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Assessment of Compost on Dryland Wheat Yield and Quality, Soil Fertility and Water Availability in Utah

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ASSESSMENT OF COMPOST ON DRYLAND WHEAT YIELD AND QUALITY,

SOIL FERTILITY AND WATER AVAILABILITY IN UTAH

by

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ABSTRACT

Assessment of Compost on Dryland Wheat Yield and Quality, Soil Fertility and Water Availability in Utah

by

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Utah has a semi-arid climate, which is characterized by low precipitation, and calcareous soils generally low in soil organic matter. Dryland winter wheat is widely grown, significant acreage of which is certified organic. In the growing season, limited water decreases nutrient availability to the root surface and topsoil. Yields are severely constrained by lack of precipitation, and many dryland organic wheat growers do not apply fertilizers due to an inability to recoup costs. Compost enhances long-term improvement in soil quality, soil fertility and increases yield in low input environments. Understanding of compost carryover effects in dryland wheat systems is necessary for improved yields and quality that will allow adequate supply of nutrients for several years after initial application. A previous study on Utah calcareous soil showed evidence of soil benefits twenty-two years after a single application at 50 Mg ha^{-1} dry weight. A new experiment was initiated at the Blue Creek farm in 2011 to test the reproducibility of these findings on a less marginal soil type. Compost was applied at 0, 12, 25, and 50 Mg ha^{-1} plus a conventional fertilizer control in a wheat fallow rotation. Both phases of the rotation were present each year with a total of six replicates. Wheat yield was significantly increased three years after application at the 50 Mg ha^{-1} compost rate only. Conventional fertilizer increased grain protein. Mineralizable carbon (C), microbial biomass and phosphatase enzyme activity increased significantly at all compost rates, while available soil P increased at the 25 and 50 Mg ha^{-1} rates and total soil N at the 50 Mg ha $rate^{-1}$. Subsoil moisture content increased linearly as moisture moved down the soil profile for both cropping seasons. Compost application rate of 50 Mg ha^{-1} had the highest amount of soil moisture. A lack of yield response to conventional fertilizer suggests improved soil health and or soil moisture was responsible for improved yields at the high compost rate.

(73 pages)

PUBLIC ABSTRACT

Assessment of Compost on Dryland Wheat Yield and Quality, Soil Fertility and Water Availability Utah

Kareem Adeleke

In 2014-2016 Kareem Adeleke undertook a graduate project under the supervision of Utah State University (USU) Plants, Soils and Climate professors, Drs. Jennifer Reeve, Astrid Jacobson, and Earl Creech. Organic wheat producers face numerous challenges, such as low soil moisture, soil erosion, and low soil fertility. Organic wheat growers generally do not apply fertilizer due to inability to recoup the costs in the short-term. Compost enhances long-term improvement in soil quality, soil fertility and increase yield in low input environments. Understanding of compost carryover effects in dryland wheat systems is necessary for increased yield that will allow adequate supply of nutrients for several years after the initial application. A previous study on a Utah calcareous soil showed evidence of soil benefits twenty-two years after a single application of compost at 50 Mg ha^{-1} dry weight. A new experiment was started at the Blue Creek farm in 2011 to test the reproducibility of these findings on a less marginal soil type. Compost was applied at 0, 12, 25, and 50 Mg ha^{-1} plus a conventional fertilizer control. Wheat yield was significantly increased three years after application at the 50 Mg ha^{-1} compost rate only. Conventional fertilizer increased grain protein. Mineralizable soil carbon, microbial biomass and phosphatase enzyme activity increased significantly at all compost rates, while available soil phosphorus increased at the 25 and 50 Mg ha^{-1} rates and total soil

nitrogen at the 50 Mg ha^{-1} rate. A lack of yield response to conventional fertilizer suggests improved soil health and or soil moisture was responsible for improved yields at the high compost rate.

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Kareem A. Adeleke

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CHAPTER I

GENERAL INTRODUCTION AND LITERATURE REVIEW

1 | INTRODUCTION

Wheat is one of the oldest and most well-known cereal crops that produces edible one-seeded caryopses called a grain or kernel. It is an essential source of food composed of starch, dietary fiber, protein, minerals, and vitamins (Bhave et al., 2012). Dryland wheat has been a significant crop grown in Utah for over 100 years. The dominant cropping system is a wheat-fallow rotation, which means one crop is produced every other year. Water availability increases in the fallow period by storing water in the absence of crop growth (Unger, 1994; Bonfil et al., 1999; Verburg et al., 2012; Zeleke, 2017). Utah has a semi-arid climate, which is characterized by low precipitation, low soil organic matter, calcareous soils and low soil fertility that translates into variable wheat yields. In the growing season, limited water decreases nutrient availability to the root surface and topsoil (Marschner & Rengel, 2012). Dryland organic wheat production is managed conventionally in most of the Intermountain West in the United States. However, Utah also has significant acreage of certified organic wheat with approximately 41,834 acres harvested per year (USDA NASS, 2015). Utah organic growers lack economically viable inputs to improve yield and soil properties, however, which limits further adoption. (Reeve et al., 2012). Compost enhances long-term improvement in soil quality and soil fertility and increases yield in low-input environments. Compost application increases soil moisture, water infiltration, soil structure and soil organic matter (SOM). Understanding compost carryover effects in dryland wheat systems is necessary for improved yield that will allow adequate supply of nutrients for several years after the initial application.

2 | LITERATURE REVIEW

2.1 | Soil organic matter and soil quality

Soil organic matter (SOM) consists of a series of substances, ranging from undecomposed remains of plants and animals, through the intermediate and final stages of decomposition. Humus is well-decomposed stable organic matter, concentrated in the topsoil but found throughout the soil profile, while the undecomposed organic matter is normally found at the soil surface. Soil organic matter consists of carbon (C), hydrogen (H), oxygen (O), nitrogen (N), phosphorus (P), and sulfur (S) (Strawn et al., 2015). SOM is an important component of soil quality that influences soil characteristics like nutrient mineralization, aggregate stability, and nutrient and water retention properties (Antil et al., 2005). It plays a large role in increasing cation exchange capacity and water-holding capacity in soils (Brady & Weil, 2002). It is pivotal in all soil processes and primarily important in maintaining soil productivity (Tomáš, 2007).

Soil quality is defined as the capacity of soil to sustain biological productivity, perform ecological functions, maintain environmental quality, and promote plant and animal health (Lal, 1998; Weil & Magdoff, 2004). Soil organic matter increases with organic amendments by enhancement of biological diversity and microbial activity, which in turn improves soil quality (Tautges et al., 2016). Combinations of chemical, physical, and biological properties are used to assess soil quality. The most important soil quality indicators observed by researchers are SOM-related properties like total organic carbon, extractable carbohydrates, microbial biomass C, and micro-aggregate stability that show significant values in highly productive soils (Weil & Magdoff, 2004).

2.2 | Soil enzymes and microbial biomass

Microbial biomass is the living part of soil organic matter (Garcial-Gil, et al., 2000). Microbial activity is found to be closely related to soil fertility because the most important organic elements (C, N, P, and S) are released through biomass mineralization (Frankenberger & Dick, 1983). Studies have shown that microbial biomass and enzyme activities are good indicators of soil quality (Moghimian et al., 2017). Soil enzyme activities as important indicators of microbiological and biochemical processes are always involved in SOM decomposition, and synthesis, nutrient cycling, nutrient availability, and soil fertility and quality (Bastida et al., 2008). Additionally, the build-up of a large and active soil microbial biomass is very important for sustaining soil productivity in organic farming systems because it aids mineralization of organic matter (Cong et al., 2005). Tautges et al., (2016) observed greater soil microbial abundance and activity in manure-amended soils than conventional soils.

2.3 | Compost use and carryover

Composts and manure are commonly used in organic and low input farms to maintain or improve soil fertility. They are used to supply nutrients within a season and play an important role in SOM accumulation. Compost enhances long-term improvement in soil quality and is effective in building soil microbial biomass (Flieβbach & MaÈder, 2000; Olsen et al., 2015). Compost carryover is the persistence of positive effects of compost by supplying essential nutrients beyond the year of application. Compost carryover is also influenced by non-nutritive effects, which are related to the physical benefits of increased soil organic matter on the soil (Reeve et al., 2012).

In traditional organic agricultural systems, the purpose of applying compost is to ensure a natural ecological system of soil management that supports plant nutrition, and conserves soil and water. The goal is a sustainable system of soil management that involves the addition of organic materials, like cover crops, crop residue incorporation and use of compost. The long-term effects of these management practices lead to soil organic matter build up and an increase in soil quality and health. Compost has long-term effects on soil health and provides a residual nutritive benefit, which is not always considered in fertility planning (Olsen et al., 2015). While inorganic fertilizers are available immediately for crop uptake, compost decomposes gradually, mineralizing nutrients over many years at decreasing rates. The nutrients contained in compost are not always available in optimal proportions, however. Typically, the N/P ratio of manures and composts is less than that of plants, so growers who base their application rates to achieve an N target often apply P more than crop needs (Eghball & Power, 1999).

Compost quality varies widely depending on the source of materials and time of the year it is produced. Compost analyses for nutrient content and C/N ratio are very important. The National Organic Program standards require that raw materials used for composting have C/N ratios between 25:1 and 40:1. Organic amendments with low C/N ratios are more easily decomposed than those with high C/N ratio (Swift et.al., 1979; Henriksen & Bredland, 1999a, 1999b; Potthoff et al., 2005) The moisture content of finished compost ranges between 25 to 35 % and 1 to 2 % N on dry weight basis and a C:N ratio between 12 and 18:1 (Heckman, et al, 2009). The

C/N ratios of applied compost determine N availability to the crop and N concentration is the most important quality index of organic inputs. Other elements like P, S, Ca, Mg and K concentration may also affect decomposition, however (Tyler, 2005; Cleveland et al., 2006; Salamanca et al., 2006).

In organic crop production, chemical fertilizers and pesticides are excluded, but crop management practices are used that support plant nutrition and conserve soil and water resources. Generally, the most important benefit of compost use is the capacity to increase the soil organic matter. With the increase in the soil organic matter, soil physical characteristics are improved through compost application by increasing aggregate stability, porosity, infiltration and decrease bulk density (Diacono & Montemurro, 2009). This will increase water-holding capacity due to enhanced soil structure (Barker, 2010). In addition, Stukenholtz et al., (2002) reported that the previously stated non-nutritional benefits of compost, which improve soil moisture retention, might surpass its nutrient benefits in dryland farming systems where moisture is the yield-limiting factor. From sustainable standpoint, compost application will increase the soil moisture, water infiltration, soil structure and SOM.

Previous research on one-time compost application on dryland organic wheat in Snowville, Northern Utah. Stukenholtz et al., (2002) partitioned the yield response into nutrient and nonnutrient with different rate of compost application. The study showed significant results of nonnutrient effects of compost application in comparison to nutrient effects in moisture limiting environment. The study suggested that the lower yield in dryland wheat farming systems deserved less nutrient that could be achieved with low rates of compost application. Eldelman et.al., (2010), formulated a theory of economically optimal rates (EORs) for one time compost applications to determine carry-over effects on yield in the years after application, the results of the study showed EOR decreases as the compost/crop prices ratio increases, and the EOR could only be maximized with long term carry-over. Reeve et al., (2012) published further investigation on the carry-over effects of one-time application of compost applied in 1995.

2.4 | Water Availability Effects on Dryland Wheat Yield and Quality

Wheat is a widely adapted crop that can be grown in many different environments, and under different conditions, from irrigated to dry and high rainfall zones (Acevedo et al., 2002). Water is the most important limiting factor in dryland wheat production. (Chang-Xing et al., 2009; Kaur et al., 2015). Dryland winter wheat yield is constrained by low precipitation, high evaporation and low water storage in the soil profile (Soon et al., 2008). In the growing season, limited water decreases nutrient availability to the root surface and topsoil (Marschner & Rengel, 2012). Furthermore, in water-limited environments, crops underutilize the advantage of improved varieties and higher fertilizer inputs (Turner & Begg, 1981). However, wheat-fallow systems allow moisture storage for the subsequent wheat crop, which helps prevent crop failure (Kaur et al., 2015). During the fallow period, no crop is grown and weeds are controlled by cultivation or herbicide application. This practice increases nitrogen supply and conserves moisture for the following wheat crop (Unger, 1994; Anderson & Impiglia, 2002). The problems associated with the wheat-fallow rotation in the semiarid region include inefficiency in soil water storage caused by evaporation due to prolonged hot and dry periods before the subsequent crop, wind and water erosion, and declining organic matter (Stewart, 2016).

