INTERACTIONS BETWEEN BIOCHAR AND COMPOST IN ORGANIC WINTER WHEAT PRODUCTION AND SOIL QUALITY UNDER DRYLAND CONDITIONS

by

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A thesis submitted in partial fulfillment of the requirements for the degree of

MASTER OF SCIENCE

in

Plant Science

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2018
ABSTRACT

Interactions Between Biochar and Compost in Dryland Organic Winter Wheat Production and Soil Quality Under Dryland Conditions, Utah, USA

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Nitrogen and moisture availability are considered the most limiting factors in producing organic wheat in rain-fed semi-arid areas. The objective of this study was to determine whether using a mixed compost-biochar application results in synergistic improvements in organic wheat yield, wheat quality, and soil quality. ‘Juniper’ hard red winter wheat (Triticum aestivum L.), was planted. The experiment was a field trial conducted on a United States Department of Agriculture certified organic wheat production farm in a semi-arid area near Snowville, Utah, United States. The experimental design was split-plot with two compost treatments comprising the whole plots. The compost treatments included a control (0 Mg ha\(^{-1}\)) and an application of dairy manure compost at 18 Mg ha\(^{-1}\) (8 ton ac\(^{-1}\)). There were three replications of whole plot treatments. Split-plot treatments included four biochar application rates: control (0), 2, 10, and 40 Mg ha\(^{-1}\). Biochar was produced from lodgepole pine pyrolized between 550 °C and 600 °C. Soil types were silt loam, sandy loam, and sandy clay loam.
Composts had significant effects on nitrate nitrogen ($\text{NO}_3^- - N$), potassium (K), sulfate-sulfur (S), and manganese (Mn) in the soil. Compost application also had a significant effect on soil dehydrogenase activity (DHA). Biochar significantly increased total carbon (TC), pH, Mn, copper (Cu), and soil moisture. Compost increased wheat yield 1.7 times in comparison to control. Neither biochar nor compost had impacts on test weight or protein of the wheat. However, interactions between compost and biochar significantly impacted predicted loaf volume. Wheat flour mixographs in this study ranged from assigned strengths of 3M to 6H. Without compost application, the mixograph types ranged from 3M to 4H. With compost application, all mixograph types ranged from 3H to 5H, which were considered desirable characteristics for bread. Compost had a slight positive impact on wheat flour mixographs in this study.

It is difficult to quantify effects of biochar and compost application on organic winter wheat systems because of complicated interactions between biochar, compost, and environmental factors. To assess the impacts of biochar and compost on soil quality and plant production for a rain-fed dryland farming system, testing in field conditions during long-term experiments is required and should not be substituted with measurements from laboratory conditions. Since the soil moisture in dryland systems is limited, soil disturbance activities should be taken into account.

Keywords: organic wheat, biochar, compost
PUBLIC ABSTRACT

Interactions Between Biochar and Compost in Dryland Organic Winter Wheat Production and Soil Quality Under Dryland Conditions, Utah, USA

Phearen Miller

Organic wheat grown under dryland conditions encounters challenges such as limited nutrients and water. Maintaining organic wheat production requires solutions to these problems in order to retain economic sustainability for the farmers.

Research on biochar and compost have been conducted globally. Despite well known benefits of compost on soil and crop production, few organic farmers apply compost to their fields. Research on biochar is still new. Biochar is charcoal created from pyrolyzing agricultural material under conditions of low oxygen and high heat. Many studies claim that biochar is a valuable soil amendment for improving organic production and reducing environmental pollution (such as greenhouse gas emission, water pollution, or nutrient leaching). It may hold more moisture in the soil and retain nutrients. We conducted a study on the interactions between biochar and compost in organic winter wheat production and soil quality under dryland conditions. We analyzed the response to biochar and compost, and investigated individual and combined effects on wheat yield, wheat quality, and soil quality.

This study revealed that compost had significant impacts on increasing wheat yield and had slight impacts on soil quality while biochar had none to slight impacts on soil and wheat production. We validated the usefulness of compost for organic wheat production in dryland condition, but found no real benefit for biochar in this first year.
ACKNOWLEDGMENTS

I would like to thank the United States Department of Agriculture National Institute of Food and Agriculture, Organic Agriculture Research and Extension Initiative, Utah Agricultural Experiment Station, and Utah State University for funding this research.

I would also like to thank my committee (Dr. David Hole, Dr. Paul Grossl, Dr. Richard Beard, and Dr. Earl Creech) for their support, assistance, and editorial reviews.

In particular, I would like to thank Dr. David Hole and Mr. Myles Miller for editing assistance going above and beyond the call of duty.

I give special thanks to Ms. Amanda Miller, Mrs. Pamela Hole and Dr. David Hole for their support and generosity.

I also would like to thank the farm owner, Mr. David Deakin, and Green Mountain Grain for their cooperation and allowing us do the experiment on their farm. In addition, I would like to thank Mr. Justin Clawson, Mr. Adam Aguillón, Mr. Cody Mozingo, Mr. Tyler Roberts, Mr. Idowu Atoloye, Mr. Sarit Chanprame, Mrs. Shuyang Zhen, and Mrs. Crista Sorenson for technical assistance. I also want to thank the faculty and staff of the Plants, Soils and Climate Department for their mentoring and friendship.

I give a special thanks to my husband, parents, and family for their encouragement and patience. I could not have done it without all of you.

Phearen Kit Miller
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CHAPTER I: INTRODUCTION

Sustainability of dryland crop production will play an important role in feeding the world’s increasing population. Success of agriculture in dryland farming is dependent on farmers’ ability to manage nutrient deficiency and water (Peterson et al., 2006). Relatively few crops can be economically produced using a rain-fed production system in areas with low rainfall. Wheat is a major crop grown in temperate, semi-arid, cultivated areas. Under dryland conditions, nitrogen and moisture availability in the soil are limiting factors in crop production (Lenssen et al., 2007). To increase yield, farmers often spend money adding nutrients to their fields. Some studies have reported benefits of biochar and compost functioning as the organic soil amendments for improving crop yield and soil fertility. Purchasing fertilizer can be a risky investment due to factors such as unfavorable weather, soil conditions, and other environmental factors. Additionally, they may face problems such as soil quality degradation and erosion, which can lead to reduced production.

Consumers are beginning to express concerns about wheat quality and environmental degradation. They are willing to pay more for food produced using sustainable agricultural practices. Therefore, organic wheat farming is becoming more popular among wheat producers in dryland areas. However, production of consistent, inexpensive organic wheat with acceptable end-use quality is difficult. Some studies have reported benefits of biochar and compost functioning as the organic soil amendments for improving crop yield and soil fertility (Trupiano et al., 2017). Biochar and compost can be
used as organic soil amendments certified by the Organic Materials Review Institute (OMRI). These may enhance environmental quality by sequestering carbon (C) in the soil, retaining soil moisture, increasing plant nutrient availability, and increasing plant productivity. These findings are usually based on greenhouse research or use a mixed application of compost and/or biochar with inorganic fertilizers. As a result, they may be less applicable in real-world organic farming. More research is required on the utilization of biochar and compost in organic wheat production under field conditions. Farmers need more information on strategies to manage water use, retain soil moisture, reduce erosion, and manage nutrients on their farm to increase productivity with less water use.

Organic Wheat

The United States of America (USA) is the world’s largest organic market. In 2015, the growth of organic markets in the USA was 11.5% (IFOAM, 2016). According to International Federation of Organic Agriculture Movements (IFOAM) (2016), the USA was the leading organic market with 27.1 billion Euros, followed by Germany (7.9 billion Euros), France (4.8 billion Euros), and China (3.7 billion Euros). The increasing market demand for organic products encourages more producers to explore the possibilities of certified organic production, including organic small grains.

To grow organic small grains, farmers must utilize specific codified practices. They are not allowed to use certain conventional inputs such as inorganic fertilizers, synthetic pesticides, herbicides, or fungicides. Natural substances such as soaps, lime sulfur, and hydrogen peroxide are allowed to be used as pesticide ingredients in organic farming production (Nipic.orst.edu, 2017). Those ingredients need to meet the national
list of allowed and prohibited substances, which is maintained by the United States Department of Agriculture (USDA) (USDA.gov, 2012). Potent natural extracts such as pyrethrin, derived from chrysanthemums, and azadirachtin, from the Asian neem tree, are allowed to be used as organic pesticides as well (NPR.org, 2011). In the USA, dryland organic wheat production in the semi-arid west comprises a large percentage of the total organic wheat acreage (Reeve and Creech, 2015). To maintain soil fertility, they use animal waste, compost, or green manures (Wander, 2015).

Summer Fallow Farming Practices on Organic Wheat

Much of the dryland wheat production in the inter-mountain west utilizes a crop fallow production system. According to Peterson et al. (2006), the success of agriculture under dryland farming conditions depends on farmers’ ability to manage water. In the 1890s, farmers started to recognize the benefit of summer fallow in conserving soil moisture (Manitoba Historical Society, 2009) and it has been widely used in semi-arid and arid areas of West Asia and North America (Nielsen et al., 2011). According to Nielsen et al. (2011), about 15 western states in the United States have been practicing summer fallow. Farmers in dryland areas adopted summer fallow because summer fallow was good for soil moisture conservation for the next season as well as providing additional time for crop residues to break down, return nutrients to the soil for the subsequent crop, and provide breaks in insect and disease cycles (Smith and Young, 2000; Manitoba Historical Society, 2009). Additionally, farmers believed this practice would increase their chance for economic success in farming (Lyon et al., 2007; Lyon and Hergert, 2012).
Although the summer fallow management system provides some benefits to farming in semi-arid areas, it also has some disadvantages. Long term summer fallow can degrade soil quality through wind and water erosion, soil organic matter depletion, and increased soil salinity (Smith and Young, 2000; McInnis, 2004). When mechanical tillage is used, frequent use of summer fallow may result in increased soil erosion, loss of soil C, and decreased soil structure quality. This results in reduced grain yields and protein content of cereal crops (Lyon and Hergert, 2012). In addition to soil issues, summer fallow may constrain farmers’ incomes. Farmers have to recoup their cost and make up for the lost production in subsequent years because the fallow year produces no crop for sale (University of Saskatchewan, 2006). Over the past forty years, agroecologists have worked with farmers to develop management systems that make better use of limited soil water while reducing the need for summer fallow. The key to these systems is better snow trapping. This is achieved with conservation tillage practices such as direct seeding, which leaves the crop residue standing to trap snow and improves water conservation by reducing evaporation losses associated with tillage (Agriculture and Agri-Food Canada, 2016).

