**	0.7229	0.9398	**<0.0001**	0.7086
Olsen K	0-30 cm	0.4397	**0.0055**	0.9128	0.9688	**0.0028**	0.9647
DTPA - Zinc	0-30 cm	0.7733	0.4387	0.3957	0.4984	0.1691	0.9634
DTPA - Iron	0-30 cm	0.6192	**0.0370**	0.4148	0.8474	0.3040	0.9743
DTPA - Copper	0-30 cm	0.3828	0.1994	0.4033	0.5681	0.3681	0.8431
DTPA - Manganese	0-30 cm	0.9526	**0.0023**	0.8368	0.7303	0.3284	0.6182
EC	0-30 cm	0.3953	**0.0544**	0.8056	0.3982	0.4456	0.9008
pH	0-30 cm	0.7881	**0.0075**	0.9602	0.5631	0.1237	0.5577
Dehydrogenase	0-10 cm	**0.0560**	0.2268	0.4702	0.2463	**0.0009**	0.7425
Respiration -SIR	0-10 cm	0.5907	0.1225	0.2170	0.5607	**0.0083**	0.8657
Respiration - RMC	0-10 cm	0.5139	0.4683	0.5361	0.9736	**0.0045**	0.4874
Respiration - BR	0-10 cm	0.5006	0.5470	0.4668	0.7857	**0.0099**	0.2782
Phosphatase Acid	0-10 cm	0.1716	0.3650	0.4482	0.3157	**0.0079**	0.1354
Phosphatase Alkaline	0-10 cm	0.6721	0.6813	0.3639	**0.0621**	**0.0540**	0.9034
TOC	0-30 cm	0.6964	**0.0008**	0.8931	0.1880	**0.0002**	0.1392
DOC	0-30 cm	0.6296	**0.0579**	0.998	0.4001	**0.0054**	0.4724
Aggregate Stability	0-10 cm	**0.0432**	0.9959	0.3593	**0.0242**	0.1472	**0.0055**

TABLE 8 Significance of F values for soil quality parameters on dryland organic wheat farms near Snowville, UT in 2017.

Dependent Variable	Sample Depth	Cover Crop	Compost	Cover Crop x Compost
		----------	P > F	----------
NH_4 †	0-30 cm	0.9306	0.3469	0.6235
NH_4	30-60 cm	0.4831	0.2219	0.3637
NH_4	60-90 cm	0.5749	0.6304	0.4658
NO_3 †	0-30 cm	0.9110	**0.0539**	**0.0043**
NO_3	30-60 cm	0.4866	0.8963	0.7038
NO_3	60-90 cm	0.1185	**0.0497**	0.6731
DOC †	0-30 cm	0.4001	**0.0054**	0.4724
DOC	30-60 cm	0.0311	0.9236	0.9944
DOC	60-90 cm	0.1539	0.9836	0.5990

† The 0-30 cm depth values were reported earlier in Table 14.

TABLE 9 Interaction effect and significance compost and cover crop on soil nitrate and total nitrogen at 0-30 cm depth on dryland organic wheat farms near Snowville, UT in 2017. Means (n = 3) designated by different letters are significant within year at $p < 0.10$.

	Fallow	
Compost	**NO_3**	**Total Nitrogen**
------ Mg ha^{-1} ------	**------ mg Kg^{-1} ------**	**------ % ------**
0	3.12 B	0.138 B
12.5	1.38 A	0.148 B
25	1.41 A	0.143 B
50	1.65 AB	0.165 A
	Oat-pea Cover Crop Mix	
Compost	**NO_3**	**Total Nitrogen**
------ Mg ha^{-1} ------	**------ mg Kg^{-1} ------**	**------ % ------**
0	3.08 C	0.132 C
12.5	1.22 B	0.148 B
25	1.77 B	0.164 A
50	0.83 A	0.168 A
	Vetch-pea Cover Crop Mix	
Compost	**NO_3**	**Total Nitrogen**
------ Mg ha^{-1} ------	**------ mg Kg^{-1} ------**	**------ % ------**
0	1.75 B	0.143 B
12.5	1.62 B	0.168 A
25	1.15 B	0.151 B
50	3.60 A	0.175 A

TABLE 10 Effect and significance of compost on pH, electrical conductivity, DTPA iron, and DTPA Manganese at 0-30 cm depth, on dryland organic wheat farms near Snowville, UT in 2015. Means (n = 9) designated by different letters are significant within year at $p < 0.10$.