Water stress in the vegetative growth stage limits leaf and tiller development of winter wheat. It increases the rate of senescence at jointing stage and decreases the number of spikelets per head (Musick & Dusek, 1980). The most critical growth stages most affected by water are heading, flowering and grain filling (Singh, 1981; Kirkham & Kanemasu, 1983). Subsoil water is very important in dryland wheat yield. Water stored in the deep profile becomes available to crops during the post-anthesis period when the water is most needed for grain filling (Kirkegaard et al., 2007).

Wheat quality is very important because the market values protein content, which increases the premium paid on the grain. Therefore, grain cultivars with good bread making attributes attract a price premium higher than grain sold for biscuit making and livestock feed (Smith & Gooding, 1999; Lerner et al., 2006). Protein quality and digestibility are very important in the assessment of the nutritional value of a food (Coda et al., 2017). In addition, the protein content of wheat is one of the qualities for deciding the suitability of a flour for bread baking (Miskelly & Suter, 2017). Agronomic management such as fertilizer rate, can influence quality wheat production. Organic wheat breeders have developed varieties well adapted to low N availability, with improved plant heights, better utilization of nutrients at early growth stages, and higher protein content than conventional varieties (Wolfe et al., 2008). However, Utah growers still have problems meeting grain protein targets. Limited N availability is one of the major problems in organic farming

The goal of this research is to demonstrate and quantify the effects of a one-time application of compost in organic dryland wheat for increased fertility, wheat yield and quality, and water use efficiency. We still have limited information on how profitable compost use could be for farmers, in order to regain the cost of purchase, haulage and application. Understanding of compost carryover effects in dryland wheat systems is necessary for optimal yield that will allow adequate supply of nutrients for several years after initial application. Optimal compost rates and carryover effects that will have a short break-even period before a producer starts making a profit needs to be investigated. There is a need to link compost carryover to improved soil fertility, soil quality, and water storage and to understand to what extent this will affect grain quality. The specific objectives and hypotheses are described below.

The thesis is written in three chapters. Chapter I introduces the challenges facing dryland organic wheat production in Utah. It describes the problems associated with the wheat-fallow rotation, importance of soil fertility and quality, compost use and carryover in organic systems and its impact on water availability. It further introduces water availability effects on dryland wheat yield and quality. Finally, the need for further research to improve soil fertility, soil quality and grain quality in Utah organic dryland wheat systems is described and the goals and objectives for the research described in this thesis are presented. Chapter II presents the results of the research. This paper describes the effects of different rates of compost on dryland wheat yield, grain quality, soil fertility and quality and water availability observed over the 2012 to 2015 growing seasons. Chapter III presents general conclusions, provides a summary of the findings of the whole project and describes the implications of the effects of using a one-time compost application in organic dryland wheat systems.

3 | OBJECTIVES AND HYPOTHESES

(I) To examine the effects of compost on wheat yield and quality in a continuous wheat-fallow rotation under dryland conditions.

Hi: The yield and quality of winter wheat will increase after a one-time compost application.

(II) To evaluate the effects of compost on soil quality and water availability in a dryland organic wheat system.

Hii: Compost incorporation will increase soil moisture, soil fertility and quality in dryland organic wheat

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CHAPTER II

ASSESSMENT OF COMPOST ON DRYLAND WHEAT YIELD AND QUALITY, SOIL FERTILITY AND WATER AVAILABILITY IN UTAH

Abstract

Dryland wheat has been a significant crop grown in Utah for over 100 years. The dominant cropping system is a wheat-fallow rotation. Organic wheat producers face numerous challenges, such as low soil moisture, soil erosion, and low soil fertility. Organic wheat growers often do not apply fertilizer due to the inability to recoup costs in the short-term. Compost enhances long-term improvement in soil quality and soil fertility and increases yields in low-input environments, however. Improved understanding of compost carryover effects in dryland wheat systems could lead to increased use by growers. A previous study of calcareous soil in Utah showed evidence of soil benefits twenty-two years after a single application at 50 Mg ha^{-1} dry weight. A new experiment was initiated in 2011 at the Blue Creek farm to test reproducibility on a less marginal soil type. Compost was applied at 0, 12, 25, and 50 Mg ha^{-1} plus a conventional fertilizer control. Wheat yield was significantly increased three years after application at the 50 Mg ha^{-1} compost rate only. Conventional fertilizer increased grain protein. Mineralizable C, microbial biomass and phosphatase enzyme activity increased significantly at all compost rates, while available soil P increased at the 25 and 50 Mg ha^{-1} rates and total soil N at the 50 Mg ha rate^{-1}. A lack of yield response to conventional fertilizer suggests improved soil health and or soil moisture was responsible for improved yields at the high compost rate.

Abbreviations: DW, dry weight; TOC, total organic carbon; TN, total nitrogen; DOC, dissolved organic carbon; DHA, Dehydrogenase; RMC, readily mineralizable carbon; BR, basal respiration

1 | INTRODUCTION

Wheat (*Triticum aestivum* L.) is Utah's largest certified organic crop, with organic winter wheat accounting for 41,834 acres harvested in 2015, which generates $12,171,794 revenue (USDA-NASS, 2015). However, organic wheat producers face numerous challenges, such as low soil moisture, soil erosion, and low soil fertility, especially in dryland areas. Organic dryland wheat is commonly managed with a wheat-fallow rotation to conserve soil moisture. Organic dryland wheat-fallow systems risk soil loss as a result of overreliance on tillage for weed control, declining wheat yield, lack of economically viable inputs to improve yield and soil properties, and long hauling distances for organic inputs (Carr et.al., 2012).

Soils do not have a perpetual reserve capability to supply the required nutrients to crops, and thus call for sustainable management with a long-term economic, resource conservation, and environmental benefits approach. A major challenge of organic farming is the maintenance of soil fertility, which is a function of nutrient sources and crop management. Maintenance of soil fertility in organic systems for sustainable crop production is complex and requires a combination of cover crops, extended crop rotations, compost and other organic inputs (Watson et al., 2002).

The use of compost and manure by organic and low-input farmers has been shown to maintain or improve soil fertility by modification of soil chemical, physical and biological properties (Barker, 2010). Compost has a positive effect on soil microbial biomass that can last for several years. Organic amendments activate soil microbial populations and increase bacteria and fungi in the soil, which eventually increases the nutrient cycling of elements such as nitrogen (N), and phosphorus (P) for soil sustainability (Flieβbach et al., 2000; Hernandez at al., 2016). Soil amendments such as compost or manure from livestock may be necessary for dryland farming to maintain long-term soil fertility of dryland organic wheat (Miller et al. 2008). However, many organic dryland wheat growers do not use compost or manure because it is bulky and costly to apply (Reeve et al., 2012).

In drylands, low soil water content further limits nutrient availability. During the growing season as water distribution declines, nutrient availability decreases and root growth is impaired by dry soil (Marschner & Rengel, 2012). There is a high correlation between winter wheat yield and available soil water at planting (Nielsen et al., 1999; Nielsen & Vigil, 2005). Also, reduced crop yield and grain quality is attributed to low inputs, and inadequate weed and pest control (Cavigelli et al., 2013). Grain quality is as important as yield quality for farmers growing wheat as a cash crop because the commercial wheat value is dependent on grain protein content and other quality characteristics. The main benefits of compost are the slow mineralization of plant available nutrients and contributions to soil organic matter. Research shows that compost has long-term carryover that persists at least 16 years after a one-time application. (Reeve et al., 2012). Organic wheat growers in Utah are interested in the potential for single applications of compost to increase yield and improve grain quality at a reasonable cost of production. The goal of this research is to determine how long the beneficial effects of compost carryover last, what rate is adequate to maximize yield and to what extent is the influence on grain quality that brings about higher commercial value. More information is needed to determine optimum compost application rates that will be economically viable in the short to mid-term and improve soil fertility and quality.

To meet this goal, we had two main objectives. The first is to examine the effects of four rates of compost and a conventional fertilizer control on wheat yield and quality in a continuous wheat-fallow rotation system under dryland conditions. The second is to evaluate the effects of the same treatments on soil quality and water availability in a dryland organic wheat system. We hypothesized that yield and quality of winter wheat would increase after a one-time compost application. We expected that compost incorporation would increase soil moisture, soil fertility and quality in dryland organic systems.

2 | MATERIALS AND METHODS

2.1 | Site Description

The study was conducted in the years 2011-2015 at the Utah State University Blue Creek Dryland Experimental Station (N41 º 56’6” W 112º25’48” W, 1575.8 m elevation above sea level). The study site soil is classified as Parleys silt loam (fine-silty, mixed, superactive, mesic Calcic Argixerolls) (USDA Soil Survey, 2016) with an average pH of 8.0, and calcium carbonates equivalent ranging from 15 to 30%. The total annual precipitation is 432 mm, mean air temperature is 10º C, and total annual evapotranspiration is 1479 mm (Utah Climate Center, 2016). The compost trial was established in 2011 with four replicates (blocks 1-4). A steer manure compost was purchased from Miller's (Hyrum, UT) and applied at the rates of 0, 12.5, 25, and 50 Mg ha^{-1} on a dry matter basis. A positive control treatment consisted of 0.05 Mg ha^{-1} of anhydrous ammonium applied annually in October with buffers of 7.3 m on either side of the inorganic fertilizer control so as not to compromise organic certification. In the fall of 2012, two more replicates were added (blocks 5 and 6) to the second phase of the rotation. Compost was applied as described above in late August, before planting of winter wheat. The cropping system is a wheat-fallow rotation, with winter wheat planted in even years in blocks (5, 6) and odd years in blocks 1 through 4. The experimental design is a randomized complete block design (RCBD) with six replicates. The size of the whole plot is 6.86 by 8.53 m.

2.2 | Measurement of Wheat Yield and Quality

Data on wheat yield and quality from this trial was collected from 2012 to 2015. The trial was planted with winter wheat cultivar Promentory in October (starting in 2011) and harvested in July of the following year throughout the study. Wheat yield were monitored annually. Winter wheat yield (block 1-6) was harvested using a combine on a plot-by-plot basis. Wheat quality assessment was analyzed using Near Infrared (NIR) reflectance spectroscopy with a Bran-Luebbe InfraAlyzer 2000 (United Dominion Industries Limited, Norderstedt, Germany) instrument to analyze flour for moisture, and protein concentration (ICC Method 159).

2.3 | Soil Sampling and Analysis

Soils samples were collected in 2011 (Block 1-4) and 2012 (Block 5 and 6) for baseline data while experimental data samples were collected in the spring of 2013 and 2015 in block 5 and 6. Five subsamples of soil were collected at 0-0.3, 0.3-0.6, 0.6-0.9 and 0-0.1m from the center of each plot and combined into one representative sample per depth for each plot. Soils were sieved through a 2 mm screen, a portion air-dried and the remaining stored at 4 ºC until analysis within a week. The following standard soil analyses were conducted on air dried soils using methods described in

Soil and Plant Reference Methods for the Western Region (Gavlak et al., 2003): Olsen P and K (Method S4.10), DTPA – extractable elements Fe, Zn, Cu, Mn (Method S6.10), pH (Method S2.20); electrical conductivity (EC) (Method S2.30); and cation exchange capacity (Method S10.10). Total carbon (TC), inorganic carbon (IC) and total nitrogen (TN) were determined on air-dried and finely ground (0.2 µM) soils from the 0-10 cm depth with Primacs^{SLC} for total C and Primacs^{SN} for N instruments (Skalar Inc., Buford, GA) respectively. Total organic carbon (TOC) was determined by calculating the difference between TC and IC.

Dissolved organic carbon (DOC) was extracted from the field moist soils collected at 0-30, 30-60, and 60-90 cm depth in 2013 and 2015. DOC extracted in water was analyzed with a UV-Persulfate TOC analyzer (Phoenix 8000, Teledyne Tekman, Mason, OH). Soil nitrate (NO_3^-) and ammonium (NH_4^+) were extracted in 1 M KCl (S-3.50 Gavlak et al., 2003) from field moist samples collected at 0-30, 30-60, and 60-90 cm depth in 2013 and 2015 and measured in the range of 0 to 5 mg N L^{-1} to detect NH_4^+-N (QuickChem method 12-107-06-1-B) and in the range of 0 to 20 mg N L^{-1} for NO_3^--N (QuickChem method 12- 107-04-1-B) with a Lachat QuickChem 8500 Flow Injection Analyzer (Hach Company, Loveland, Colorado). The following measurements were conducted on the 0-10 cm field moist samples in 2013 and 2015.