Sources of Nitrogen for Organic Crop Production

In organic farming, nitrogen (N) deficiency is one of the biggest challenges. Compost, animal manure, and green manure are considered the main sources of N for organic farming (Robert, 2016). Integrating animal waste into organic production systems through direct application of animal manure or compost provides N for the production system. Green manures allow N fixation as a source of fertility.
Compost and Animal Manure as the Nitrogen Source for Organic Crop Production

Composted animal waste is one of the best sources of plant available nitrogen (PAN) for organic grain production. Not all nutrients present in manure/compost are immediately released (Endelman, 2009). Nutrients become available for uptake over time. About 1-3% of total N year\(^{-1}\) will become available in composted manure (Al-Bataina et al., 2016). According to Eghball and Power (1999), about 15% of N was available in the first year after applying compost, and about 8% of N was available in the second year. According to Mangan et al. (2013), 10-30% of N becomes available for the plant in the first year and some remaining nutrients become available in the subsequent year at a much slower rate. Decomposition and PAN is widely variable dependent on type of compost (Gale et al., 2006).

In addition to precipitation, which affects grain production, the slow release of N into the soil is a major factor in reducing PAN. Nitrogen is the most limiting nutrient for global food production. Although air is 78% N, it is unavailable to plants until it is fixed in a form available to plants, such as ammonia or nitrate (Science Learning Hub, 2013). Decomposition of organic N into plant-available forms takes several months or years to complete.

Animal manure is another source of N for the crop. Animal manure contains large amounts of N, but most N is in the form of ammonia, which is subject to loss through volatilization (Robert, 2016). Timing of nutrient release is highly variable and may not be available for plant uptake (Endelman, 2009). Other methods of enhancing sufficient N supply in organic farming are through the use of cover crops and green manures.
Green Manure

In 1849, Boussingault in France presented evidence that leguminous plants could fix atmospheric dinitrogen. His observations were contested until the experiments of Hellriegel and Wilfarth, in 1886, convinced the skeptics (Burris and Roberts, 1993). Biological soil fixation occurs in legume plants through a symbiotic relationship with *Rhizobium* bacteria (Lyon and Hergert, 2012). It is difficult to estimate the yield of annual biological fixation of N, which likely varies from $1.0 \times 10^8$ to $1.8 \times 10^8$ metric tons of N per year (Burris and Roberts, 1993).

Many organic farming systems introduce leguminous plants as green manure or as rotational crops to increase N content in the soil (Lyon and Hergert, 2012). Organic farmers in semi-arid areas use legumes to increase yields and crop quality. According to Jones and Olson-Rutz (2012), the longer a green manure crop is allowed to grow, the more N is fixed, especially with irrigation or in areas with adequate soil moisture. However, using green manure crops did not increase yield in semi-arid dryland conditions (Lyon and Hergert, 2012). After using green manure, grain yield and test weight were reduced.

Sorenson (2017) also demonstrated decreased yield of winter wheat following green manure crops in the semi-arid Snowville, Utah area. The reasons for decreased wheat yields were likely the result of soil moisture loss and a delay in N release from green manure decomposition. Similar research found that winter wheat yields were correlated with soil moisture at planting (Nielsen et al., 2002; Stukenholtz et al., 2002). To avoid reducing crop yields following green manure, farmers should consider
balancing the water used by green manure and wheat, which may be difficult in semi-arid regions (Jones and Olson-Rutz, 2012).

Biochar

Biochar Characteristics

Biochar is a form of charcoal produced at a relatively low temperature (400-700 °C) using oxygen-starved combustion (pyrolysis) of carbonaceous biomass (Lehmann and Joseph, 2015). Biochar can be made from materials such as wood chips, plant residues, manure, or other agricultural waste products (International Biochar Initiative, 2018). Biochar is used as a soil amendment, which results in carbon sequestration and mitigation of global warming effects by reducing carbon dioxide, nitrous oxide, and methane emission (Jindo et al., 2014). Different feedstock types and pyrolysis conditions effect biochar quality including physical and chemical properties, such as the pH and surface area of biochar (Jindo et al., 2014; Wang et al., 2013).

During low temperature pyrolysis, the yield of biochar derived from rice material was higher than the yield of biochar derived from wood material (Jindo et al., 2014). Yields of biochar at pyrolysis temperature of 400 °C obtained from rice husk and rice straw were 48.6% and 39.3%, respectively, while yields of biochar obtained from apple tree branches and oak tree wood were 28.3% and 35.8%, respectively. At a pyrolysis temperature of 800 °C, yields of biochar obtained from rice husk and rice straw were 32.0% and 18.3%, respectively, while yields of biochar from apple branches and oak wood were 15.5% and 19.1%, respectively. Crop residue material produced higher yields of biochar than the wood based material and higher pyrolysis temperature conditions.
produced lower yields of biochar than lower pyrolysis temperature conditions.

Different types of feedstocks and pyrolysis temperatures also influence the pH of biochar. Multiple studies have found that high temperature pyrolysis produces higher pH biochar (Jindo et al., 2014; Wang et al., 2013). The pH of crop-based biochar at 500 °C and 700 °C were 9.2-10.7 and 10.7-11.1, respectively, while the pH of wood-based biochar at 500 °C and 700 °C were 7.8-10 and 8.9-10.5, respectively (Wang et al., 2013). They concluded that crop-based biochars had higher pH value than wood-based biochars under similar pyrolysis conditions.

Wood stocks produced higher surface areas of biochar than crop residue stocks at higher temperatures of pyrolysis. At a pyrolysis temperature of 400 °C, the surface area of biochar obtained from rice husk and rice straw were 193 m²g⁻¹ and 46.6 m²g⁻¹, respectively, while surface areas of biochar obtained from apple branches and oak wood were 11.90 m²g⁻¹ and 5.60 m²g⁻¹, respectively. At a pyrolysis temperature of 800 °C, surface areas of biochar obtained from rice husk and rice straw were 295.57 m²g⁻¹ and 256.96 m²g⁻¹, respectively, while apple branches and oak wood were 545.43 m²g⁻¹ and 398.15 m²g⁻¹, respectively (Jindo et al., 2014). At 800 °C, the surface area of rice husk and rice straw diminished while those of apple branches and oak wood expanded. This may be attributed to the high ash content in biochar that filled or blocked access to microspores which led to the lower surface area of the biochar (Jindo et al., 2014). Additionally, surface area development of biochar was influenced by residence time and gas flow rate during pyrolysis which had impacts on development of porosity of the biochar (Novak et al., 2009b). At a pyrolysis temperature of 700 °C, biochar from pecan
shell had the highest surface area of 222 m²g⁻¹ while poultry litter had surface area of 9.00 m²g⁻¹. There is little doubt that feedstock selection and pyrolysis temperature influence total surface area of biochar.

Biochar and Carbon Sequestration

Biochar has been used as a method for carbon sequestration (Wang et al., 2013). Biochar is carbon negative and can decrease atmospheric carbon dioxide by sequestering large quantities of atmospheric C in the soil (Hofstrand, 2010). In addition, sequestering C also builds soil organic matter, which is important for soil microorganisms. Enhancing C storage in the soil is vital for microbial mediated processes, particularly soil respiration and nitrogen mineralization (Fontaine et al., 2003).

According to Novak et al., (2009a), biochar has the potential to sequester C in the soil. They found no loss of soil organic carbon (SOC) during a 67 day incubation. The biochar, which was produced from pecan shell-base, was stable and resistant to microbial attack. These qualities of biochar had potential to increase the recalcitrant pool of soil C and to persist in soil environments much longer than C added in the form of crop residues or other biogenic soil organic matter.

Effects of Biochar on Soil Fertilities

Biochar may increase soil porosity (Karhu et al., 2011). Biochar may also decrease soil bulk density and improve water retention (Basso et al., 2013; Mukherjee & Lal, 2013). Novak and his colleagues conducted an incubated laboratory study to test if pecan shell-based biochar had an impact on fertility of a southeastern coastal plain soil (Novak et al., 2009a). The biochar had a pH of 7.6, C of 834.2, and N of 3.41 g kg⁻¹.
The soil type was Norfolk loamy sand, which had a taxonomic class of fine-loamy, kaolinitic, thiemtic typic Kandiudults. They mixed soil with different rates of biochar (0, 0.5, 1.0, and 2.0% (wt/wt)) and incubated them at 10% (wt/wt) moisture for 67 days. Biochar increased SOC, soil pH, calcium (Ca), potassium (K), and phosphorous (P). Biochars from low pyrolysis paper mill waste had significant impacts on increasing cation exchange capacity (CEC), pH, and total soil C (Van Zwieten et al., 2010).