	2015			
Compost	**pH**	**EC**	**Fe**	**Mg**
Sample Depth	**0-30 cm**	**0-30 cm**	**0-30 cm**	**0-30 cm**
--- Mg ha^{-1} --	**-----**	**-- µs cm^{-1}--**	**-- mg kg^{-1}--**	**-- mg kg^{-1}--**
0	8.66 A	311 B	4.40 B	6.91 C
12.5	8.47 B	370 AB	4.64 AB	7.95 B
25	8.50 B	466 A	4.92 A	8.24 AB
50	8.49 B	426 A	4.99 A	8.66 A

TABLE 11 Effect and significance of compost on soil the microbiology parameters of dehydrogenase, phosphatase acid, phosphatase alkaline, respiration SIR, respiration RMC, and respiration BR, at 0-10 cm depth, on dryland organic wheat farms near Snowville, UT in 2017. Means (n = 9) designated by different letters are significant within year at p < 0.10.

	2017					
Compost	**Dehydrogenase**	**Phosphatase Acid**	**Phosphatase Alkaline**	**Respiration - SIR**	**Respiration - RMC**	**Respiration - BR**
Sample Depth	**0-10 cm**	**0-10 cm**	**0-10 cm**	**0-10 cm**	**0-10 cm**	**0-10 cm**
---- Mg ha^{-1} ---	**- mg TPF g^{-1} soil - hr^{-1}**	**- µg p-nitrophenol - g^{-1} soil**	**- µg p-nitrophenol g^{-1} soil -**	**- Mg Cmic g^{-1}- soil**	**- µg C g^{-1} soil - hr^{-1}**	**- µg C g^{-1} soil - hr^{-1}**
0	4.84 B	41.0 B	248 B	707 C	27.0 C	8.21 C
12.5	5.58 A	49.0 B	308 A	777 BC	31.2 B	9.57 BC
25	6.02 A	48.2 B	257 AB	809 B	35.4 A	9.80 AB
50	5.97 A	60.8 A	244 B	922 A	35.2 A	11.3 A

TABLE 12 Effect and significance of cover crop on soil aggregate stability, dehydrogenase, and phosphatase alkaline at 0-30 cm depth, on dryland organic wheat farms near Snowville, UT in 2015 and 2017. Means (n = 12) designated by different letters are significant within year at $p < 0.10$.

	2015		**2017**	
Cover Crop	**Aggregate Stability**	**Dehydrogenase**	**Aggregate Stability**	**Phosphatase Alkaline**
Sample Depth	**0-10 cm**	**0-10 cm**	**0-10 cm**	**0-10 cm**
	------- % -------	**---- mg TPF g^{-1} soil hr^{-1} ----**	**------- % -------**	**µg p-nitrophenol g^{-1} soil**
Oat-pea	56.9 B	4.96 B	44.4 B	256 B
Vetch-pea	58.3 B	4.83 B	54.8 A	294 A
Fallow	61.6 A	5.65 A	52.2 A	244 B

TABLE 13 Significance of F values for soil moisture on dryland organic wheat farms near Snowville, UT in 2015 and 2017.