The following measurements were conducted on soils collected from the 0-0.1m sample depth. Readily mineralizable carbon (RMC), basal microbial respiration (BR) and active microbial biomass by substrate-induced respiration (MB) was measured according to Anderson & Domsch (1978). Ten grams of wet weight soil was brought to 22% moisture content and incubated at 24 °C for 14 d. Total CO_2

released after 14 d was considered RMC. Vials were recapped for 2 h and the hourly rate measured for BR. For MB, 0.5 mL of 60 g L^{-1} aqueous solution of glucose was added to the same soil samples and rested for 1 h before being recapped for 2 h. Carbon dioxide was measured in the headspace using an infrared gas analyzer (model 6251, LICOR Biosciences, Lincoln, NE). Dehydrogenase enzyme activity was measured according to Tabatabai (1994) on 2.5 g field moist soil in triplicate. Soils were moistened to 22% by weight with double distilled water and incubated overnight at 25º C. On the second day, 0.5 ml of 3% triphenyl tetrazolium chloride (TTC) and 1.0 ml 2% $CaCO_3$ solution were added to each tube, mixed thoroughly then incubated at 37° C for exactly 24 hours. The product of the incubation, triphenylformazan (TPF), was extracted with 10 ml methanol and measured at 490 nm with a microplate reader (SpectraMax M2, Molecular Devices, Sunnyvale, CA). Control readings were subtracted from each sample and the µg TPF g^{-1} dry weight soil was determined using a standard curve. Acid and alkaline phosphatase enzyme activities were determined using 1 g dry weight soil (Tabatabai, 1994). A control for each sample was included to account for color exuded by humic materials in the soil like that of p-nitrophenol. To each tube was added 4.0 ml modified universal buffer (MUB) (pH 6.5 for acid and pH 11 for alkaline), and 1.0 ml disodium p-nitrophenyl hexahydrate solution in MUB (excluding the controls). Samples were mixed thoroughly and incubated for exactly one hour at 37°C. After incubation, 1.0 ml 0.5 M $CaCl_2$ solution, and 4.0 ml 0.5 M NaOH was added to both samples and controls. Disodium p-nitrophenyl phosphate solution was then added to the controls only. After mixing thoroughly, all samples were centrifuged at 4,000 rpm for 5 minutes. The supernatant from each sample was transferred in 200 µl aliquots to a micro titer plate. Absorbance was measured at 405 nm using a microplate reader (SpectraMax M2, Molecular Devices, Sunnyvale, California). Control readings were subtracted from each phosphate reading and the µg p-nitrophenol g^{-1} dry weight soil was determined using a standard curve.

Measurement of Soil Water Availability

Soil moisture was determined in Blocks 5 and 6 bi-weekly from May through June in 2013 and 2015 during the wheat phase of the rotation. Soil moisture was measured using a 503 DR Hydroprobe Neutron Scattering Device (CPN International, Concord CA). The neutron probe is a recommended method of measuring soil moisture drawdown in rocky soils. Six aluminum access tubes were `installed per plot at 1.8 m away from the edge and 7.6 m apart to avoid disturbance of the center of the plots used to take yield measurements.The access tubes were fitted with collapsible-stoppered sleeves that could be raised and lowered below the soil surface to facilitate tillage and other field operations. Moisture availability was measured at the following depth increments 0.3-0.6, 0-6-0.9, 0-9-1.2, 1.2-1.5 and 1.5-1.8 m. A wet soil gives a high count per time of test (16 seconds in this situation) and dry soil gives low count for the same period of time (16 seconds). The neutron probe was calibrated using gravimetric soil water measurements on intact cores taken from the subplots at each depth during access tube installation. Gravimetric soil water was converted to volumetric water by multiplying by the soil bulk density for each depth. Bulk density was determined from the dry weight of the soil cores.

2.4 | Statistical Analyses

The results were analyzed as a randomized complete block (RCBD) design with repeated measure over the first and third year after compost application. Within each block, there were five whole plots assigned randomly to the five compost treatments. For soil characteristics, another repeated factor, depth was included in the model. All analyses were performed using PROC GLIMMIX in SAS 9.4 System for Windows (SAS Institute, Cary, NC, USA). Fixed factors are compost rate, year after compost application and depth (for soil characters only) and their interactions. Block is the random factor. Baseline soil data were used to develop a covariance model. The covariance structure was compound symmetry for year and first-order autoregressive for depth grouped by year. The compost treatment had five levels: Fertilizer check, 0, 10, 25 and 50 Mg ha^{-1}. We also used PROC FACTOR on the soil baseline data to generate two soil baseline structures that were used as co-variates for the wheat yield. The soil baseline structures reflect previous site management and were found to highly significantly ($p < 0.001$) affect wheat yield. Lognormal distribution was used for all the variables. Compost least square means were separated using Tukey-Kramer adjustments for multiple comparisons.

3 | RESULTS

Wheat Yields and Quality

Information on the impact of compost application rates and compost carryover effects is central to organic dryland wheat production. The main effect of compost on wheat yield was strongly significant ($p= 0.0006$), with no significant effect of year after compost application. In addition, there was no significant interaction between the year after compost application and compost rate ($p=0.85$). Higher yields (3.8 Mg ha^{-1}) were obtained with compost application rates at 50 Mg ha^{-1} (Figure 1). Although not significant, wheat yield increased with compost rate (Control< 12C< 25 Mg ha-1< 50 Mg ha^{-1}). There was also no significant difference between the fertilizer check (PC) and other treatments except 50 Mg ha^{-1} ($p=0.003$). Kernel counts were measured only in the year 2015 (three years after compost application). Kernel counts follow a similar trend (Figure 2) as wheat yield with the 50 Mg ha^{-1} application rate having the highest number of kernels compared to the fertilized (PC) and unfertilized control. There were no significant differences amongst the compost treatments.

Wheat quality that was measured as protein content in the year 2015 only (Figure 3). The conventional fertilizer check (PC) had the highest protein content (14.5%) which was significantly greater than the 50 Mg ha^{-1} rate (12.4%). There were no significant differences among the compost rates. Grain moisture was also not different amongst compost application rates, although PC was significantly different from the control (Figure 4). The interaction of compost and year after compost application on the grain test weight was significant $p<0.0001$ (Figure 5). There was no significant difference between compost treatments in 2013 and 2015, however. The third year after compost application showed an overall increase in grain test weight in comparison with the first year and PC had the lowest grain test weight.

Soil Properties

In general, measured soil properties responded strongly to compost. The impact of a one-time application of compost was measured for available P (Olsen), alkaline phosphatase (AP) and acid phosphatase (ACP), mineralizable C (min C), microbial biomass (MB), total organic C (TOC), total nitrogen (TN), for the two cropping seasons (2013, and 2015) after compost application in a wheat- fallow rotation. Available soil P (Olsen) and readily mineralizable carbon (RMC) main effect means were significantly greater at compost rates of 50 Mg ha^{-1} and 25 Mg ha^{-1} ($p< 0.05$). The response to compost increased linearly with rate, and PC and control had the lowest P and Min C (Figure 6 and Figure 7). Alkaline phosphatase enzyme assay was not significantly different one year after compost application while three years after compost application showed a highly significant ($p<0.0001$) difference between the 50 Mg ha^{-1} rate and the other treatments. The 12 Mg ha^{-1} and 25 Mg ha^{-1} treatments were also significantly higher in comparison with PC and control (Figure 8). Acid phosphatase enzyme assays were not significantly ($p=0.75$) different across the treatments (Figure 9). Soil microbial biomass was significantly lower in PC than other treatments, However, it was observed that microbial biomass increases as the rate of compost increases (Control<12C<25C<50C), although it was not significantly different across the treatments (Figure10). Application rate of compost increasing for both years with 50 Mg ha^{-1} greater than other treatments. Control and PC were consistently lower and except for EC in the year 2015.

Total organic carbon (TOC) and total nitrogen (TN) were significantly higher ($p<0.005$) at both depths in 2013 and 2015 at the 50 Mg ha^{-1} compost rate. The compost response was linear with PC and control having the lowest means at both depths (Figure 11 and Figure 12). Although, in 2013, there was no significant difference ($p<0.005$) in soil among the treatments in TOC at 30cm depths (Figure11B) and TN at 10 cm depth (Figure 12A). Total organic carbon was significant for year ($p<0.0001$) and interaction of year x compost x depth ($p<0.035$) while the TN year x compost x depth interaction was not significant ($p=0.133$). There was elevated NH_4^+-N in the 0-30 cm depth of 50 Mg ha^{-1} in comparison with PC. However, there were no significant differences at the other depths (30-60 and 60-90 cm). Nitrate and DOC did not significantly differ amongst the treatments in the 0-30 cm depth in 2013 (Table 4). Dissolved organic carbon was more pronounced at 0-30 cm in 2015 with compost treatment of 50 Mg ha^{-1} and significantly ($p = 0.05$) higher than PC and control, however there was no differences at the other depths (Table 4). Subsoil (30-60, and 60-90 cm) NO_3^- -N varied in the year 2015 (Table 4) with both PC and control having higher nitrate than the compost amended plots. In Table 5, the analysis of variance showed there was no significant difference with compost application on soil NH_4^+-N, NO_3^- -N and DOC (p=0.84, p=0.70, and p= 0.34) main effect means (n=2). However, year after application and depth were highly significant ($p<0.001$). Interactions of year and compost were greatly significant for NH_4^+-N and NO_3^- -N ($p<0.02$, $p<0.0001$), while year x compost x depth was also significant ($p<0.0025$) for NH_4^+-N (Table 5).

Higher pH, EC, BR, and DHA were observed in the first year after compost application (2013) at 50 Mg ha^{-1}. There was no significant difference in soil pH in 2013, while EC, BR, and DHA for compost-amended plots were higher, with 50 Mg ha^{-1} significantly different from control (Table 6). However, in the third year after compost application (2015), soil pH was significantly higher (p=0.001) in amended plots in comparison with the fertilized control (PC) and unfertilized control, while EC, BR and DHA were not significantly different across the treatments. Main effects from analysis of variance (Table 6) showed a significant compost effect for soil pH (p=0.003), but no significant differences were observed for EC, BR and DHA. Year and interaction of year and compost was highly significant for all the soil parameters observed (Table 6).

The main effects and interactions for soil K, Fe, Cu and Zn were not significant among the treatments except for Mn ($p<0.003$) with both controls (PC and control) significantly different from compost amended plots. The year after compost application was also different for K, Fe, and Mn ($p<0.0001$, $p<0.0032$ and $p<0.0001$)

respectively while year × compost did not significantly differ for all the parameters observed (Table 7).

Subsoil Moisture Variability

Subsoil moisture content increased linearly with depth (0.3 m to 1.5 m depth) in the soil profile in the 2013 cropping season for all the compost treatments (Figure 13). A similar trend was observed in 2015 (Figure 14). Generally, there was more water availability in the compost treated soils, most especially plots with highest compost application rates than the other treatments, although variability was high and there were no significant differences. The compost application rate of 50 Mg ha^{-1} had the highest amount of soil moisture at 1.5 m depth from early-May 2013 to mid-June 2013 (Figure 13, Panel A –D) and from early-May to mid-May in the year 2015 at the 1.8 m depth (Figure 14, Panel A-C). The highest soil moisture content (27%) was observed at the 0.9 m depth with 50 Mg ha^{-1} compost application in late-May 2015 (Figure 14 panel C). There was a sharp decline in water availability across treatments at the same period at 1.2 m depth to 1.8 m with the compost rate of 25 Mg ha^{-1} (22%) followed by 50 Mg ha^{-1} (19.5%). The lowest moisture recorded at 1.80 m depth was in late-May, 2015 that deviated from the linear pattern observed in the years 2013 and 2015. The moisture variability in late-May can be attributed to accumulation of precipitation received a week before data collection that caused the upper part of the soil to be saturated. Data obtained from the Utah Climate center for total precipitation for seven days before each moisture data collection was 49.78 mm for 2013 and 34.03 mm for 2015 (Table 2). The differences in the result explain why percent moisture for 2013 is generally higher than 2015**.**

4 | DISCUSSION

Dryland organic wheat systems were evaluated for improved soil fertility. Wheat yield and soil organic C, DOC, soil TN, NH_4^+-N, NO_3^- -N, microbial biomass and activity, and moisture availability increased 3 years after a one-time compost application. The results obtained showed the high rate of compost at 50 Mg ha^{-1} DW significantly increased TOC, TN, P, RMC, alkaline phosphatase, kernel count, and grain test weight. Water availability was influenced by compost in the subsoil and increased linearly with depth in the soil profile. Our hypothesis that residual effects of compost will increase wheat yield and quality, increase soil fertility and soil moisture was therefore confirmed. Compost as a soil amendment is important in dryland farming to maintain long-term soil fertility of dryland organic wheat (Miller et al., 2008). Efficient use of compost depends solely on its carryover effect to enhance crop yield on a long-term basis for economic sustainability.