**Effects of Biochar on Soil Water Content**

Biochar has the potential to increase water holding capacity of sandy soil. Biochar made from red oak feedstock by fast pyrolysis (500 °C) was incubated for 91 days (Basso et al., 2013). Biochar was applied in two different depths, in the bottom 11.4 cm or in the top 11.4 cm, to simulate deep-banding in rows or uniform topsoil mixing. Each set of columns had three rates of biochar application (0%, 3% and 6% (wt/wt)). After incubating 91 days, it was confirmed that adding biochar into the sandy soil significantly reduced soil bulk density. They concluded that increased soil bulk density in the control treatment may have been caused by decreased water content compared with the biochar treatment. Additionally, biochar increased available water holding capacity. Little variation of gravimetric water content in the columns with biochar was observed during the incubation. However, they found significant decreases of gravimetric water content in the control treatment. The study confirmed the positive impact of biochar on soil water holding capacity, available soil water holding capacity, and maintaining the soil bulk density. They also suggested the need for field research (Basso et al., 2013).
Biochar Improves Soil Microbial Activity

Biochar also has impacts on crop growth and biological processes in plants and in the rhizosphere because of its effects on a range of chemical and physical phenomena in soil (Prendergast-Miller et al., 2014). Applying sugarcane-bagasse biochar and NPK fertilization increased soil microbial activity (Azeem et al., 2016). A significant increase of dehydrogenase activities (DHA) in the mash bean field was observed in the biochar and NPK treatment. They concluded that biochar derived from sugarcane-bagasse had positive priming effects on DHA, which could improve soil functions by revitalizing microbial activities. According to Van Zwieten et al. (2010), slow pyrolysis paper mill biochars showed variable impacts on microbial activity because of different types of soil, biochar, and crops. In their study, two biochars were produced. Biochar 1 was produced from 32.6% (by mass) enhanced solids reduction (ESR) sludge, 18.8% clarifier sludge, and 48.6% waste wood chips. Biochar 2 was derived from 19.5% ESR sludge, 11.2% clarifier sludge, and 69.3% waste wood chips. Ten ton $\text{ha}^{-1}$ of biochar was applied in pot experiments in a greenhouse. They used two types of soils (Ferrosol and Calcarosol) and three different crops (wheat, soybeans, and radishes). They found that the two biochars, with or without addition of fertilizer, made no difference in microbial activity on any crop specie or soil type, except for soybean in the Calcarosol. In the Ferrosol soil, biochar 1 impacted soil microbial activity in the soybean crop but not in other crops. In the Calcarosol soil, biochar 1 resulted in reduced soil microbial activity with wheat only. In the Ferrosol soil, biochar 2 without the addition of fertilizer decreased microbial activity in the soybean treatment, and biochar 2, with or without addition of fertilizer, decreased
microbial activity in the radish and wheat treatments. Biochar 2, with and without the addition of fertilizer, increased microbial activity in the Calcarosol soil with soybean production. They found that biochar has significant effects on microbial activity under certain conditions but results were not consistent (Van Zwieten et al., 2010).

Biochar and Nitrogen Dynamics

The impacts of biochar on N status in the soil have been studied worldwide. Some studies confirmed a positive impact, whereas others found no or negligible impact of biochar on N status in the soil. Biochar altered soil N non-uniformly due to different types of stock material and pyrolysis conditions (Prendergast-Miller et al., 2014). A study on the impacts of biochar amendment on fertility of a southern coastal plain soil demonstrated that pecan shell-based biochar resulted in no significant improvement on N status (Novak et al., 2009a). This might be because of the high C:N ratio (244:1) and high aromaticity of C (58%). This could slow down decomposition through resistance to microbial attack.

Biochar tends to have an overall negative charge, so exchange sites for cations may be increased (Prendergast-Miller et al., 2014). Yao et al. (2012) conducted a study on the effects of biochar amendment on sorption and leaching of nitrate, ammonium (NH$_4^+$ – N), and phosphate in a sandy soil. Thirteen biochars were tested in the laboratory for impacts on sorption and most of them showed little or no ability to sorb nitrate or phosphate. Biochar made from Brazilian pepperwood and peanut hulls pyrolyzed at 600 °C were used in a column leaching experiments to assess their ability to hold nutrients in a sandy soil. Compared with the soil alone, the pepperwood biochar
effectively reduced the total amount of nitrate, $\text{NH}_4^+ - \text{N}$, and phosphate in the leachates by 34.0%, 34.7%, and 20.6%, respectively. The peanut hull biochar also reduced the leaching of nitrate and $\text{NH}_4^+ - \text{N}$ by 34% and 14%, respectively, but caused additional phosphate release from the soil columns. This indicated that the effect of biochar on leachate of agricultural nutrients was not uniform and varied by biochar and nutrient type. Therefore, the nutrient sorption characteristics of a biochar should be studied prior to its use in a particular soil amendment project (Yao et al., 2012).

Biochar also had impacts on N retention (Prendergast-Miller et al., 2014). Biochar increased retention of fertilizer N in the topsoil (Güereña et al., 2013). Feedstocks, pyrolysis conditions, soil types, and crop types influenced the potential of biochar to impact N uptake (Van Zwieten et al., 2010). Two biochars were applied at 10 ton ha$^{-1}$ in a greenhouse pot experiment. Biochar 1 was produced from 32.6% (by mass) ESR sludge, 18.8% clarifier sludge, and 48.6% waste wood chips. Biochar 2 was derived from 19.5% ESR sludge, 11.2% clarifier sludge, and 69.3% waste wood chips. They used two soils, Ferrosol and Calcarosol, and three different crops. They found that biochar 1 increased N uptake in the Ferrosol soil when they added fertilizers (1.25 g Nutricote®). However, biochar 1 alone did not significantly increase N uptake in Ferrosol soil. Biochar 2, with or without additional fertilizer, increased N uptake in Ferrosol soil. In Calcarosol, only the biochar 2 with fertilizer treatment (1.25 g Nutricote®) increased N uptake. There was no significant increase in N uptake in the treatment that used biochar alone (Van Zwieten et al., 2010). According to Prendergast-Miller et al. (2014), biochar had small N contents and negligible extractable N. Biochar application alone is not an
initial direct source of N and is not sufficient to supply adequate N for plant growth. In their experiment they found that nitrate nitrogen (NO$_3^-$ − N) content was greater than ammonia (NH$_4^+$).

**Biochar and Compost Effects**

Applying biochar and compost together can have positive impacts on improving soil quality, crop productivity, and remediation of contaminated environments. Schulz et al. (2013) found that composted biochar had positive impacts on plant growth and soil fertility. In the study, composted biochar was the product resulting from mixing biochar with organic material and then composting at a professional facility for 8 weeks. Biochar was made from beech wood, which was pyrolyzed in a charcoal kiln for 6 days at 350-450 °C. The organic materials for compost were derived from 50% sewage sludge (comprising 25% dry matter), 25% freshly chaffed lop (high percentage of fine material like grass, leaves and twigs), and 25% sieved leftovers of earlier composting (50% soil and 50% braches and un-decayed composting leftovers). In their study, they demonstrated that adding composted biochar to sandy and loamy soil increased the plant growth, total organic carbon (TOC), total nitrogen (TN), and plant available and mineralizable nutrients in greenhouse conditions. Available NH$_4^+$ − N and nitrate did not increase. They concluded that to overcome biochar’s inherent nutrient deficiencies, biochar should be composted with other organic materials (Schulz et al., 2013).

Biochar and compost demonstrated a synergistic effect on soil organic matter content, nutrient levels, and water-storage capacity of a sandy soil in the field condition in Dystric Cambisol in NE Germany (Liu et al., 2012). Only the highest biochar-compost
application (biochar 20 Mg ha\(^{-1}\) and compost 32.5 Mg ha\(^{-1}\)) had significant impacts on TOC content. Treatments in which compost were applied increased TN as expected. However, TN was not significantly increased in the treatment with biochar alone. They observed that K and Ca contents in biochar-compost treatment (biochar 20 Mg ha\(^{-1}\) and compost 32.5 Mg ha\(^{-1}\)) were 282 mg kg\(^{-1}\) and 844 mg kg\(^{-1}\), respectively. In the control treatment, K and Ca were 114 mg kg\(^{-1}\) and 385 mg kg\(^{-1}\), respectively. Thus, the highest biochar and compost applications increased K and Ca by a factor of about 2. CEC varied from 10 cmolc kg\(^{-1}\) in the control to 13 cmolc kg\(^{-1}\) at the highest biochar-compost addition. Compost addition significantly increased CEC, and no additional increase was observed after biochar addition. The same was true for base saturation. Soil pH values ranged from 6 to 7. Compost addition significantly increased soil pH by 0.6 compared to control treatment. However, biochar had no significant effect on soil pH. After 2 months, soil water content generally increased in the order control < compost < biochar-compost applications. The highest biochar-compost treatment (biochar 20 Mg ha\(^{-1}\) and compost 32.5 Mg ha\(^{-1}\)) often showed higher soil water content compared to treatments with lower levels of biochar (Liu et al., 2012).

The combination of rice husk biochar and straw compost gave better effects than single individual applications on rice production components (numbers of panicle and grains of rice) and gave the highest yield (Barus, 2016). Compost and biochar had strong potential to improve SOC, soil water content, soil nutrient status, crop yield, and to abate greenhouse gas fluxes on tropical Ferralsols (Agegnehu et al., 2015). However, because in their experiment, they set up treatments that used fertilizer as the control treatment and
applied biochar and/or compost with the fertilizer, it is hard to determine if compost, biochar, or fertilizer alone were responsible for the positive impacts on soil nutrients and crop production.