Dependent Variable	Sample Date	Sample Depth	Cover Crop	Compost	Cover Crop x Compost
			------------------	P > F	------------------
Soil Moisture	04/23/2015	0-10 cm	**0.0290**	0.9638	0.1722
Soil Moisture	04/23/2015	0-30 cm	0.2243	0.8305	0.7584
Neut. Probe Soil Moist.	04/09/2015	30 cm	0.3244	0.7775	0.9825
Neut. Probe Soil Moist.	04/09/2015	60 cm	0.6464	0.8915	0.6564
Neut. Probe Soil Moist.	04/09/2015	120 cm	0.9498	0.5686	0.6276
Neut. Probe Soil Moist.	04/09/2015	150cm	0.8857	0.5454	0.3205
Neut. Probe Soil Moist.	04/09/2015	180 cm	0.7079	0.2584	0.8306
Neut. Probe Soil Moist.	04/23/2015	30 cm	0.1315	0.8860	0.2484
Neut. Probe Soil Moist.	04/23/2015	60 cm	0.1503	0.9309	0.9893
Neut. Probe Soil Moist.	04/23/2015	120 cm	0.9461	0.7712	0.6511
Neut. Probe Soil Moist.	04/23/2015	150cm	0.9712	0.7060	0.2438
Neut. Probe Soil Moist.	04/23/2015	180 cm	0.5518	0.9217	0.8589
Neut. Probe Soil Moist.	05/07/2015	30 cm	0.2851	0.4106	0.3438
Neut. Probe Soil Moist.	05/07/2015	60 cm	0.4456	0.8332	0.8714
Neut. Probe Soil Moist.	05/07/2015	120 cm	0.6527	0.1759	0.5893
Neut. Probe Soil Moist.	05/07/2015	150cm	0.8963	0.9681	0.2120
Neut. Probe Soil Moist.	05/07/2015	180 cm	0.3631	0.7001	0.9547
Neut. Probe Soil Moist.	05/21/2015	30 cm	0.8607	0.5373	0.5292
Neut. Probe Soil Moist.	05/21/2015	60 cm	0.4257	0.5442	0.9055
Neut. Probe Soil Moist.	05/21/2015	120 cm	0.6159	0.4831	0.7710
Neut. Probe Soil Moist.	05/21/2015	150cm	0.9463	0.7241	0.4407
Neut. Probe Soil Moist.	05/21/2015	180 cm	0.4706	0.4882	0.6805
Soil Moisture	05/02/2017	0-10 cm	0.3072	0.1833	0.8466
Soil Moisture	05/02/2017	0-30 cm	0.8408	0.9511	0.8567
Soil Moisture	05/04/2017	30-60 cm	0.1262	0.1804	0.9276
Soil Moisture	05/04/2017	60-90 cm	0.9785	0.6061	0.9937
Soil Moisture	05/11/2017	0-30 cm	0.2233	0.2106	0.9620
Soil Moisture	05/26/2017	0-30 cm	0.3537	0.3560	0.4543