Overall, the response to compost at the Blue Creek site was small with a 30% increase in yield at the highest compost rate only. In contrast, Stuckenholz et al., (2002) observed a 2.5-fold yield increase to compost applied at the same rate at a nearby location in Snowville, Utah. The lack of large differences in wheat yield can at least in part be attributed to available Olsen P, which was high at the location of this experiment ranging from NC (31 mg kg^{-1} P), 12 (31 mg kg^{-1} P), 25 (34 mg kg^{-1} P), PC (31 mg kg^{-1} P) and 50 Mg ha^{-1} (31mg kg^{-1} P). Cardon et al., (2008) reported soil P at 30 mg kg^{-1} to be high and at sufficiency level in Utah State. Reeve et al., (2012) documented a long-term yield benefit to compost to the Snowville site and attributed the response to plant available P. The different response measured at the Snowville experimental site and this present location can also be explained by several other factors, such as a different less marginal soil type, with lower calcium carbonate and a neutral pH and almost double the annual precipitation (Table 1). All these are indicators of more plant available nutrients and soil moisture availability at the Blue Creek site.

Kernel count responded to the compost rate and increased linearly with compost-amended plots, significantly different from PC (Figure 2). Grain protein concentration for conventional fertilizer was significantly higher than the compost amended soil and control treatment (Figure 3); the results can be attributed to the application of anhydrous ammonium as PC. Grain protein concentration increases with increased N application. Negative correlation between grain yield and grain protein content was observed in the results. High compost rate (50 mg ha^{-1}) has a higher yield but lower protein than PC (Figure 1 & Figure 3). Long et al., (2017) observed increased grain protein concentration of spring wheat with increased N application under low water regime while yield response was low. While compost clearly did not provide sufficient N to the system to increase grain protein it is important to note that increased yield did not result in decreased grain protein relatively to the control.

Total N in compost-amended plots were found to be significantly higher at 0-10cm in 2013, and at both depths (0-10 cm, 0-30 cm) in 2015, while there was no change at 0-30 cm depth in 2013 (Figure 12A & 12B). Nitrate concentrations were found to be significant in 2015 at 30-60 and 60-90 depth with both control having higher NO_3^- -N than compost the amended plots, no difference was found in other depths across the treatment. Soil ammonium were very low overall, and it was statistically different in both years and across depths except at 0-30 cm in 2013 which had the highest NH_4^+-N where 50 Mg ha^{-1} compost was applied. Nitrogen response in grains could be affected by NH_4^+-N because of precipitation amount, soil depth, previous crop, and level of residual N (Miller et al., 2000).

Compost application at 50 Mg ha^{-1} has the highest grain test weight although not significant difference amongst the treatment means. Test weight was higher in 2015 although it was very low overall and there were no significant treatment effects (Figure 5). Bern & Brumm, (2009) stated that grain test weights below 704g L^{-1} are not adequate. Limited plant available water and short growing period could be responsible for low test weight during grain filling (Gooding, et al., 2003). Subsoil water stored deep in the soil profile is very important in dryland wheat production (Kirkegaard et al., 2007). Effect of compost on water availability after compost application was not significantly different although increased soil moisture in response to compost was noticeable at some time points throughout the experiment particularly at the 50 Mg ha^{-1} rate at lower depths.

Available K on this site was very high and the 50 Mg ha^{-1} application rate had higher K than the other treatments, although not significantly different. These results agree with the findings of Reeve et al. (2012). Available K was not limiting in any of the treatments and so likely did not contribute to the yield response observed (Cardon et al. 2008). Extractable Mn (DTPA) was higher in control than amended soil although not significantly different from compost-amended plots. While Fe, Cu and Mn deficiencies are not generally diagnosed in Utah, extractable Zn in the amended soils was adequate for winter wheat and increased with compost rate (Cardon et al., 2008). It is worthy to note that Zn and Fe reported by Reeve et al., (2012) to be deficient in the top 0.30 m at their site was adequate at this research location.

Comparison between years showed a significantly greater soil pH in 2015 with compost-amended plots significantly higher than PC and control. Meanwhile, EC was significantly greater in the first year after application with compost-amended plots. Near neutral Soil pH and acceptable EC in our experimental site which is an important indicator of soil health.

Despite the lack of yield and grain quality response to compost, many of the soil health indicators tested were significant. Microbial biomass was found to be elevated with compost amended plots than PC and control although it was not significant different from control. Tautges et al., (2016) also observed greater soil microbial abundance and activity in organically managed soils than plots amended with N fertilizer. Many researchers found high amount of organic inputs often results in high microbial biomass (Flieβbach & MaÈder, 2000; Peacock et al., 2001). Dehydrogenase activity (DHA) is considered a good indicator of active microorganism (Kieliszewska-Rokicka, 2001) associated with the carbon cycle and SOM (Tabatabai, 1994; Blonska et al., 2016). DHA varied in 2013 across the treatments but it was not significant in 2015. Higher DHA was observed in both years at the lower compost rates. The DHA results obtained were similar to Reeve et al., (2012) in that there where there was no significant difference below 10cm depth. Phosphatase activity is very important for organic P mineralization. The 50 Mg ha^{-1} amended plots were strongly significantly greater in alkaline phosphatase activity three years after compost application, and other compost treatments were significantly higher than PC and control.

Readily mineralizable C is an important indicator for measuring soil health and quality (Moebius-Clune et al., 2016). It was significantly higher at the 50 Mg ha^{-1}

application rate but not different from 25 Mg ha^{-1}. RMC is an integrated measurement used for measuring microbial biomass (Anderson & Domsch, 1978), microbial activity and soil carbon availability (Wang et al., 2003). BR measures metabolic activity of the microbial community by capturing CO_2. Higher BR was measured in 2013 at the 50 Mg ha^{-1} rates although no difference was observed in 2015. Reeve et al. (2012) reported that because mineralizable C and basal respiration were not significant, this indicates that organic C in amended soil may be in a recalcitrant form that is not readily available to microbial breakdown. This difference in the two sites could be attributed to water availability differences at the two locations (Table 1). Because the drying and re-wetting cycle is more frequent at Blue Creek due to higher precipitation, this could increase microbial mineralization of C as a result of microbial activities.

Treatment differences in DOC increased with compost rate but were limited to the top 0-30cm in the first year of application. In 2015, DOC was found to be very low compared to 2013. Dissolved organic C is mobile in the soil profile and is an important C source for microorganisms. It is easily decomposable with microorganisms shown to consume up to 10-40% in a few days to months (Kalbitz et al., 2000). Total organic C (TOC) measured at two depths (0-10 cm, 0-30 cm) was highly variable with no significant difference at 0-10 cm while 0-30 is significantly high with 50 Mg ha^{-1} in 2013. The TOC result in 2015 showed significantly higher TOC at the top 10 cm with 50 Mg ha^{-1} while there was no difference in 0-30 cm. This switch in the depth of TOC results could be attributed to the amount of rainfall received in the different years of sample collection. The year 2013 was wetter year than 2015 and this might explain why more organic C was found at the top depth in

2015. Reeve et. al., (2012) found more TOC in the drier site at the top 10 cm in the compost amended plots than the control plots.

5 | CONCLUSIONS

This is a long-term experiment for organic dryland wheat management strategies to evaluate compost carryover effects for increased water availability, soil fertility, wheat yield, and economic viability for dryland organic wheat growers in Utah. Although, the experiment site is less marginal compared to the legacy plots at Snowville that were tested in Reeve et al., (2012). As expected with a certain level of nutrient sufficiency fertilizer response will be low. The study's objective was to examine the effects of compost on wheat yield and quality in a continuous wheat-fallow rotation system under dryland conditions. We evaluated the effects of different compost rates and a single rate of conventional fertilizer on soil quality and water availability in a dryland organic wheat system. We hypothesized that compost incorporation would increase soil moisture, soil fertility, and quality in a dryland wheat system, and that yield, and quality of winter wheat will increase after a one-time compost application. Increased wheat yield was observed three years after application at 50 Mg ha^{-1} plots compost rate only while conventional fertilizer only increased grain protein. Mineralizable C, microbial biomass, and phosphatase enzyme activity increased significantly at all compost rates, while available soil P increased at the 25 and 50 Mg ha^{-1} rates and total soil N at the 50 Mg ha^{-1} rate. A lack of yield response to conventional fertilizer suggests improved soil health and/or soil moisture was responsible for improved yields at the high compost rate. The percent yield increase due to compost was 30 %, and this is relatively low compared to earlier results published (2-fold yield increase) in a drier winter-wheat fallow site in

Snowville. The lack of response in grain protein following compost application may be related to low N availability compared with conventional fertilizer. Predicting the economic benefits of compost on soil health and yield may be mediated by variation in soil properties and microclimatic conditions, which could likely affect the compost's effects. However, despite the documented evidence of compost on soil health from this research and previous works, the growers' adoption rate is slow because of the time it takes to breakeven. To scale back the breakeven years and increase the adoption rate, best management strategies that will enhance long-term soil productivity with less input for more output should be employed. Minimum compost application that will increase the net returns through increased yield, grain protein content that translates to high premium need to be explored. Further research is needed on soil organic matter changes and water availability. Soil moisture should be measured with the gravimetric method at 0-0.3 m since the neutron probe use in this research can only measure water content below 0.3 m. In terms of soil fertility and soil quality, effects of leguminous cover crops should be investigated for sustainability with available N for the next wheat production, reduced N leaching, soil erosion, diseases and weed suppression.

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FIGURES

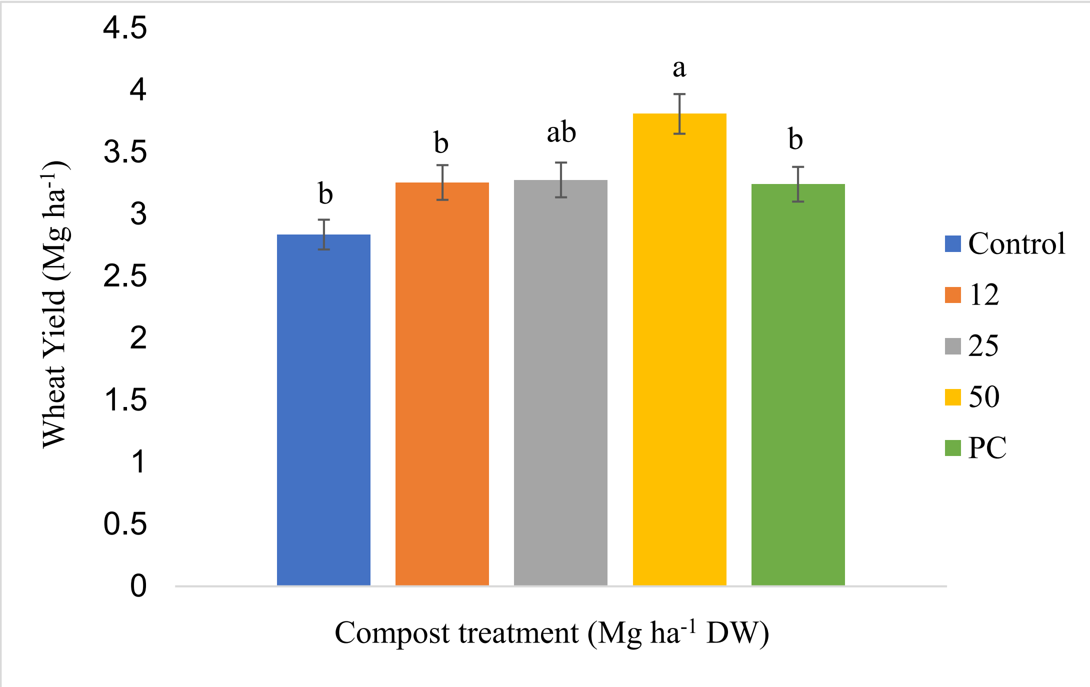

FIGURE 1 Main effects (n=6) of compost on wheat yield (PC =anhydrous ammonium). Error bars indicate ± standard errors. Means designated by different letters are significant at p<0.05.