Juniper

‘Juniper’ (Reg. No. CV-1021, PI 639951) is a hard red winter wheat (Triticum aestivum L.) developed by the Idaho Agriculture Experiment Station and released in February 2006. Juniper was derived from a cross, designated A91013W, with the pedigree ID0352/UT165093 (Souza et al., 2008). Juniper was released to replace Weston in the crop-fallow rotations where only one grain crop per two years is produced. It is the preference of growers to grow very tall cultivars with adequate emergence from deeper plantings in these low rainfall zones. Seeds are often planted in moisture accumulated during the fallow period, which is below the cultivation zone (10-15 cm deep) for weed control during the fallow year. Performance of Juniper in southern Idaho from 2001-2005, were 3290 kg ha⁻¹, 802 kg m⁻¹, 134 g kg⁻¹ for grain yield, test weight, and grain protein, respectively (Souza et al., 2008). Juniper is resistant to stripe rust (Puccinia striiformis Westend) and dwarf bunt (Tilletia controversa Kuhn in Rabenh). Juniper is also known for acceptable bread baking quality (Souza et al., 2008).

Research Needs

Many experiments on biochar and compost systems have been conducted globally. However, most of the research has been conducted in greenhouses or under laboratory conditions. No research has been identified that has been conducted using organic farming practices in semi-arid conditions with limited available nutrients, soil
moisture, and precipitation in soil containing high calcium carbonate (calcareous soil). Factors such as soil type, climate, biochar, or other agricultural environments might have different results on soil fertility and organic wheat production. Therefore, more research on application of biochar and compost combinations under organic production in field studies is required. Research in organic dryland production conditions will play an important role in helping farmers improve production and sustainability globally.

Objectives of Study

There are two objectives of this study. The first objective is to determine whether using compost, biochar, or a mixed compost-biochar application results in improvements in soil available nutrients, soil water retention, and soil microbial activity. The second objective is to determine if compost and biochar application result in improved wheat yield and quality. The null hypothesis is that neither biochar, nor biochar-compost additions will improve wheat yields, quality, or soil properties at the applied rates.
CHAPTER II:  
SOIL RESPONSE TO COMPOST AND BIOCHAR APPLICATION

Introduction

Composted animal waste is one of the best sources of nitrogen (N) available. Not all nutrients present in manure/compost are immediately available for plant uptake (Endelman, 2009). For composted organic matter, 1-3% of total nitrogen (TN) year\(^{-1}\) is available for crop utilization (Al-Bataina et al., 2016). According to Eghball & Power (1999), approximately 15% of N was available for the crop in the first year of applying composted manure and approximately 8% of N was available in the second year. According to Mangan et al. (2013), 10-30% of N becomes available for the plant in the first year and some of the remaining nutrients become available in the subsequent year at a slower rate. Decomposition and plant available nitrogen (PAN) are widely varied and depend on compost type (Gale et al., 2006). In addition to that, lack of precipitation slows the release of available N and can negatively impact crop production. Nitrogen is the most limiting nutrient for global food production. Although the air is 78% N, it is unavailable to plants until it is fixed in a form available to plants, such as ammonia or nitrate (Science Learning Hub, 2013). Decomposition of organic N into plant available forms takes several months or years (Ngo and Cavagnaro, 2018).
Materials and Methods

Study Area

The field trial was conducted on a United States Department of Agriculture (USDA)-Certified organic wheat production farm in a semi-arid environment near Snowville, Utah, USA (41°53'3.23"N, 112°44'45.76"W). The elevation of the study area is 4444 feet (1354.226 m) (Fig. 2-1 and 2-2). There is no irrigation on the field. Wheat followed by summer fallow is the typical culture.

The soil is categorized as Thiokol series (USDA NRCS, 2018). The Thiokol series contains very deep, well-drained soils that form lacustrine deposits (derived from limestone and sandstone) (National Cooperative Soil Survey, 2005). This soil is also considered calcareous (James and Topper, 1993). The soil contains approximately 40 percent calcium carbonate (CaCO₃) (USDA NRCS, 2018). The Food and Agriculture Organization (FAO) (1973) defines calcareous soil as soil with high CaCO₃ resulting in physical problems of land and water use for crop production. Because calcareous soil develops in regions with limited precipitation and nutrient availability, irrigation is required to be productive (Imas, 2000). This is a challenge for farmers in Snowville because their farms do not have irrigation. According to Imas (2000), the nutrient management in calcareous soils is different from that in non-calcareous soil. The pH of calcareous soil has effects on nutrient availability and chemical reactions which affect the loss or fixation of nutrients (Imas, 2000). According to the FAO (2018), calcareous soil lacks N, Phosphorus (P), micronutrients such as Zinc (Zn) and Iron (Fe), and has low organic matter (OM). The rate of N transformations in calcareous soils is affected by the
alkaline pH which has influence on efficiency of N use by plants (Imas, 2000). In addition, P availability in calcareous soil is usually restricted. Certified organic regulations prohibit the use of inorganic fertilizers. The availability of nutrients in the soil is a challenge for the organic farmers in Snowville.

Compost has been applied on the farm (8 ton ha$^{-1}$) for several years and was applied in strips for this study in an area not previously treated. Average wheat yield for the farm is 17.2 bushel acre$^{-1}$ (1,139 kg ha$^{-1}$) with an average wheat protein of 12.8%. The annual precipitation is 12-14 inches (304.8-355.6 mm) much of which occurs as snow during the winter. Soil erosion caused by wind is more severe than that caused by water. The annual precipitation in 2013, 2014, 2015, 2016, and 2017 were 8.1 mm (0.33 inches), 260.9 mm (10.4 inches), 303.4 mm (12.1 inches), 345.1 mm (13.8 inches), and 266.4 mm (10.7 inches). The yield of wheat in 2013, 2014, 2015, 2016, and 2017 were 7.7, 15.9, 4.9, 21.4, and 14.4 lb acre$^{-1}$. According to the farm owner, they had a dry fall with inadequate rain and did not start planting until October in 2013. Due to insufficient soil moisture, they planted the wheat very shallow (known as “dusting in”). Snowfall was minimal and the wheat did not sprout. Although there was ample spring rain, it did not have any positive impact on wheat growth and development. Farmers planted wheat abnormally early in 2016 due to adequate rainfall in early August. Fall conditions were warm with above average precipitation resulting in excess growth in the fall. The winter had minimal snowfall and extremely low temperatures, which resulted in desiccated wheat. The crop suffered winterkill and was also infested with winter wheat aphids. The spring had low rainfall. These conditions resulted in low wheat yields.
Experimental Plot Design

The experimental design was a split-plot with two compost treatments comprising the whole plots. Compost treatment included a control (0 ton ha\(^{-1}\)) (compost0) and an application of dairy manure compost at 8 ton ac\(^{-1}\) (18 ton ha\(^{-1}\)) (on an as-is matter basis) (compost8). Compost was immediately incorporated to about 0.025 m by the host farmer using standard disc tillage prior to biochar application. There were three replications of whole plot treatments. The split-plots included four biochar application rates. Those rates were biochar0 (0 of biochar ton ha\(^{-1}\)), biochar2 (2 ton of biochar ha\(^{-1}\)), biochar10 (10 ton of biochar ha\(^{-1}\)) and biochar40 (40 ton of biochar ha\(^{-1}\)) (Fig. 2-1). We expected biochar could increase C content by approximately 1% on a hectare furrow slice basis. Biochar was applied before planting on 18 Aug. 2016. Biochar was immediately incorporated into a soil depth of 0.25 m by rotary tilling. Seeding rate of wheat was 73 kg ha\(^{-1}\) (65 lbs ac\(^{-1}\)). To minimize carryover effects, a buffer space was left between plots. The size of the biochar treated split-plot was 6 m (20 ft) × 10 m (32 ft). There was a buffer zone between split-plots of 6 m (20 ft) × 10 m (32 ft). The whole plots for compost treatment and control were 46 m (150 ft) × 30 m (100 ft). The buffer zone was also 46 m (150 ft) × 30 m (100 ft) (Fig. 2-1 and 2-2).

To lay out the plot, Real Time Kinetic (RTK)-corrected GPS with tractor auto-steering provided a repeatable trial location. The RTK base stand is fixed for repeatable measurements across years. The RTK-corrected GPS provides accurate positons where the plots were located. This will facilitate locating plots in subsequent planting cycles.
Fig. 2-1. Compost and biochar experimental plot design in Snowville, UT
Fig. 2-2. Experiment field picture taken from Google Earth™

Fig. 2-2 shows the overall area of experimental plots at Snowville, UT and a close-up (light green color) of the compost treatments. This satellite image was taken in summer 2017. Each plot is listed with plot number on top and amount of
biochar (ton ha\(^{-1}\)) below. The blue lines show the GPS Georeferenced plot downloaded from the tractor’s Trimbel GPS system. There was a buffer zone between each split plot (i.e. 111 to 121). Buffer zones and biochar treatment split-plots are equal in size (6 m (20 ft) \(\times\) 10 m (32 ft)). Buffer zone and compost whole plots are also equal in size (46 m (150 ft) \(\times\) 30 m (100 ft)).

Soil Moisture Content

Soil moisture content was measured using Time domain reflectometry (TDR, Campbell Scientific, HydroSense II, Logan, UT). Soil moisture was taken twice (09 May and 23 June 2017). Time domain reflectometries with 12 cm and 20 cm rods were used. Five soil cores were taken from each plot. See Fig. A-5 for a more detailed explanation of soil moisture procedures.

Soil Sampling Procedure

Soil samples from each treatment were taken on two occasions. Samples were taken before the biochar and/or compost application and planting for baseline soil analysis on 10 July 2016. There were 12 soil samples (2 samples from each whole plot) in total.