FIGURES

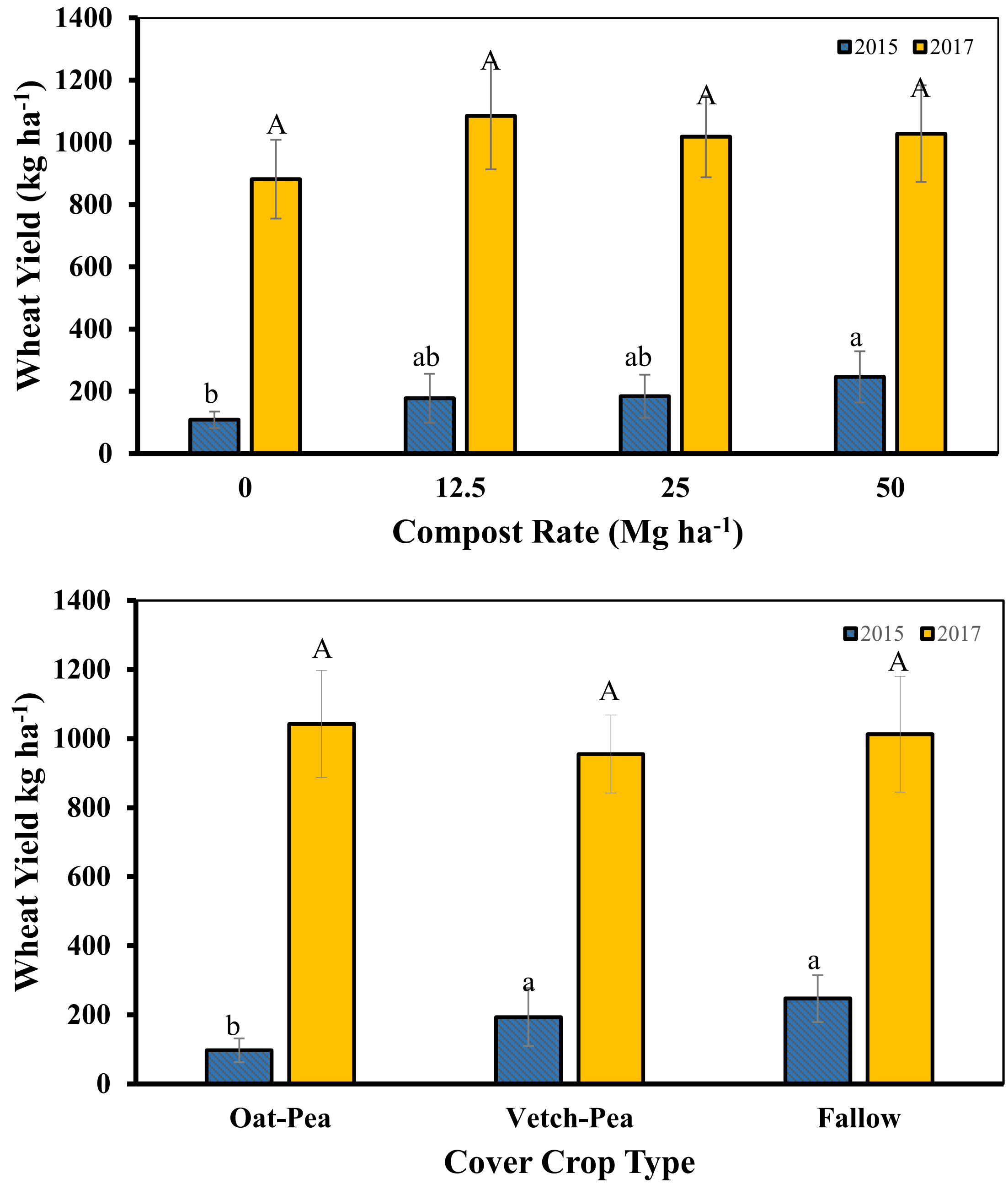

FIGURE 1 Effect and significance of compost and cover crop on wheat yield on dryland organic wheat farms near Snowville UT in 2015 and 2017. In 2015, the 50 Mg ha^{-1} compost treatment was significant vs. 0 Mg ha^{-1} treatment at $p = 0.02$. The fallow treatment was significant vs the oat-pea treatment at $p = 0.006$. The fallow Error bars indicate ± standard errors. Means ($n = 9$ top figure, $n = 12$ bottom figure) designated by different letters are significant within year at $p < 0.10$.