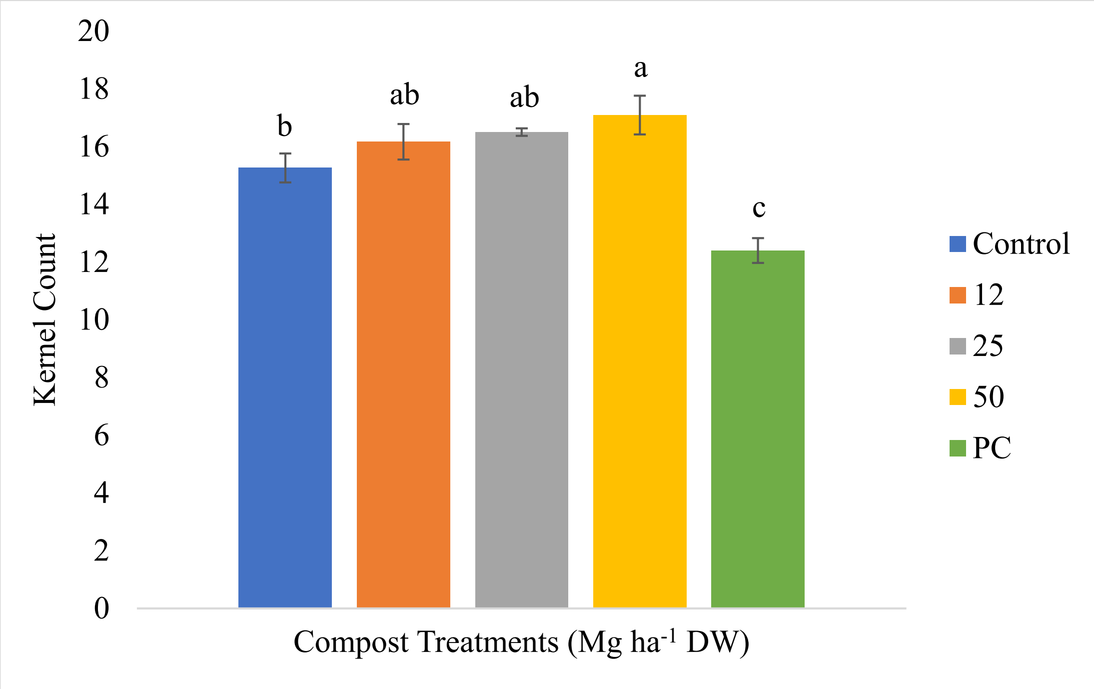

FIGURE 2 Means (n=2) and standard errors for kernel count in the year 2015. The 50 Mg ha^{-1} DW application rate had a greater kernel count than the unfertilized and fertilized control, (PC= anhydrous ammonium). Error bars indicate ± standard errors. Means designated by different letters are significant at $p<0.05$.

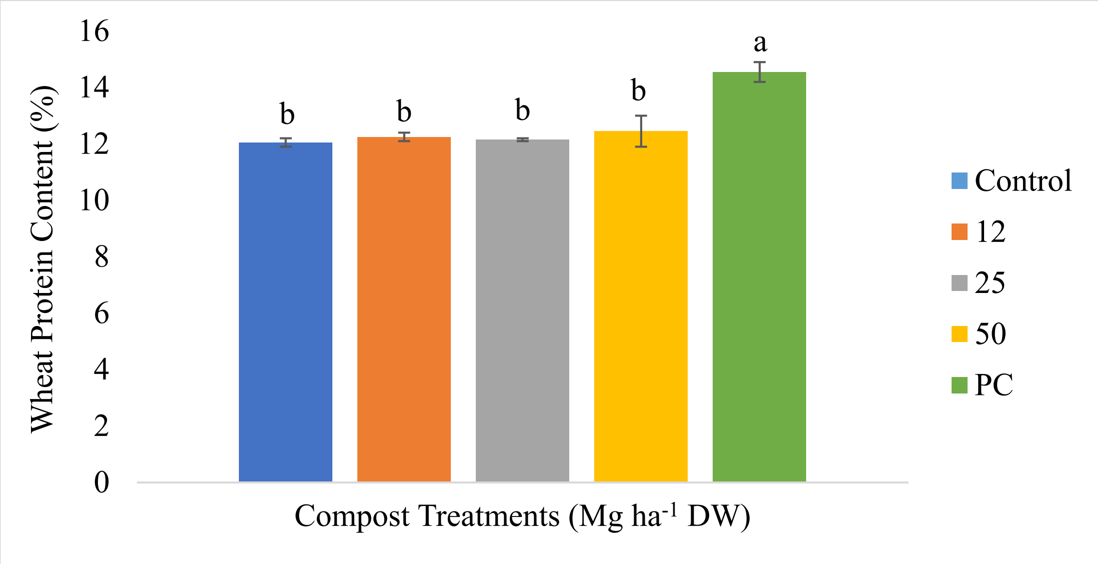

FIGURE 3 Means (n=2) for wheat protein content for the year 2015 showed PC (anhydrous ammonium) with highest protein content. Error bars indicate ± standard errors. Means designated by different letters are significant at $p<0.05$.

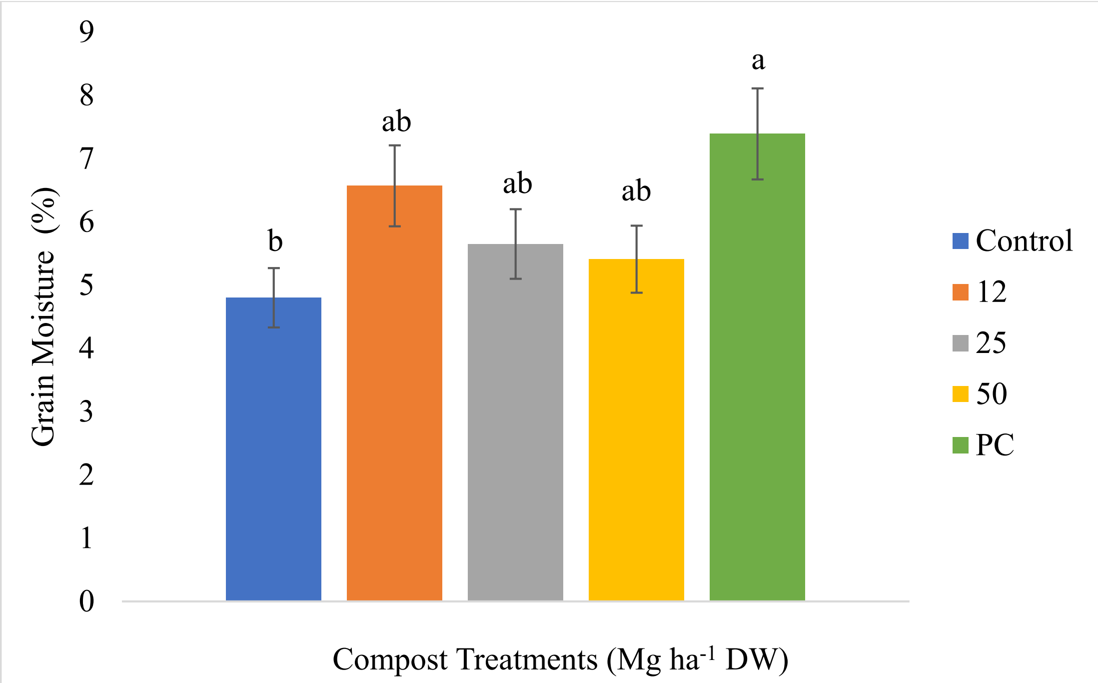

FIGURE 4 Main effect means (n = 2) of compost application rate on grain moisture. There were no differences amongst compost application rates, although anhydrous ammonium (PC) was significantly different from the control. Error bars indicate ± standard errors. Means designated by different letters are significant at $p<0.05$.

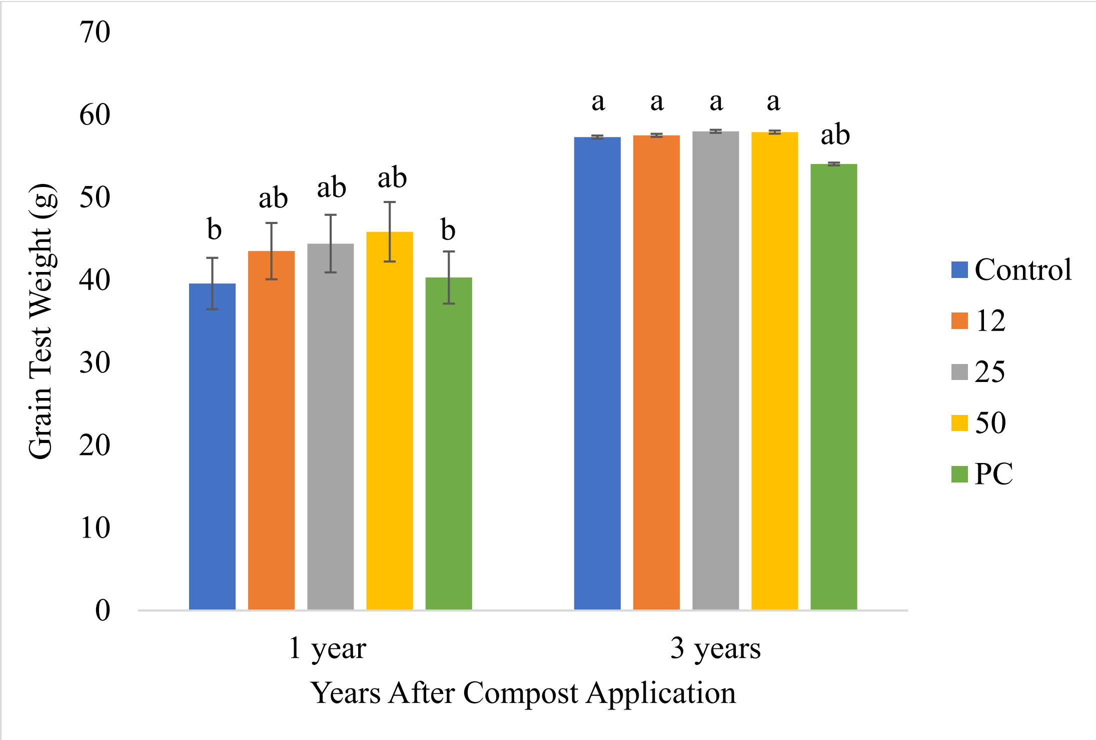

FIGURE 5 Compost application (PC, anhydrous ammonium) showed no significant difference in the first year and 3 years after compost application in the grain test weight. Error bars indicate ± standard errors. Means designated by different letters are significant at $p<0.05$.