On 09 May 2017, soil samples were taken from each sub-plot for a total of 96 samples. Forty-eight samples were submitted for complete soil analysis (24 samples from 0-15 cm and 24 samples from 15-30 cm). The remaining 48 samples underwent an enzyme test (24 samples from 0-15 cm and 24 samples from 15-30 cm) See Fig. A-4 for more detailed explanation of taking soil samples
Soil Analysis for Nutrient Availability

The soil was air dried for 72 hours, ground, and sieved to pass a 2 mm mesh screen. Soil texture was determined by feel (USDA Soil Texture Triangle and NRCS Guide) (Thien, 1979). Electrical conductivity (EC) and pH were analyzed using standard saturated paste (Rhoades, 1982). pH was measured directly on soil saturated paste and EC was measured from the solution extracted from the saturated paste. Available P and Potassium (K) were analyzed using sodium bicarbonate extract method (0.5M NaHCO3, pH 8.5) (Olsen and Sommers, 1982). For available K, the extract was analyzed by Atomic Emission Spectroscopy (AA, ThermoFisher Scientific, Waltham, MA, USA). Soil Nitrate (NO\textsubscript{3}− – N) was extracted with Calcium hydroxide (Ca(OH)\textsubscript{2}) and analyzed by flow-injection analysis using a Lachat QuikChem 8000, Hach Co., Loveland, CO, USA (Simpson and Jackson, 1971). Micronutrients Zn, Fe, copper (Cu), and manganese (Mn) were extracted with diethylenetriamine pentaacetic acid (DTPA) and analyzed using Inductively Coupled Plasma Optical Emission Spectrophotometer (ICP-OES, Thermo iCAP6300, ThermoFisher Scientific, Waltham, MA, USA), hereafter referred to as ICP-OES (Lindsay and Norvell, 1978). Sulfate-sulfur was extracted with dicalcium phosphate and was analyzed using ICP-OES (Gavlak et al., 2003). Total nitrogen and total carbon (TC) were analyzed with a combustion analyzer (Elementar Vario Max Cube, Elementar Americas, Mt. Laurel, NJ, USA), hereafter referred to as Elementar (Peters et al., 2003). Organic matter was determined colorimetrically according to the Walkley-Black method (Nelson and Sommers, 1982).
Biochar Analysis

The biochar used for this experiment was from lodgepole pine (Biochar Now, Colorado; OMRI certified). It was slow pyrolyzed to reach a temperature between 550 °C and 600 °C. The biochar particle size was 26 to 50 mesh. Electrical conductivity and pH were analyzed according to recommended method of manure analysis described in Peters et al. (2003). Total carbon and TN were analyzed by combustion using the Elementar according to the recommended methods of manure analysis (A3769) (Peters et al., 2003). Other elements, such as P, K, calcium (Ca), magnesium (Mg), sodium (Na), sulfur (S), boron (B), Zn, Cu, Fe, and Mn were wet ashed using nitric acid and peroxide using methods adapted from EPA 3050A (Peters et al., 2003), and analyzed using ICP-OES. The biochar cation exchange capacity (CEC: 1N NH4oAc, pH 7) was determined (Richards et al., 1954). Organic matter was determined colorimetrically according to the Walkley-Black method (Nelson and Sommers, 1982).

Compost Analysis

The source material for the compost was dairy cow manure. Salinity and pH were analyzed according to description of the recommended methods of manure analysis (Peters et al., 2003). Total Nitrogen and TC were analyzed by combustion using an Elementar according to the recommended methods of manure analysis (A3769) (Peters et al., 2003). Other elements, such as P, K, Ca, Mg, Na, S, B, Zn, Cu, Fe, and Mn were wet ashed using nitric acid and peroxide using methods adapted from EPA 3050A (Peters, et al., 2003,) and analyzed using an ICP-OES. The biochar CEC (1N NH4oAc, pH 7) was determined (Richards, 1954). Moisture and dry matter were measured according to
recommended methods of manure analysis (Peters et al., 2003).

Dehydrogenase Enzyme Activity

Dehydrogenase enzyme activity (DHA) was measured based on the description by Tabatabai (1994). Water was added to 2.5 g of fresh soil sample in a 15 ml centrifuge tube to bring the soil sample to field capacity. After overnight incubation, 0.5 ml of 3% triphenyltetrazolium chloride (TTC) was added to each tube along with 1 ml of 2% CaCO₃ solution. The tubes were incubated for exactly 24 hr at 37 °C. Then, 10 ml of methanol was added to each tube and the tubes vortexed for 1 min. Tubes were centrifuged (Allegra® X-15R Benchtop Centrifuge, Beckman Coulter®) for 5 min at 5,000 rpm (4500 G) and 200 ul aliquots of each supernatant were transferred into two consecutive wells in a microtiper plate. A SpectroMax® M2/M2e microplate spectrometer was used to measure absorbance at 490 nm in the microtiper plate cells.
Statistical Analyses

The data analysis was done using R-Studio (model R version 3.3.1 (2016)) for compost and biochar effects and interactions. The experimental design was split plot with two compost treatments comprising the whole plot: compost0 (0 ton of compost ha$^{-1}$) and compost8 (18 ton of compost ha$^{-1}$). There were three replications of the whole treatment. Compost treatment was the whole plot factor. The split-plot included four application rates of biochar 0, 2, 10 and 40 ton of biochar ha$^{-1}$. Biochar treatments were randomized on each replication. Compost, biochar, and replication were the three factors in these experiments. Biochar is equivalent to the interaction between compost and replication. The goal of the study was to assess whether there is an interaction between compost and biochar or whether the two factors produce any effect.
Results

Soil Characteristics from Preliminary Soil Result

Preliminary soil samples indicated that soil texture and soil characteristics are not uniform. Soil textures are silt loam, sandy loam, and sandy clay loam. The soil pH ranged from 7.7-7.9, and soil OM ranged from 1.6-2.1%. The soil had nutrient deficiencies such as N, Zn, P, Fe, and S. The recommendation for additional nutrients was expected (Table 2-1).

According to Imas (2000), the nutrient management in calcareous soils is different from that in non-calcareous soil. The soil pH of calcareous soil has effects on soil nutrient availability and chemical reactions that affect the loss or fixation of nutrients. The rate of N transformations in calcareous soils is affected by the alkaline pH which influences efficiency of N use by plants. In addition, P availability in calcareous soil is usually restricted. Other Nutrients such as Fe, Zn, and Cu are deficient in calcareous soil because of reduced solubility at alkaline pH values.
Table 2-1. Preliminary soil test collected before planting (05 June 2016).

<table>
<thead>
<tr>
<th>Soil Test Results</th>
<th>Interpretations</th>
<th>Recommendations</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Texture</strong></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Silt loam</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sandy loam</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Sandy clay loam</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>pH</strong></td>
<td>7.7-7.9</td>
<td>Normal</td>
</tr>
<tr>
<td>Salinity - EC</td>
<td>0.6-0.8</td>
<td>Normal</td>
</tr>
<tr>
<td>Phosphorous - P</td>
<td>8.2-15</td>
<td>Low</td>
</tr>
<tr>
<td>Potassium - K</td>
<td>607.0-776.0</td>
<td>Very high</td>
</tr>
<tr>
<td>Nitrogen - N</td>
<td>10.8-18.9</td>
<td></td>
</tr>
<tr>
<td>Zinc - Zn</td>
<td>0.2-0.3</td>
<td>Very low</td>
</tr>
<tr>
<td>Iron - Fe</td>
<td>3.3-4.7</td>
<td>Low</td>
</tr>
<tr>
<td>Copper - Cu</td>
<td>0.9-1.5</td>
<td>Adequate</td>
</tr>
<tr>
<td>Manganese - Mn</td>
<td>4.6-6.3</td>
<td>Adequate</td>
</tr>
<tr>
<td>Sulfate-Sulfur - S</td>
<td>3.8-5.2</td>
<td>Low</td>
</tr>
<tr>
<td>Organic Matter</td>
<td>%</td>
<td>1.6-2.1</td>
</tr>
</tbody>
</table>

Characteristics of Compost

Composted dairy cow manure with a pH of 9.0 was applied. Compost contained 1.37-1.83 % N (13.7-18.3 kg N metric ton$^{-1}$) and 15.2-21.4 % C (152-214 kg C metric ton$^{-1}$) (Table 2-2). Electrical conductivity of compost was very high (15.0-17.0) (Table 2-2). Electrical conductivity higher than desirable levels (saturated paste < 4.0) can be harmful to plant and soil health (University of Missouri Extension, 1993). Although soil in the study area did not have a problem with EC, future impacts of compost application on EC should be considered.
<table>
<thead>
<tr>
<th>Compost Properties</th>
<th>Result</th>
<th>Metric Equivalent</th>
</tr>
</thead>
<tbody>
<tr>
<td>C:N ratio</td>
<td>11.0-12.0</td>
<td></td>
</tr>
<tr>
<td>Moisture content %</td>
<td>10.7 - 11.1</td>
<td>107.0-111.0 kg metric ton⁻¹</td>
</tr>
<tr>
<td>pH</td>
<td>9.0</td>
<td></td>
</tr>
<tr>
<td>pH, calc sat paste</td>
<td>8.7</td>
<td></td>
</tr>
<tr>
<td>EC, dS/m</td>
<td>15.0 - 17.0 (very high)</td>
<td></td>
</tr>
<tr>
<td>EC, dS/m-calc sat paste</td>
<td>46.4 - 52.7 (very high)</td>
<td></td>
</tr>
<tr>
<td>Nitrogen (N), %</td>
<td>1.4 - 1.8</td>
<td>13.7-18.3 kg N metric ton⁻¹</td>
</tr>
<tr>
<td>Carbon (C), %</td>
<td>15.2 - 21.4</td>
<td>152.0-214.0 kg C metric ton⁻¹</td>
</tr>
<tr>
<td>Phosphorus (P), %</td>
<td>0.6 - 0.9</td>
<td>6.3-8.8 kg P₀₂₀₅ metric ton⁻¹</td>
</tr>
<tr>
<td>Potassium (K), %</td>
<td>1.7 - 2.5</td>
<td>17.5-25.2 kg K₂O metric ton⁻¹</td>
</tr>
<tr>
<td>Calcium (Ca), %</td>
<td>3.1 - 6.7</td>
<td>31.5-67.2 kg Ca metric ton⁻¹</td>
</tr>
<tr>
<td>Magnesium (Mg), %</td>
<td>0.8 - 1.9</td>
<td>8.2-19.8 kg Mg metric ton⁻¹</td>
</tr>
<tr>
<td>Sodium (Na), mg/kg</td>
<td>3504.8 - 5208.9</td>
<td>3.5-5.2 kg Na metric ton⁻¹</td>
</tr>
<tr>
<td>Sulfur (S), %</td>
<td>0.4 - 0.6</td>
<td>4.5-6.5 kg S metric ton⁻¹</td>
</tr>
<tr>
<td>Boron (B), mg/kg</td>
<td>26.8 - 35.9</td>
<td>0.03-0.04 kg B metric ton⁻¹</td>
</tr>
<tr>
<td>Zinc (Zn), mg/kg</td>
<td>189.5 - 265.2</td>
<td>0.2-0.3 kg Zn metric ton⁻¹</td>
</tr>
<tr>
<td>Copper (Cu), mg/kg</td>
<td>34.1 - 48.1</td>
<td>0.03-0.05 kg Cu metric ton⁻¹</td>
</tr>
<tr>
<td>Iron (Fe), mg/kg</td>
<td>1825.3 - 2236.0</td>
<td>1.8-2.2 kg Fe metric ton⁻¹</td>
</tr>
<tr>
<td>Manganese (Mn), mg/kg</td>
<td>162.2 - 202.3</td>
<td>0.1-0.2 kg Mn metric ton⁻¹</td>
</tr>
</tbody>
</table>
Characteristics of Biochar