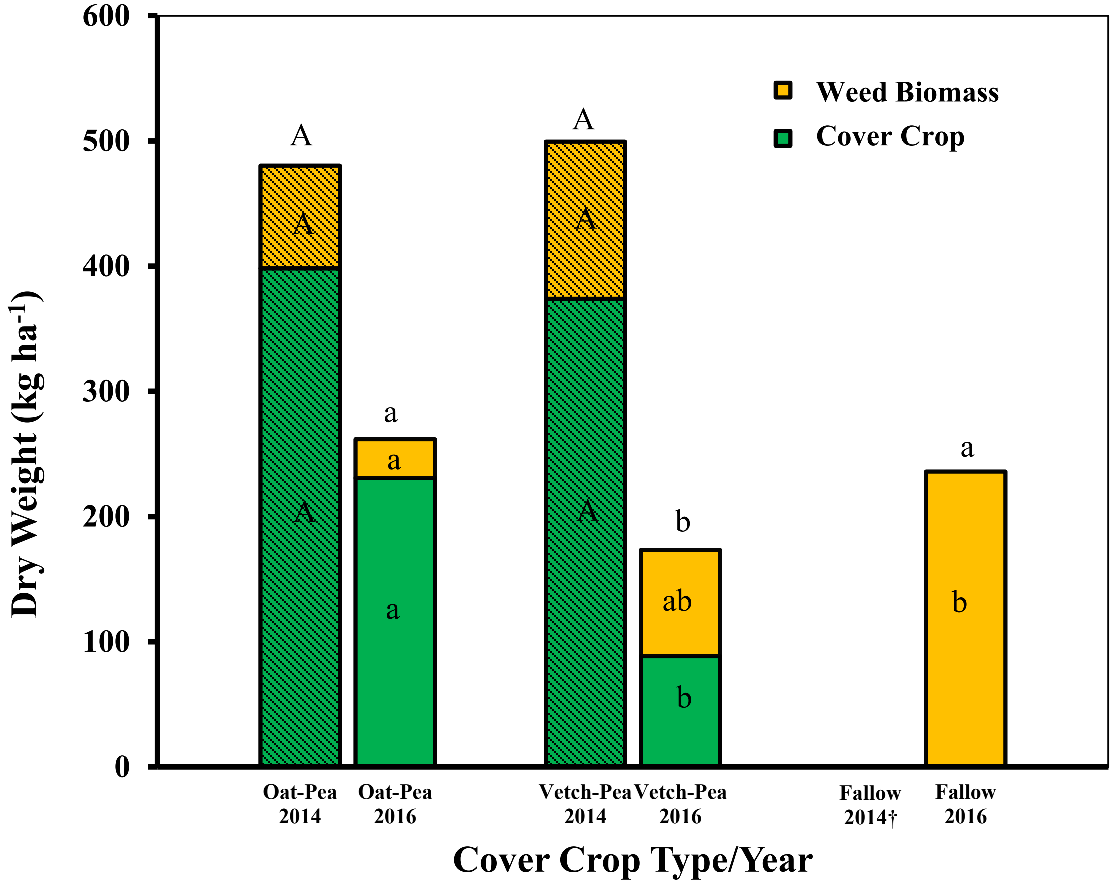

FIGURE 2 Effect and significance of cover crop type on total biomass, cover crop biomass and weed biomass at 0 Mg ha^{-1} rate, on dryland organic wheat farms near Snowville, UT in 2014 and 2016. Means (n = 3 in 2014, n = 12 in 2016) designated by different letters are significant within year at $p < 0.10$. The letters designate significant cover crop treatment differences for total cover crop biomass and each biomass component, comparing between similar components within year. Upper case letters indicate 2014 comparisons and lower case 2016 comparisons.

† Weeds were controlled in fallow plots by mechanical cultivation in 2014 only.

FIGURE 3 Cover Crops not completely canopied at time of termination on Farm 2, May 22, 2016.

FIGURE 4 Photographs of weeds present in 50 Mg ha^{-1} compost treatment on the right vs control on the left (top photo) and the 50 Mg ha^{-1} compost treatment in the rear vs control in the foreground (bottom photo), on Farm 1 at cover crop termination in 2016.