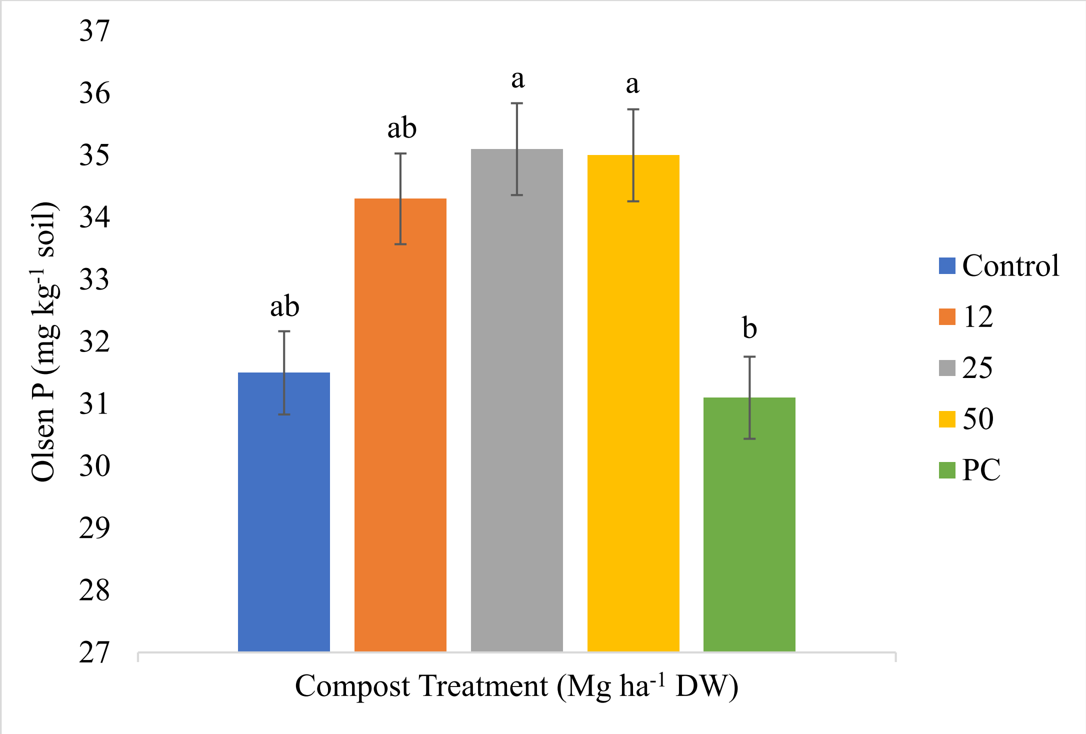

FIGURE 6 Main effects (n=2) of compost application on available P (Olsen). Available soil P concentration was significantly elevated at 25 and 50 Mg ha^{-1} ($p<0.05$) compost (NC, negative control and PC, anhydrous ammonium). Error bars indicate ± standard errors. Means designated by different letters are significant at $p<0.05$.

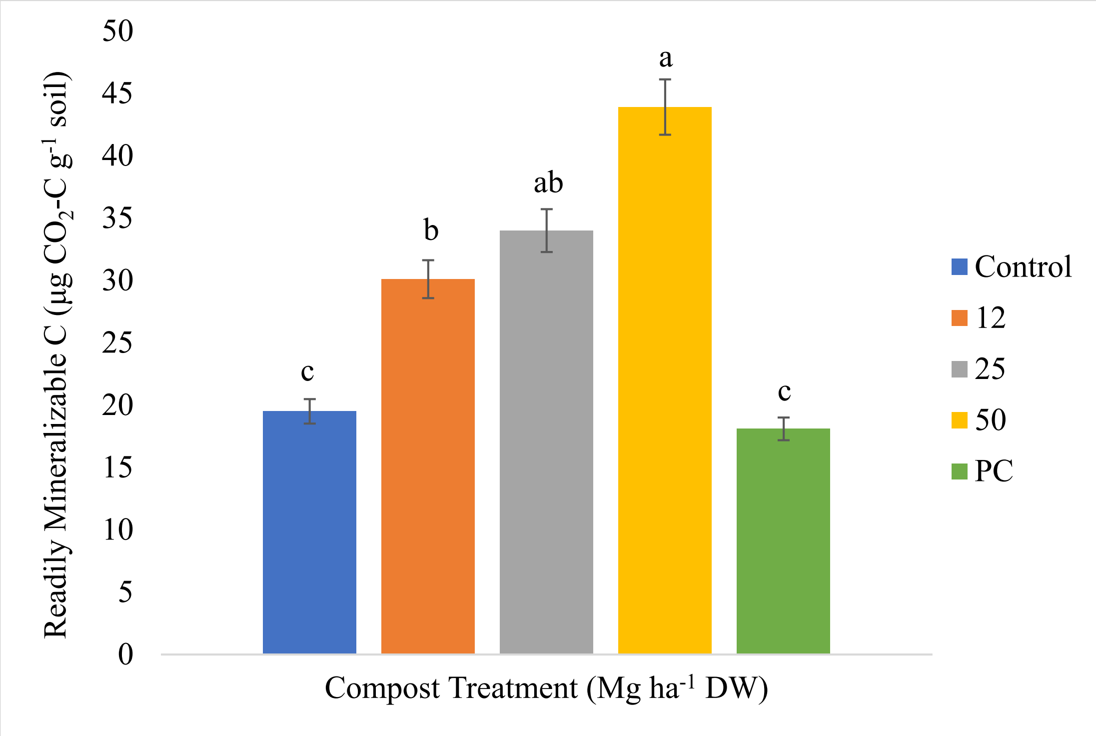

FIGURE 7 Main effect means (n=2) of compost on soil readily mineralizable C (RMC) µg CO_2-C g^{-1} soil was statistically significant ($p=0.003$) at 50 Mg ha^{-1}. RMC increased linearly with compost application rate (NC, negative control and PC, anhydrous ammonium). Error bars indicate ± standard errors. Means designated by different letters are significant at $p<0.05$.

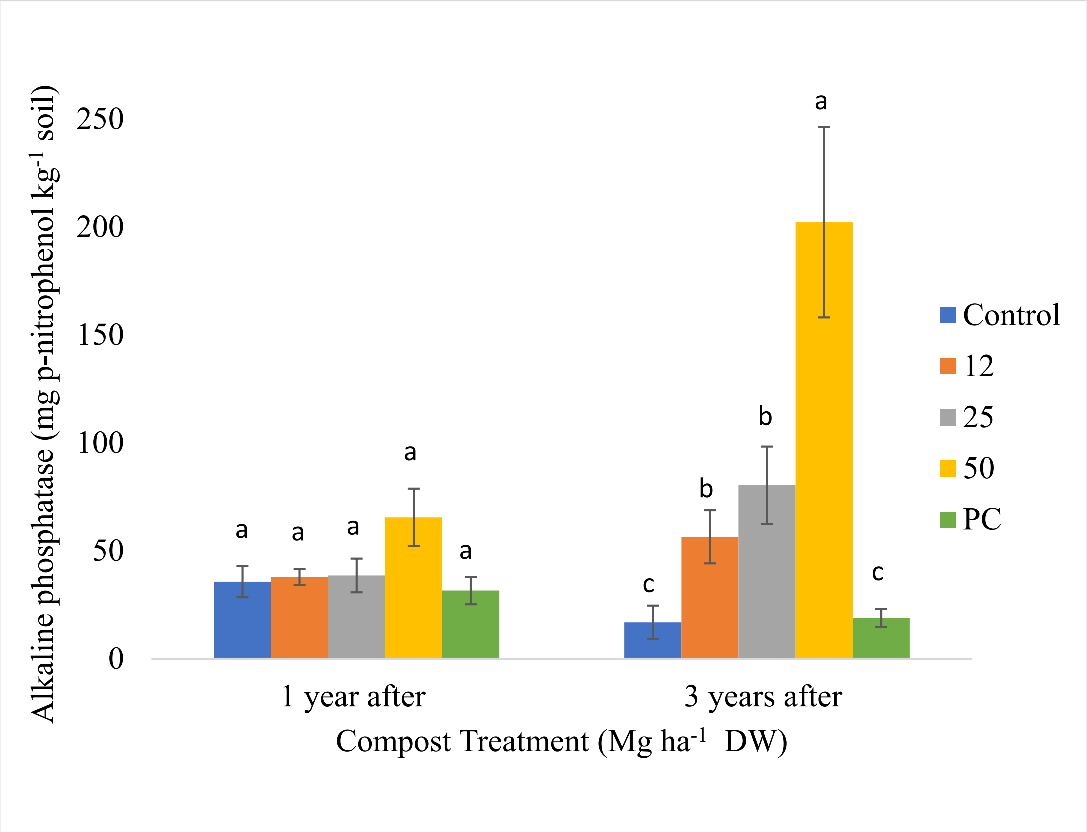

FIGURE 8 Interaction effect (n = 2) of compost and year after application on alkaline phosphatase (AP) enzyme assay. There was no significant difference in the first year while the compost significantly ($p<0.0001$) increased AP in the third year with the highest response at the compost application rate of 50 Mg ha^{-1}. NC, negative control and PC, anhydrous ammonium. Error bars indicate ± standard errors. Means designated by different letters are significant at $p<0.05$.

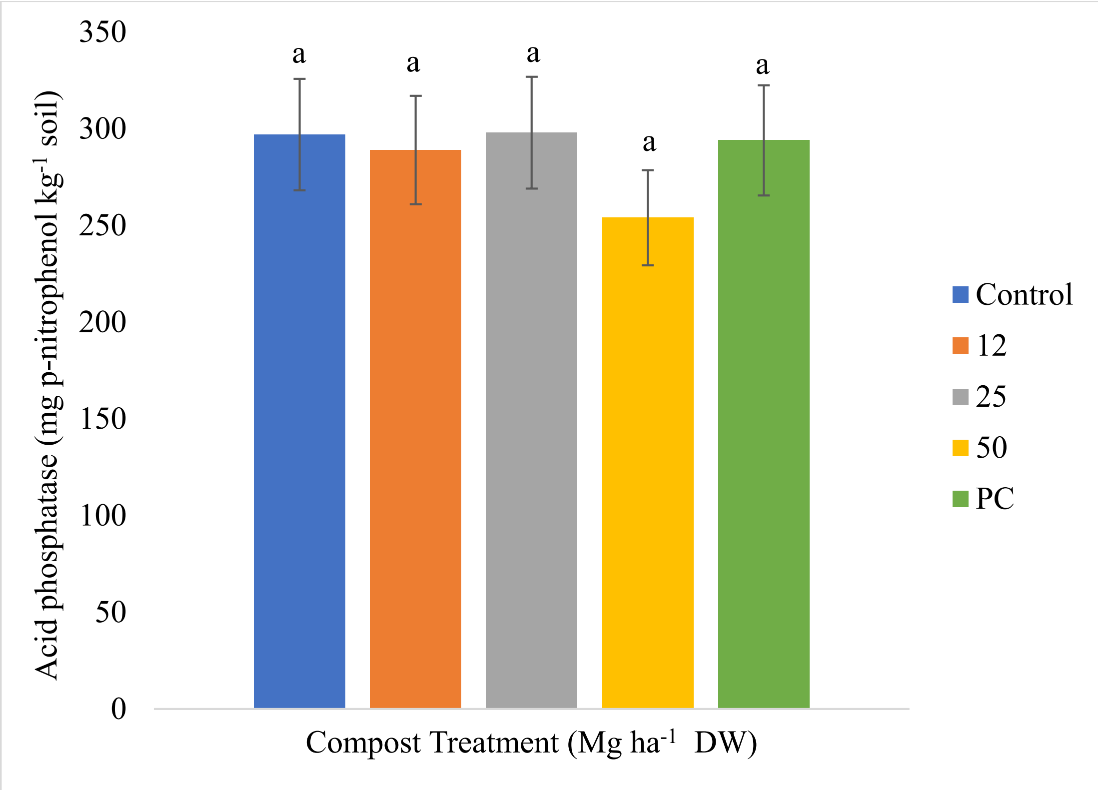

FIGURE 9 Effects of compost treatment for acid phosphatase enzyme assay was not significant among the treatments. (PC, anhydrous ammonium). Error bars indicate ± standard errors. Means designated by different letters are significant at $p<0.05$.