The applied biochar contained high C (61.6-62.7 % or 616-627 kg C metric ton\(^{-1}\)), but contained limited N (0.23-0.25 % or 2.5-2.9 kg N metric ton\(^{-1}\)) (Table 2-3). The EC of the biochar was very low (Table 2-3).

<table>
<thead>
<tr>
<th>Biochar Properties</th>
<th>Sample</th>
<th>Metric Equivalent</th>
</tr>
</thead>
<tbody>
<tr>
<td>CEC (cmol/kg)</td>
<td>8.9 - 10.7</td>
<td></td>
</tr>
<tr>
<td>C:N ratio</td>
<td>251:1-274:1</td>
<td></td>
</tr>
<tr>
<td>pH</td>
<td>7.9 - 8.5</td>
<td></td>
</tr>
<tr>
<td>pH, calc sat paste</td>
<td>7.7 - 8.3</td>
<td></td>
</tr>
<tr>
<td>EC, dS/m</td>
<td>0.3 - 0.3 (very low)</td>
<td></td>
</tr>
<tr>
<td>EC, dS/m-calc sat paste</td>
<td>0.3 - 0.4 (very low)</td>
<td></td>
</tr>
<tr>
<td>Nitrogen (N), %</td>
<td>0.2 - 0.3</td>
<td>2.3-2.5 kg N metric ton(^{-1})</td>
</tr>
<tr>
<td>Carbon (C), %</td>
<td>61.6 - 62.7</td>
<td>627.0-616.0 kg C metric ton(^{-1})</td>
</tr>
<tr>
<td>Phosphorus (P), %</td>
<td>0.05</td>
<td>0.5-0.5 kg P(_2)O(_5) metric ton(^{-1})</td>
</tr>
<tr>
<td>Potassium (K), %</td>
<td>0.3 - 0.3</td>
<td>2.5-2.9 kg K(_2)O metric ton(^{-1})</td>
</tr>
<tr>
<td>Calcium (Ca), %</td>
<td>1.0 - 1.0</td>
<td>9.7-10.3 kg Ca metric ton(^{-1})</td>
</tr>
<tr>
<td>Magnesium (Mg), %</td>
<td>0.2 - 0.2</td>
<td>1.8-2.1 kg Mg metric ton(^{-1})</td>
</tr>
<tr>
<td>Sodium (Na), mg/kg</td>
<td>357.2 - 434.9</td>
<td>0.4-0.4 kg Na metric ton(^{-1})</td>
</tr>
<tr>
<td>Sulfur (S), %</td>
<td>0.03 - 0.07</td>
<td>0.7-0.3 kg S metric ton(^{-1})</td>
</tr>
<tr>
<td>Boron (B), mg/kg</td>
<td>11.1 - 16.8</td>
<td>0.01-0.02 kg B metric ton(^{-1})</td>
</tr>
<tr>
<td>Copper (Cu), mg/kg</td>
<td>21.2 - 32.9</td>
<td>0.02-0.03 kg Cu metric ton(^{-1})</td>
</tr>
<tr>
<td>Iron (Fe), mg/kg</td>
<td>10713.0 - 6156.7</td>
<td>10.7-6.2 kg Fe metric ton(^{-1})</td>
</tr>
<tr>
<td>Manganese (Mn), mg/kg</td>
<td>283.5 - 441.9</td>
<td>0.3-0.4 kg Mn metric ton(^{-1})</td>
</tr>
<tr>
<td>Zinc (Zn), mg/kg</td>
<td>39.5 - 49.6</td>
<td>0.04-0.05 kg Zn metric ton(^{-1})</td>
</tr>
</tbody>
</table>
Soil Nutrients Response to Compost Application

Compost Effects on Nitrate Nitrogen and Total Nitrogen

Nitrate nitrogen (NO$_3^-$ – N) was significantly lower in the compost treatment (compost8) than in control (compost0) at soil depth 0-15 cm (Fig. 2-3). At depth 0-15 cm, compost0 had more NO$_3^-$ – N (1.51 mg kg$^{-1}$) than compost8 (0.64 mg kg$^{-1}$) (Table 2-4). There are many possible explanations for NO$_3^-$ – N being lower in compost8 than in compost0.

Low NO$_3^-$ – N in compost8 may be attributed to N uptake by plants. According to Swenson et al. (n.d), NO$_3^-$ – N decreases rapidly during May and June because plants take up more N. Plants take up approximately 45% of NO$_3^-$ – N during the plant tillering stage and 85% by the time they are flowering. Murdock et al. (2009) found winter wheat takes up most N from April to June or during Feekes’ stages 6, 10, and 11.1 (Page et al. 1977). Because compost significantly increases wheat yield (Table 3-1.), it can be assumed that the wheat took up more N in compost treatment than in control.

Winter wheat takes up more N from the topsoil because of higher root length density (Qin et al., 2004). The root length density of winter wheat is higher in the top most soil layer (0-5 cm) and gradually decreases after 10 cm. According to Atwell et al. (1999), the density of root systems for cereal grains is higher in the surface layer and decreases with increasing soil depth. Higher root length density results in higher nutrient uptake. In addition, NO$_3^-$ – N decreases with increasing soil depth. Results from our experiment showed that the NO$_3^-$ – N level at 15-30 cm (Table 2-5) was higher than at 0-
15 cm (Table 2-4). There are two possibilities to account for higher NO$_3^-$ – N in the deep soil profile. First, N left after plant uptake in the topsoil profile could move to deeper soil layers due to N mobility. In addition, NO$_3^-$ – N concentration increases with soil depth and concentration of nitrate in the top layer decreases if no fertilizer dressing is used (Zhang et al., 2013). Most of the nitrification takes place in the top few inches of soil (IPNI, nd). Soil nitrate accumulation occurs in the top 20 cm (Zhang et al., 2013). As the growth rate of wheat plants increases, soil nitrate accumulation decreases within a 1 m soil profile (Zhang et al., 2013).

Soil disturbances may contribute to the NO$_3^-$ – N levels observed in the present study. The experiment site was extensively disturbed due to tillage operations associated with compost and biochar treatments (Fig. A-1). Farmers used the tillage operation to prepare the seed bed, bury previous crop residue, and control weeds. The field was disturbed again when biochar and compost treatments were applied. There was also rain after planting. The soil disturbance resulted in heavy crust formation, which greatly reduced seedling emergence and required the site to be replanted. These disturbances could have influenced experimental results. According to Swenson et al. (n.d), fluctuating NO$_3^-$ – N levels tend to coincide with tillage operations.

Geographic conditions such as soil texture, soil drainage, and slope steepness in the study area were not uniform; these may also contribute to N transport and N transformation processes, which limit N availability to crops or lead to losses (USDA-NRCS, 2014). There were three different soil textures in our experiment (Table 2-1). In addition, the field was not level. It had a slope and was surrounded by mountains.
The experiment was conducted under rain-fed dryland conditions, which had an annual precipitation of 30.5-34.5 cm (12.0-13.6 inches) in 2016 and 2017, respectively (Utah Climate Center). The soil moisture was limited due to low rainfall. Soil moisture and temperature conditions constrained N mineralization (Helgason et al., 2007). Soil types and clay content influenced the rates of N release (Sørensen and Jensen 1995; Egelkraut et al. 2000 as cited in Helgason et al., 2007).

This study analyzed NO₃⁻ - N as the inorganic form of N and found no significant difference in TN between control and compost treatment (Table 2-4 and Table 2-5). We did not analyze ammonium (NH₄⁺ - N), which is another form of inorganic N that is available for plant uptake. Effects of TN in increasing NO₃⁻ - N accumulation are primarily dependent on soil moisture (Swenson et al., n.d). In our study, TN was not significantly different between the compost treatment and control. While NO₃⁻ - N was lower in the compost condition, it is possible other inorganic N (such as NH₄⁺ - N) was higher. Thus, it cannot be concluded that applying compost reduces the nitrogen availability for plant uptake.