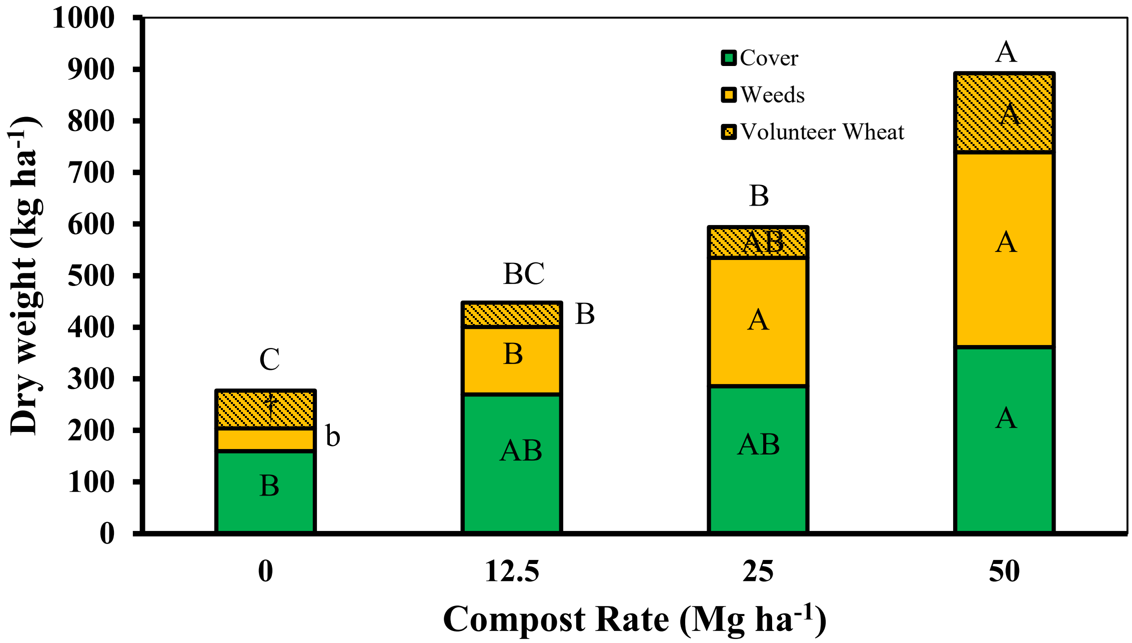

FIGURE 5 Effect and significance of compost on total biomass, weed biomass, volunteer wheat biomass, and cover crop biomass on dryland organic wheat farms near Snowville, UT in 2016. In 2015, total cover crop biomass at the 50 Mg ha^{-1} compost treatment was significant vs. 0 Mg ha^{-1} treatment at p = 0.0005. Means (n = 9) designated by different letters are significant within year at p < 0.10. The letters designate significant cover crop treatment differences for total cover crop biomass and each biomass component, comparing within each component.

† Not established, due to large variabilities in data at the 0 Mg ha^{-1}.

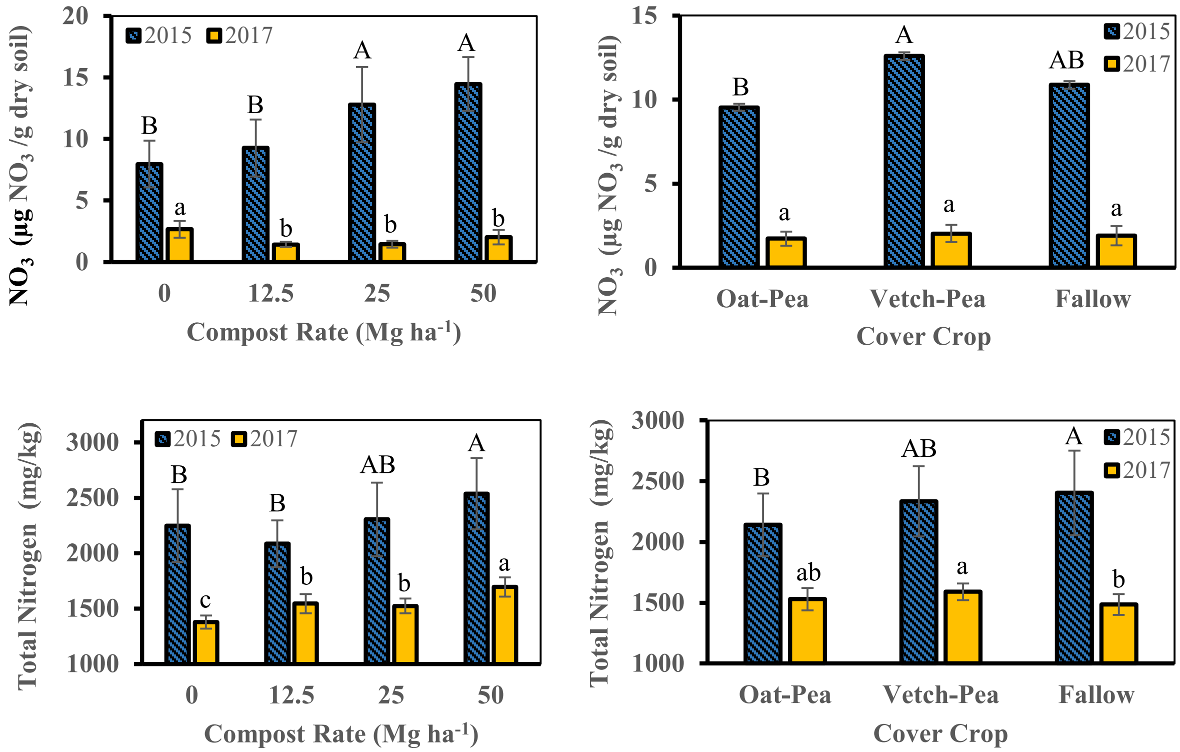

FIGURE 6 Effect and significance of compost and cover crop on soil nitrate and soil total nitrogen, at 0-30 cm depth on dryland organic wheat farms near Snowville, UT in 2015 and 2017. Error bars indicate ± standard errors. Means (n = 9 compost figures on left, n = 12 cover crop figures on right) designated by different letters are significant within year at $p < 0.10$.