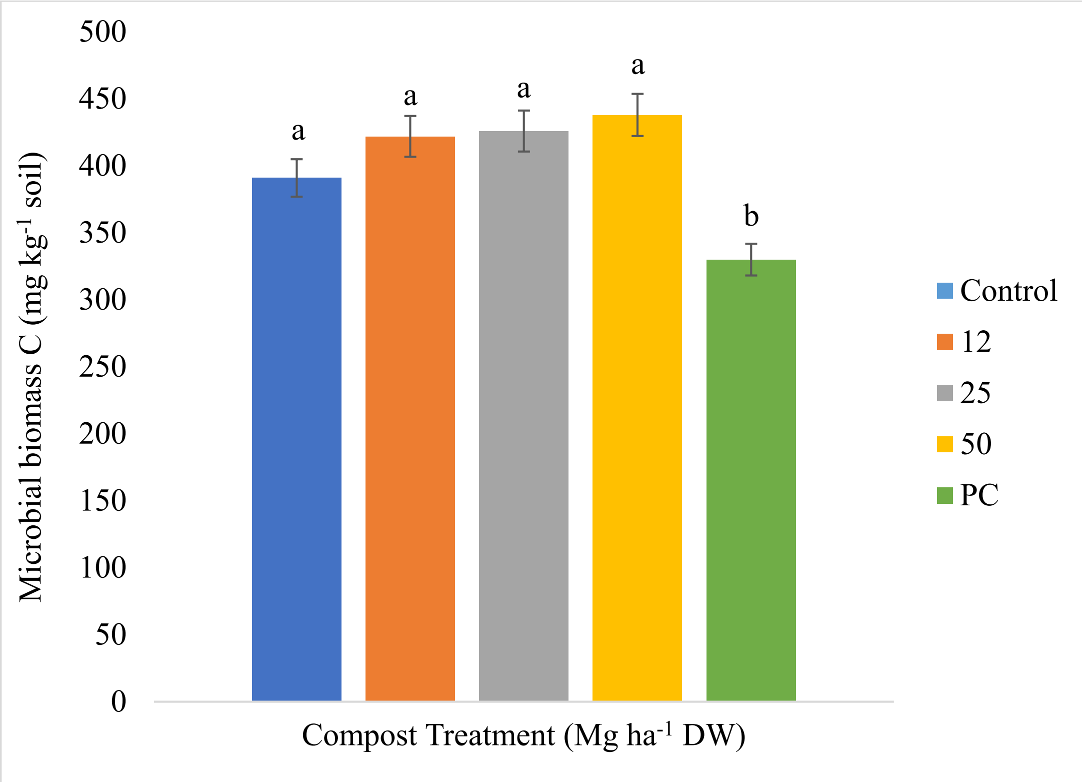

FIGURE 10 Main effect means (n=2) for compost on soil microbial biomass were not significantly affected by compost application rate but the fertilizer check (PC, anhydrous ammonia) which was significantly lower ($p=0.005$). Error bars indicate ± standard errors. Means designated by different letters are significant at $p<0.05$.

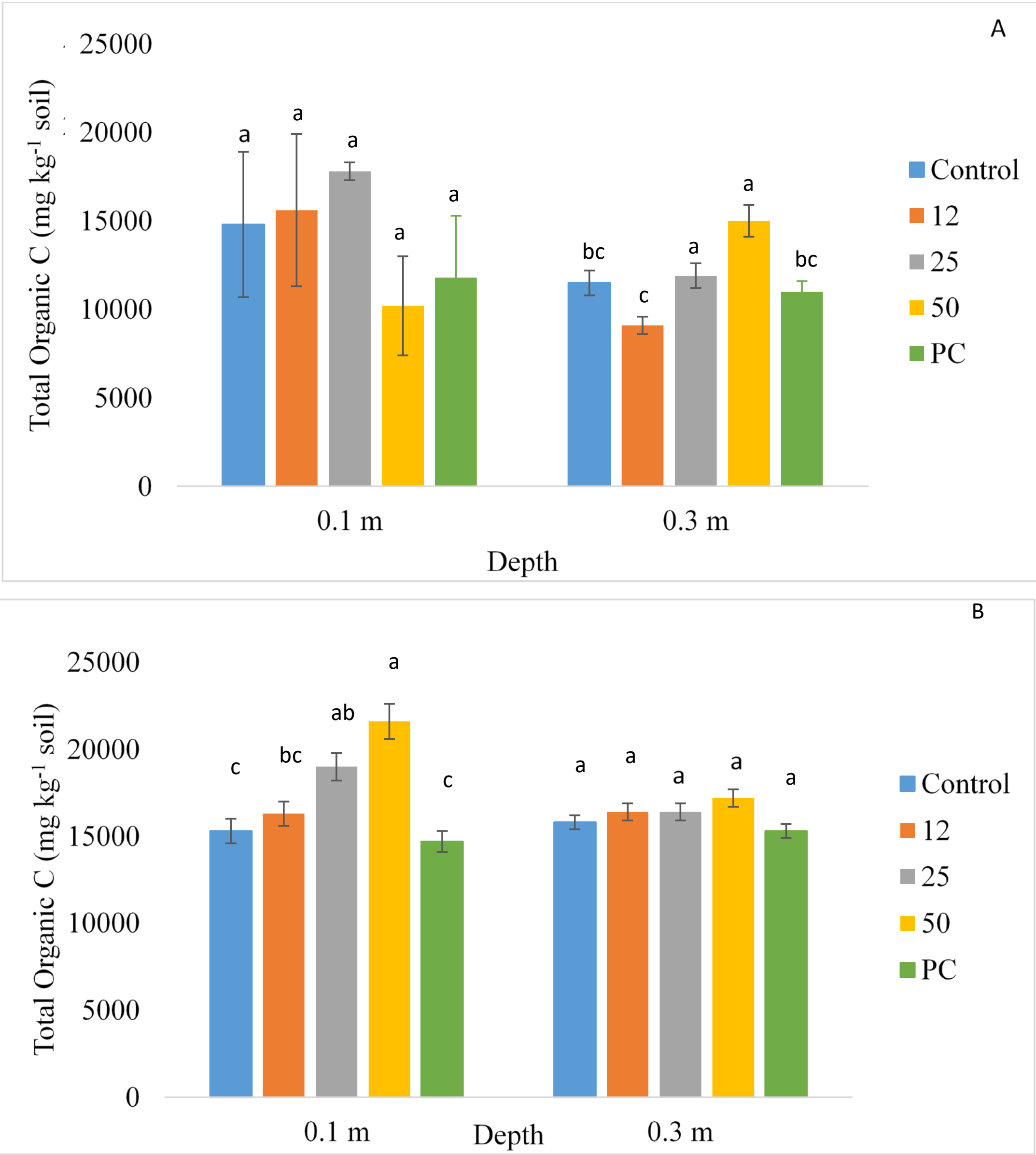

FIGURE 11 Interaction effects of compost with year after application and depth on total organic carbon (mg kg $^{-1}$ soil). Panel A is the first year after compost application (2013) and Panel B is the third year after compost application. Error bars indicate ± standard errors. Means (n=2) designated by different letters are significant at p=0.05.

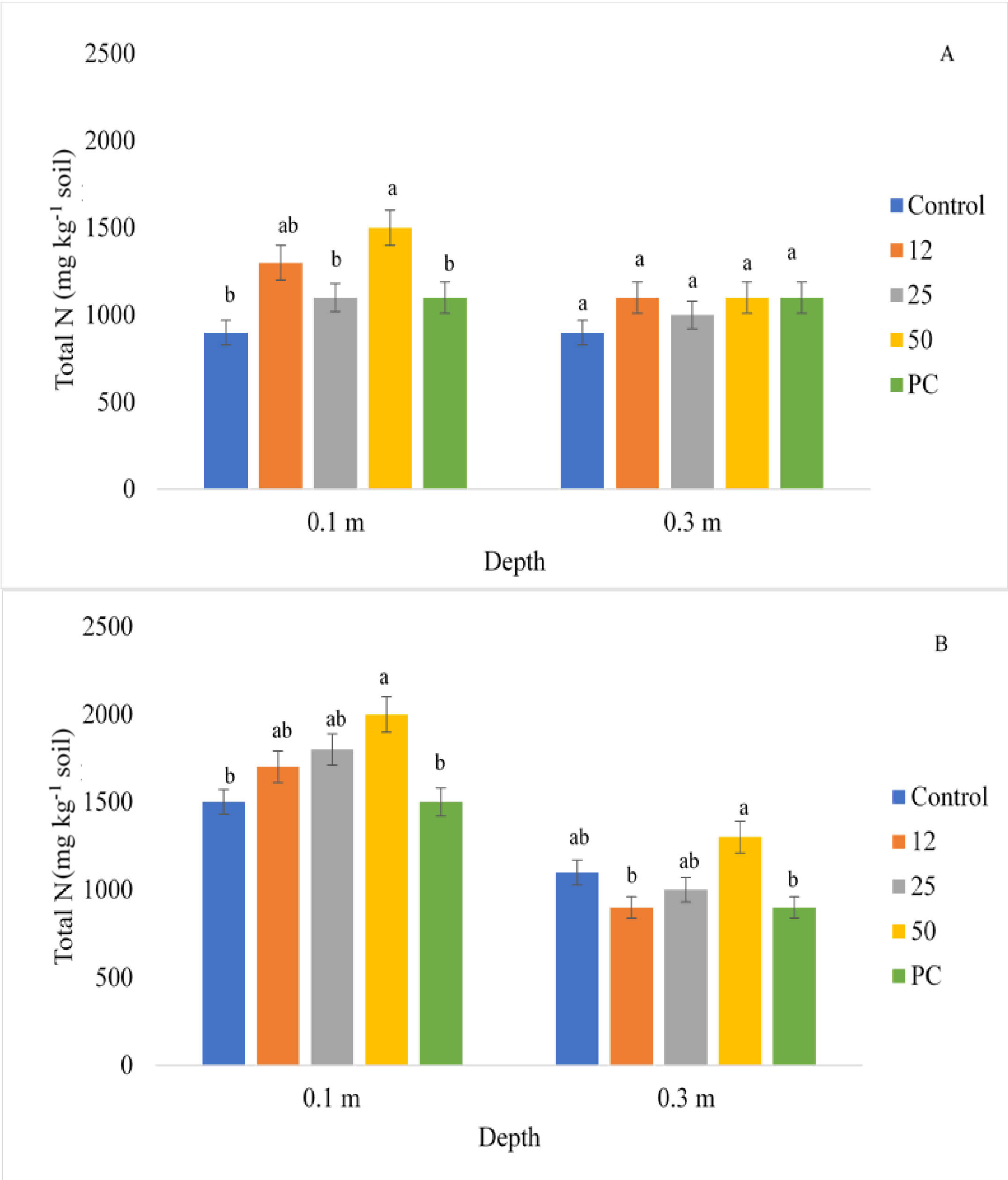

FIGURE 12 Interaction effect of compost, year after application and depth on total soil N. Panel A: total N (mg kg-1 soil) one year after compost application showed the highest compost application rate was significantly (p=0.01) different from the other treatments at 0.1 m depth while there was no significant difference amongst the treatments at 0.3 m. Panel B: increased total N was observed Near Infrared (NIR) reflectance spectroscopy with a Bran-Luebbe InfraAlyzer 2000, three years after compost application at 0.1 m depth in comparison with 0.3 m and 50 Mg ha^{-1} was

significantly ($p=0.001$) different at both depths. Error bars indicate ± standard errors. All other means ($n=2$) designated by different letters are significant at $p<0.05$.

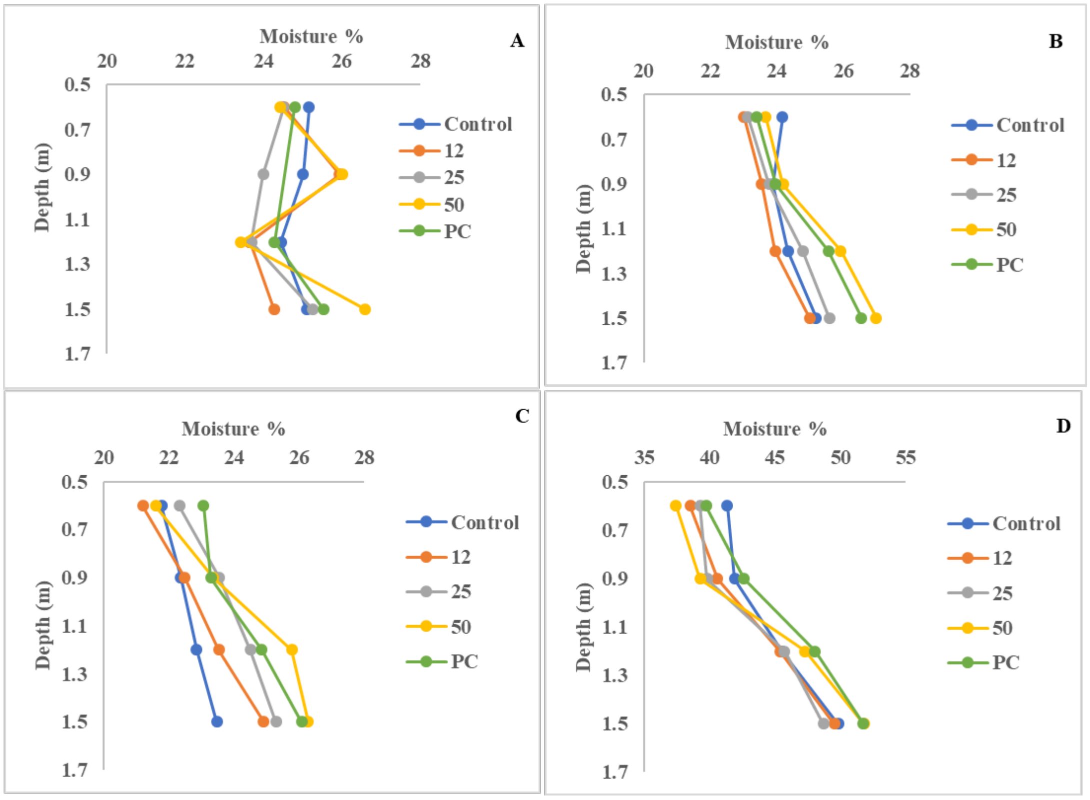

FIGURE 13 Effect of compost on water availability over time one year after compost application (2013), PC (Anhydrous ammonium). Panel A is early-May, Panel B is mid-May, Panel C is early-June, and panel D is mid-June.