Compost Effects on Potassium, Manganese, and Sulfur

Compost significantly increased potassium (K) (Table 2-4). This finding was similar to other research conducted on dryland organic winter wheat farms in Snowville, Utah (Stukenholtz, 1999; Reeve et al., 2012). Similar to results in the present study, they found that K in the soil was higher than the critical level in their preliminary soil results. According to Stukenholtz (1999), about 50 % of K is likely available in spring following application of compost with 90 to 100 % available one year after application. Since K
content was already high, caution should be used when applying large quantities of compost (Stukenholtz, 1999).

Compost also increased Mn in the deep soil profile (15-30 cm) and S in both soil profiles (0-15 cm and 15-30 cm) (Table 2-4 and 2-5). Manganese in compost and compost0 were 3.3 and 2.6 mg kg\(^{-1}\). Stukenholtz (1999) found increased Mn in his study area as well. This study found higher levels of Mn in compost treatment than in control, however the levels still fell within the range of the preliminary soil results (Table 2-1).

Sulfur deficiency was found in preliminary soil results (Table 2-1). To meet the requirements for optimum wheat growth, 10-20 lb ac\(^{-1}\) (11 - 22 kg ha\(^{-1}\)) of S should be applied to the field (Table 2-1). According to Zhao et al. (1999), S deficiency was found in Brassica and cereal crops in Western Europe for many years. A massive decrease of atmospheric S inputs was considered the primary factor contributing to S deficiency. According to Scherer (2009), only 5 % of total soil S was available for plant use. About 95 % of S in the soil is organically bound and not available for plant use. In this study, compost had positive impacts on S in the soil. Miller et al. (2013) observed increased total S with use of compost as well. According to a review article by Scherer (2009), incorporating crop residue into the soil influenced S mineralization. Applying municipal compost and farmyard manure also contributed to increasing the biomass S. The greater the amount of biomass S, the more available S will be to the plant. Seasonal variation, fertilizer application, soil moisture, and temperature are factors influencing S transformation in the soil. Research on soil S continues to be important because of its impact on crop yield and quality.
Fig. 2-3. Compost effects on nitrate nitrogen in the topsoil profile (0-15cm).
Compost0 (0ton of compost ha$^{-1}$)
Compost8 (18ton of compost ha$^{-1}$).
Table 2-4. Effects of compost on soil nutrients at 0-15 cm.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>pH</th>
<th>EC</th>
<th>NO₃⁻N</th>
<th>TN</th>
<th>OM</th>
<th>TC</th>
<th>P</th>
<th>K</th>
<th>Fe</th>
<th>Cu</th>
<th>Mn</th>
<th>Zn</th>
<th>S</th>
</tr>
</thead>
<tbody>
<tr>
<td>Compost0</td>
<td>7.8</td>
<td>0.4</td>
<td>2.1</td>
<td>0.1</td>
<td>2.0</td>
<td>2.1</td>
<td>7.6</td>
<td>3.1</td>
<td>1.1</td>
<td>3.6</td>
<td>0.2</td>
<td>2.6</td>
<td></td>
</tr>
<tr>
<td>Compost8</td>
<td>7.8</td>
<td>0.4</td>
<td>0.6</td>
<td>0.1</td>
<td>2.1</td>
<td>2.2</td>
<td>15.4</td>
<td>3.4</td>
<td>1.2</td>
<td>4.2</td>
<td>0.4</td>
<td>4.5</td>
<td></td>
</tr>
<tr>
<td>Std E</td>
<td>0.01</td>
<td>0.03</td>
<td>0.13</td>
<td>0.1</td>
<td>0.05</td>
<td>0.1</td>
<td>2.19</td>
<td>0.2</td>
<td>0.1</td>
<td>0.17</td>
<td>0.04</td>
<td>0.2</td>
<td></td>
</tr>
<tr>
<td>P value &lt;0.05</td>
<td>0.40</td>
<td>0.8</td>
<td>0.01*</td>
<td>0.1</td>
<td>0.4</td>
<td>0.6</td>
<td>0.004**</td>
<td>0.3</td>
<td>0.8</td>
<td>0.2</td>
<td>0.1</td>
<td>0.01*</td>
<td></td>
</tr>
</tbody>
</table>

Compost0 (0 ton of compost ha⁻¹) and Compost8 (18 ton of composts ha⁻¹)

* significantly different at $p < 0.05$

** significantly different at $p < 0.001$

*** significantly different at $p < 0.0001$

Table 2-5. Effects of compost on soil nutrients at 15-30 cm.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>pH</th>
<th>EC</th>
<th>NO₃⁻N</th>
<th>TN</th>
<th>OM</th>
<th>TC</th>
<th>P</th>
<th>K</th>
<th>Fe</th>
<th>Cu</th>
<th>Mn</th>
<th>Zn</th>
<th>S</th>
</tr>
</thead>
<tbody>
<tr>
<td>Compost0</td>
<td>7.9</td>
<td>0.6</td>
<td>7.7</td>
<td>0.07</td>
<td>1.4</td>
<td>3.1</td>
<td>2.9</td>
<td>541.1</td>
<td>2.9</td>
<td>0.8</td>
<td>2.6</td>
<td>0.1</td>
<td>3.9</td>
</tr>
<tr>
<td>Compost8</td>
<td>7.8</td>
<td>0.6</td>
<td>2.4</td>
<td>0.07</td>
<td>1.6</td>
<td>2.8</td>
<td>5.9</td>
<td>532.4</td>
<td>3.1</td>
<td>0.9</td>
<td>3.3</td>
<td>0.2</td>
<td>5.6</td>
</tr>
<tr>
<td>Std E</td>
<td>0.4</td>
<td>0.07</td>
<td>0.9</td>
<td>0.06</td>
<td>0.6</td>
<td>0.3</td>
<td>0.7</td>
<td>28.9</td>
<td>0.3</td>
<td>0.02</td>
<td>0.08</td>
<td>0.02</td>
<td>0.3</td>
</tr>
<tr>
<td>P value &lt;0.05</td>
<td>0.1</td>
<td>0.7</td>
<td>0.059</td>
<td>0.6</td>
<td>0.2</td>
<td>0.5</td>
<td>0.1</td>
<td>0.8</td>
<td>0.3</td>
<td>0.08</td>
<td>0.03*</td>
<td>0.3</td>
<td>0.04*</td>
</tr>
</tbody>
</table>

Compost0 (0 ton of compost ha⁻¹) and Compost8 (18 ton of composts ha⁻¹)

* significantly different at $p < 0.05$

** significantly different at $p < 0.001$

*** significantly different at $p < 0.0001$
Compost Impacts on Dehydrogenase Activity

Dehydrogenase activity in the topsoil profile (0-15 cm) was higher than DHA in the deep soil profile (15-30 cm) (Table 2-6, 2-7, and 2-8). This is because the soil OM is higher in the topsoil profile (Mirás Avalos and Sande Fouz, 2011). Neither biochar nor compost demonstrated significant impacts on DHA at a depth of 0-15 cm (Table 2-6 and 2-7). Interactions between biochar and compost did not impact DHA in the soil (Table 2-8). Only the compost treatment impacted DHA at a depth of 15-30 cm (Table 2-6 and Fig. 2-4). At a depth of 15-30 cm, DHA of compos8 was 2.1 ugTPF/g soil/hr while DHA of compost0 was 1.5 ugTPF/g soil/hr .Although reasons for impacts on DHA in the deep soil depth are uncertain, there are some factors that likely contributed.

Depth of the soil profile can affect DHA. The deeper the soil profile, the lower the DHA level (Beyer et al., 1993; Wolinska and Stepniewsk, 2012). Dehydrogenase activity level was highest in the topsoil profile (0-20 cm) while the level of DHA in the deep soil profile (40-60 cm) was 95 % lower than that in the surface layer level (Wolinska and Stepniewsk, 2012). Calderón et al. (2018) conducted a study on effects of compost inputs on dryland wheat yields, forage yields, and soil quality. Three biennial beef feedlot compost applications (0, 22.9 ton ha\(^{-1}\), and 108.7 ton ha\(^{-1}\)) were evaluated from 2010 to 2015. They found that the application of 108.7 ton ha\(^{-1}\) compost had positive impacts on soil enzyme activities at 0-30 cm. According to Burgos et al. (2002), DHA significantly increased after treatment with municipal solid waste and paper mill waste when measured at depths of 0-20 cm.

A single application of compost on organic dryland winter wheat has significant
impacts on DHA in soil even after 16 years (Reeve et al., 2012). Compost was applied to the study area in 1995. They collected samples at three depths of soil (0-5, 5-10, 10-30 cm) in May 2008 and May 2010. While they did not find any impact of compost on DHA in 2008, compost had a significant impact on DHA at depths of 0-5cm and 5-10 cm in 2010. While DHA levels in the topsoil sample of the present study were still higher than those in the deep soil profile, the topsoil experienced extensive soil disturbance, which may have slowed DHA in comparison to the deep soil profile. This disturbance may account for the compost treatment increasing DHA only in the deep soil profile.

Timing of soil sampling may have impacted DHA levels in the present study. Season has strong effects on DHA in the soil (Wolinska and Stepniewsk, 2012). Yuan and Yue (2012) found that DHA levels were highest in the fall while Wolinska and Stepniewsk (2012) found that DHA levels were higher in May than in October. This was because DHA was present inside viable microbial cells which became active at 20-30 °C resulting in microbial growth, activity, and development (Wolinska and Stepniewska, 2011; Wolinska and Stepniewsk, 2012). Błońska (2010) conducted a study on seasonal enzymatic activity in soils of selected forest sites. Minimum DHA values were noted in October 2007 and April 2008; while maximum values of DHA were found in June 2007, January 2008, and June 2008. Dormaar et al. (1984) assessed seasonal topsoil content of C, DHA, phosphatase, and urease activities in a semi-arid climate with mixed prairie and fescue grassland. They found that DHA was highest in the winter and decreased in summer. Seasonal DHA changes may depend on meteorological conditions such as temperature, soil moisture, and air condition as well as flora (Błońska, 2010). Aeration of
soil, vegetation, and soil microflora may also impact these seasonal changes (Rastin et al., 1988).