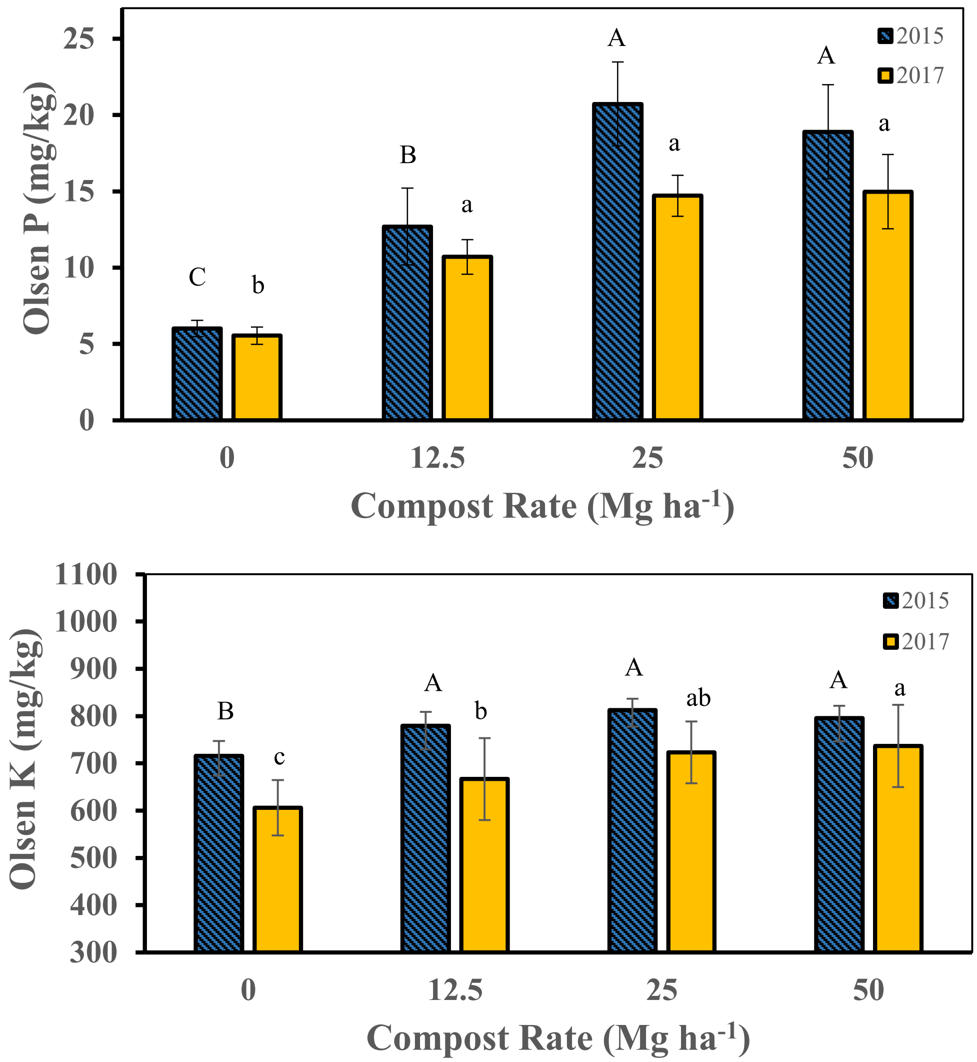

FIGURE 7 Effect and significance of compost on Olsen P and Olsen K, at 0-30 cm depth on dryland organic wheat farms near Snowville, UT in 2015 and 2017. The 50 Mg ha^{-1} compost treatment was significant vs. 0 Mg ha^{-1} treatment at $p < 0.0001$ for Olsen P and $p < 0.0005$ for Olsen K, both years. Error bars indicate ± standard errors. Means ($n = 9$) designated by different letters are significant within year at $p < 0.10$.