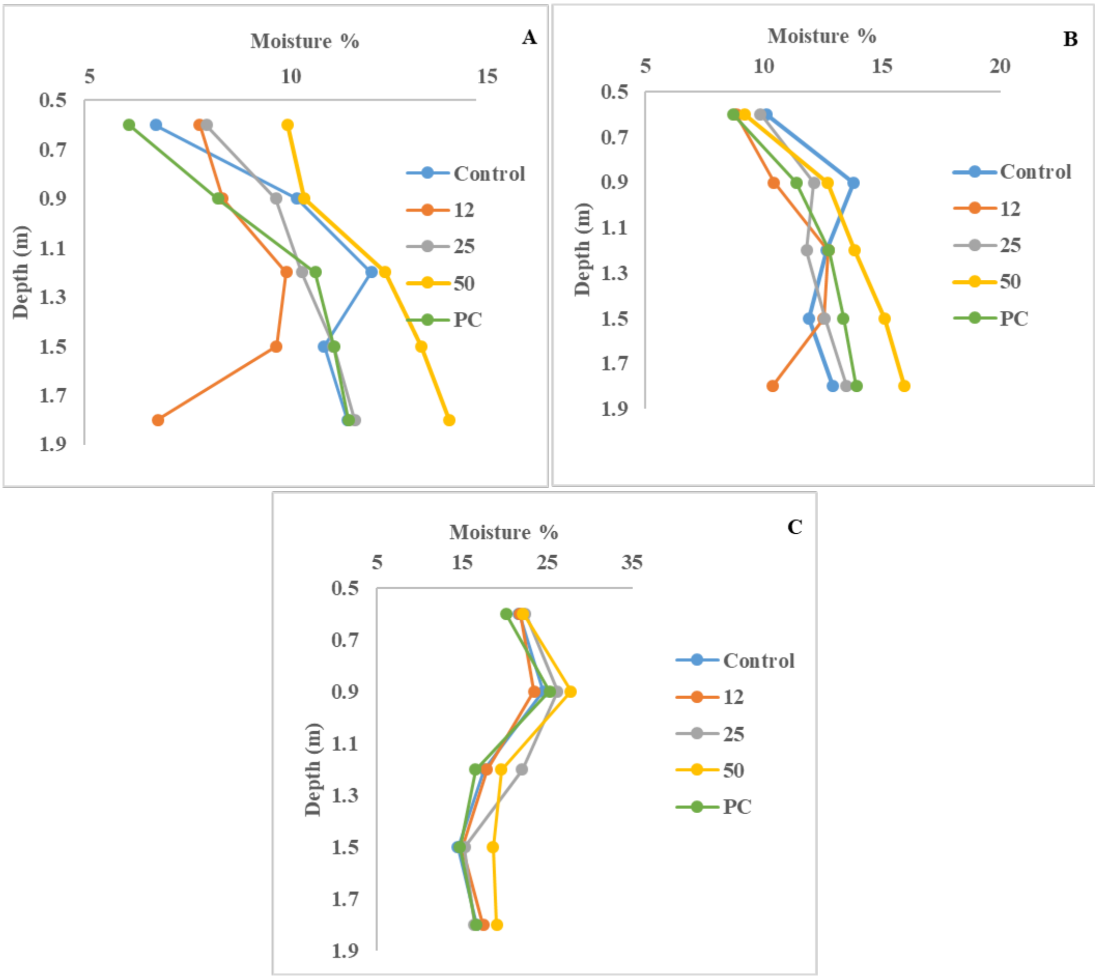

FIGURE 14 Effect of compost on soil water availability three years after compost application (2015), PC (Anhydrous ammonium). Panel A is early May, panel B is mid-May and panel C is late May 2015.

TABLES

TABLE 1 Comparison of site characteristics the two locations (Snowville and Blue Creek).

Site Characteristics	Snowville	Blue Creek
pH	8.6	7.2
ECe (µs/cm)	195	84
$CaCO_3$ (%)	18-28	0-20
Total Annual precipitation (mm)	345	521

TABLE 2 Total precipitation (mm) for 7 days before each moisture data collection.

Year	2013		2015
Period			
Early-May	7.62	Early-May	0
Mid-May	29.97	Mid-May	12.95
Early-June	12.19	Late-May	21.08
Mid-June	0		
Total (mm)	**49.78**	**34.03**	**34.03**

TABLE 3 Compost properties. Concentration reported on a dry weight basis.

Property	2011 Compost	2012 Compost
Dry Matter, (%)	73.45	86.98
Potassium, (%)	0.82	1.04
Phosphorus, (%)	0.5	0.6
Calcium, (%)	4.09	4.66
Copper, (mg kg-1)	95.4	42.2
Iron, (mg kg-1)	4853	6394
Manganese, (mg kg-1)	230	224
Zinc, (mg kg-1)	255	260
Magnesium, (%)	0.83	0.69
Sulphur, (%)	0.3	0.36

TABLE 4 Interaction effects of compost with year and soil depth on ammonium (NH^{4+}-N), nitrate (NO^{3-}-N) and dissolved organic carbon (DOC). LSMeans are presented within the depth, and different letters indicate significantly different treatment means at $p<0.05$.

Effect		NH^{4+}-N	NO^{3-}-N	DOC
Compost rates (Mg ha^{-1} DW) 2013	Depth (cm)			
0	0-30	0.21a	3.68	28.6
12	0-30	0.32a	4.19	27.33
25	0-30	0.07ab	3.17	32.02
50	0-30	0.15	4.17	22.84
PC	0-30	0.002	2.76	23.66
0	30-60	0.3	6.28	33.21
12	30-60	0.19	8.82	21.51
25	30-60	-	7.5	34.86
50	30-60	0.27	7.88	34.75
PC	30-60	0.23	4.02	31.11
0	60-90	0.11	6.57	19.83
12	60-90	0.05	8.83	18.56
25	60-90	0.15	7.84	28.47
50	60-90	0.01	6.4	20.21
PC	60-90	0.15	6.74	16.8
Compost rates (Mg ha^{-1} DW) 2015	Depth (cm)			
0	0-30	0.66	2.92	3.69b
12	0-30	2.17	3.81	5.47ab
25	0-30	1.75	2.86	5.55ab
50	0-30	1.37	2.15	7.18a
PC	0-30	2.47	4.81	3.63b
0	30-60	0.65	1.12ab	3.65
12	30-60	0.81	0.95ab	3.88
25	30-60	0.57	0.89b	5.35
50	30-60	1.03	0.69b	3.99
PC	30-60	1.2	2.14a	4.29
0	60-90	0.73	1.55a	3.29
12	60-90	0.98	1.00ab	4.24
25	60-90	0.66	1.1ab	3.53
50	60-90	1.02	0.51b	3.67
PC	60-90	0.7	1.95a	3.97

TABLE 5 Analysis of variance table for ammonium (NH^{4+}-N), nitrate (NO^{3-} -N) and dissolved organic carbon (DOC) as influenced by compost, year, depth and their interactions.

	NH^{4+}-N	NO^{3-}-N	DOC
ANOVA p- values			
Compost (C)	0.8482	0.7002	0.3443
Year after application (Y)	0.0001	0.0001	0.0001
Depth (D)	0.0595	0.0011	0.0001
Y x C	0.0294	0.0001	0.2652
C x D	0.0252	0.231	0.5543
Y x D	0.013	0.0001	0.12
Y × C × D	0.0025	0.1395	0.065

TABLE 6 Interaction effects (n=2) of compost and year after application on soil properties.

Effect	pH	EC $\mu S\ cm^{-1}$	BR $mg\ kg^{-1}$ soil	DHA mg TPF kg^{-1} soil
Compost rates 2013				
0	7.08a	92.8b	3.01bc	2.40ab
12	7.03a	111.3ab	4.93ab	3.37a
25	7.06a	107ab	6.93a	2.86ab
50	7.34a	140a	7.94a	3.05ab
PC	6.96a	89b	2.3c	2.21b
Compost rates 2015				
0	6.34c	100.4b	0.34a	2.22a
12	6.85b	122.9ab	0.32a	2.04a
25	7.05b	126.1ab	0.29a	2.41a
50	7.64a	137.2ab	0.25a	2.09a
PC	6.04c	162.1a	0.34a	2.31a
ANOVA p- values				
Compost (C)	0.0032	0.1964	0.1962	0.7385
Year after application (Y)	<0.0001	0.0003	<0.0001	0.0005
Y x C	<0.0001	0.0014	<0.0001	0.0337

Different letters within a column indicate significantly different treatment means $p<0.05$.

TABLE 7 Main effects (n=2) of compost application rate on soil potassium and micronutrients.

Treatment	K	Fe	Mn	Cu	Zn
			mg kg^{-1}		
0	465a	19.5a	45.8a	1.7a	1a
12	488a	19.1a	41.3ab	1.3a	1.1a
25	506a	18.8a	42ab	1.4a	1.2a
50	523a	15.3a	34.1b	1.2a	1.3a
PC	513a	19.6a	44.8a	1.3a	0.9a
ANOVA p- values					
Compost (C)	0.2739	0.2369	0.0334	0.4533	0.0873
Year after application (Y)	<0.0001	0.0032	<0.0001	<0.1626	0.5037
Y x C	0.4505	0.1153	0.5521	<0.0838	0.093

Values in parenthesis indicate standard error. Different letters within a column indicate significantly different treatment means $p<0.05$.

CHAPTER III

GENERAL CONCLUSIONS

This study's objective was to examine the effects of compost on wheat yield and quality in a continuous wheat-fallow rotation system under dryland conditions. We evaluated the effects of different compost rates and a single rate of conventional fertilizer on soil quality and water availability in a dryland organic wheat system. We hypothesized that compost incorporation would increase soil moisture, soil fertility, and quality in a dryland wheat system, and that yield and quality of winter wheat will increase after a one-time compost application. Increased wheat yield was observed three years after application at 50 Mg ha^{-1} plots compost rate only while conventional fertilizer only increased grain protein. Mineralizable C, microbial biomass, and phosphatase enzyme activity increased significantly at all compost rates, while available soil P increased at the 25 and 50 Mg ha^{-1} rates and total soil N at the 50 Mg ha^{-1} rate. A lack of yield response to conventional fertilizer suggests improved soil health and/or soil moisture was responsible for improved yields at the high compost rate. The percent yield increase due to compost was 30%, and this is relatively low compared to earlier results published (2-fold yield increase) in a drier winter-wheat fallow site in Snowville. The lack of response in grain protein following compost application may be related to low N availability compared with conventional fertilizer. Predicting the economic benefits of compost on soil health and yield may be mediated by variation in soil properties and microclimatic conditions, which could likely affect the compost's effects. However, despite the documented evidence of compost on soil health from this research and previous works, the growers' adoption rate is slow because of the time it takes to breakeven. To scale back the breakeven years and increase the adoption rate, best management strategies that will enhance long-term soil productivity with less input for more output should be employed, minimum compost application that will increase the net returns through increased yield, grain protein content that translates to high premium. Further research is needed on soil organic matter changes and water availability and may be leguminous cover crops can enhance compost carry-over effects by supplying N, which is marginal in semi-arid soils.