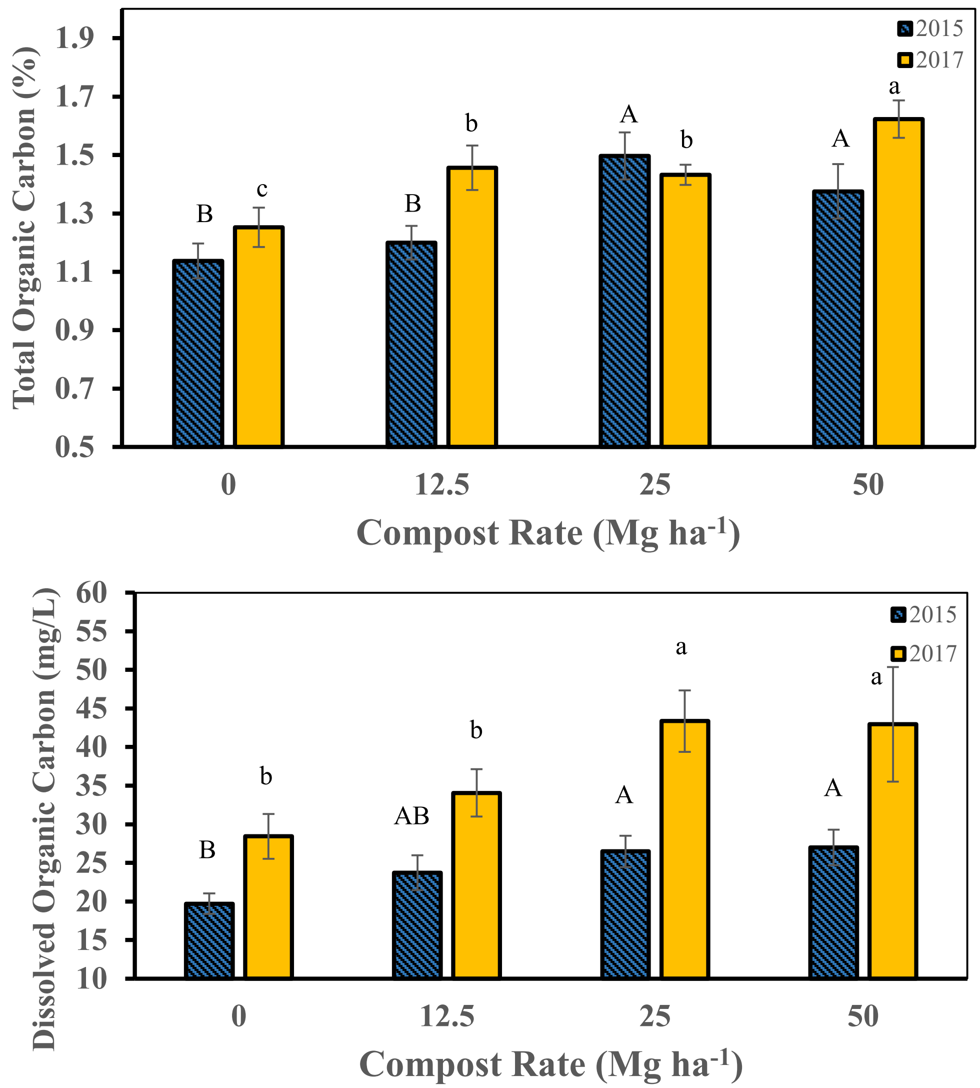

FIGURE 8 Effect and significance of compost on soil organic carbon and dissolved organic carbon, at 0-30 cm depth on dryland organic wheat farms near Snowville, UT in 2015 and 2017. The 50 Mg ha^{-1} compost treatment was significant vs. 0 Mg ha^{-1} treatment at $p < 0.02$ for total organic carbon and $p < 0.003$ for dissolved organic carbon, both years. Error bars indicate ± standard errors. Means ($n = 9$) designated by different letters are significant within year at $p < 0.10$.