Soil pH and type affect DHA (Cooper & Warman, 1997; Avalos & Fouz, 2011; Wolinska & Stepniewsk, 2012) (Cooper & Warman, 1997; Mirás Avalos and Sande Fouz, 2011; Wolinska & Stepniewsk, 2012). In this study, soil pH was not uniform. Soil was alkaline with a pH of 7.7-7.9 (Table 2-1). The optimum pH condition for DHA is 6.6-7.2 (Stêpniewsk et al., 2001; Wolinska & Stepniewsk, 2012). Cooper & Warman (1997) did an experiment on the effects of three fertility amendments on soil DHA, organic C, and pH. Three different fertilizers (composted chicken manure, fresh chicken manure, and synthetic fertilizer), and two different types of soil (Acadia silty clay and Pugwash sandy loam) were used. Regardless of fertilizer type, organic C and DHA level were higher in the sandy loam than in silty clay. According to Cooper & Warman (1997), there is a relationship between DHA and level of readily available organic C substrate in the soil. This was similar to the finding from Burgos et al. (2002) who confirmed the positive relationship between DHA and organic C in the soil. After determining the effects of different types of fertilizers on DHA in sandy loam, Cooper and Warman (1997) observed that DHA was not affected by the amendment sources (compost, manure, or synthetic fertilizer). However, in silty clay, DHA level was significantly higher in compost treatment than in manure plots while DHA decreased with synthetic fertilizer treatment. Soil texture must be considered in the study of DHA due to variability of microbial activity in fine versus coarse textured soils exposed to similar management conditions. In the present study, the soil was not uniform. There were three
soil textures found in the study (silt loam, sandy loam, and sandy clay loam) and OM in the soils ranged from 1.6 to 2.1 (Table 2-1).

Beyer et al. (1993) conducted a study on sustainability of the DHA assay as an index of soil biological activity. They found that DHA varied significantly in the same soil with the same crop. They concluded that DHA depended more on soil type than cropping system. It is suspected that DHA is affected by humidity and temperature (Diosma et al., 2003; Mirás Avalos and Sande Fouz, 2011). DHA is a sensitive enzyme which is easily influenced by environmental factors and management practices (Wolinska and Stepniewsk, 2012)

Effects of compost on DHA are complex and may be influenced by many factors. This study found significant effects of compost on DHA in the deep soil profile (15-30 cm), but not in the topsoil profile (0-15 cm). This may be due to uniformity of soil textures and characteristics, environmental factors, soil disturbance, or soil sampling practices in the present study.
Table 2-6. Effects of compost on soil dehydrogenase activities (DHA) in soil depth 0-15 and 15-30 cm

<table>
<thead>
<tr>
<th>Treatment</th>
<th>DHA (0-15cm) (ugTPF/g soil/hr)</th>
<th>DHA (15-30cm) (ugTPF/g soil/hr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Compost0</td>
<td>2.9</td>
<td>1.5</td>
</tr>
<tr>
<td>Compost8</td>
<td>3.6</td>
<td>2.1</td>
</tr>
<tr>
<td>StE</td>
<td>0.2</td>
<td>0.05</td>
</tr>
<tr>
<td>P value &lt;0.05</td>
<td>0.2</td>
<td>0.01*</td>
</tr>
</tbody>
</table>

Compost0 (0ton of compost ha$^{-1}$), Compost8 (18ton of compost ha$^{-1}$).
* significantly different at $p <0.05$
** significantly different at $p< 0.01$
*** significantly different at $p <0.001$
**** significantly different at $p <0.0001$

Table 2-7. Effects of biochar on soil dehydrogenase activities (DHA) in soil depth 0-15 and 15-30 cm

<table>
<thead>
<tr>
<th>Treatment</th>
<th>DHA (0-15cm) (ugTPF/g soil/hr)</th>
<th>DHA (15-30cm) (ugTPF/g soil/hr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biochar0</td>
<td>3.3</td>
<td>1.9</td>
</tr>
<tr>
<td>Biochar2</td>
<td>3.3</td>
<td>1.8</td>
</tr>
<tr>
<td>Biochar10</td>
<td>3.4</td>
<td>1.7</td>
</tr>
<tr>
<td>Biochar40</td>
<td>3.1</td>
<td>1.8</td>
</tr>
<tr>
<td>StE</td>
<td>0.2</td>
<td>0.2</td>
</tr>
<tr>
<td>P value &lt;0.05</td>
<td>0.6</td>
<td>0.7</td>
</tr>
</tbody>
</table>

Biochar0 (0 of biochar ha$^{-1}$), Biochar2 (2 ton of biochar ha$^{-1}$), Biochar10 (10 ton of biochar ha$^{-1}$), and Biochar40 (40 ton of biochar ha$^{-1}$).
* significantly different at $p <0.05$
** significantly different at $p< 0.01$
*** significantly different at $p <0.001$
**** significantly different at $p <0.0001$
Table 2-8. Effects of interaction between biochar and compost on soil dehydrogenase activities (DHA) in depths of 0-15 and 15-30 cm.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>DHA (0-15cm) (ugTPF/g soil/hr)</th>
<th>DHA (15-30) (ugTPF/g soil/hr)</th>
</tr>
</thead>
<tbody>
<tr>
<td>C0B0</td>
<td>2.9</td>
<td>1.6</td>
</tr>
<tr>
<td>C0B2</td>
<td>3.3</td>
<td>1.7</td>
</tr>
<tr>
<td>C0B10</td>
<td>3.0</td>
<td>1.2</td>
</tr>
<tr>
<td>C0B40</td>
<td>2.6</td>
<td>1.5</td>
</tr>
<tr>
<td>C8B0</td>
<td>3.6</td>
<td>2.3</td>
</tr>
<tr>
<td>C8B2</td>
<td>3.3</td>
<td>1.9</td>
</tr>
<tr>
<td>C8B10</td>
<td>3.8</td>
<td>2.2</td>
</tr>
<tr>
<td>C8B40</td>
<td>3.5</td>
<td>2.1</td>
</tr>
<tr>
<td>St E</td>
<td>0.3</td>
<td>0.2</td>
</tr>
</tbody>
</table>

P Value <0.05

C0B0 (0 ton of compost ha⁻¹ and 0 ton of biochar ha⁻¹), C0B2 (0 ton of compost ha⁻¹ and 2 ton of biochar ha⁻¹), C0B10 (0 ton of compost ha⁻¹ and 10 ton of biochar ha⁻¹), C0B40 (0 ton of compost ha⁻¹ and 40 ton of biochar ha⁻¹), C8B0(18 ton of compost ha⁻¹ and 0 ton of biochar ha⁻¹), C8B2(18 ton of compost ha⁻¹ and 2 ton of biochar ha⁻¹), C8B10 (18 ton of compost ha⁻¹ and 10 ton of biochar ha⁻¹), C8B4 (18 ton of compost ha⁻¹ and 40 ton of biochar ha⁻¹)

* significantly different at $p < 0.05$
** significantly different at $p < 0.01$
*** significantly different at $p < 0.001$
**** significantly different at $p < 0.0001$
Fig. 2-4. Compost effects on soil dehydrogenase activities at 15-30 cm
Compost0 (0ton of compost ha⁻¹)
Compost8 (18ton of compost ha⁻¹).
Soil Responses to Biochar Application

Biochar significantly increased TC and pH in the topsoil (0-15 cm) (Fig. 2-5 and 2-6). In the deep soil (15-30 cm), biochar did not have significant impacts on soil nutrients except Mn and Cu (Table 2-10). However, Mn levels still ranged from 4.58-6.29 mg kg$^{-1}$, which were found in the preliminary soil sample (Table 2-1). Biochar increased Cu in the deep soil profile (15-30 cm) but the level was within the range obtained in the preliminary soil sample (Table 2-1).

Biochar Effects on Nitrogen in the Soil.

The impacts of biochar on N status in the soil have been studied worldwide. Some studies confirmed a positive impact; whereas, others found no or negligible impact from biochar on N status in the soil (Harris et al., 2013; Nguyen et al., 2017). The results from this study illustrated that biochar had no significant impacts on NO$_3^-$ or TN in either soil depth (0-15 cm or 15-30 cm) (Table 2-9 and 2-10).

Our findings were similar to the findings from Novak et al. (2009a) and Harris et al. (2013). Novak et al. (2009a) studied impacts of pecan shell-based biochar as a soil amendment for fertility on southern coastal plain soil (Norfolk loamy sand: fine-loamy, kaolinitic, thermic typic Kandiudults). Biochar did not significantly improve the soil N status. Most of the residual N in biochar was likely present as recalcitrant heterocyclic N rather than more bioavailable N. The C:N ratio of biochar also contributes to the N transformation after applying biochar to soil (Clough et al., 2013; Gundale & DeLuca, 2006). Biochar derived from pecan shells used in Novak et al. (2009a) had a C:N ratio of 244:1. Other research found that N immobilization typically occurs when organic
residues possessing a C:N ratio of greater than 24:1 are added to soils (USDA NRCS, 2011). The wide C:N ratio, in association with its aromaticity, will cause slow biochar decomposition (Lehmann, 2007). Charred particles from both biomass and fossil fuel combustion are resistant to decomposition over time due to lack of chemical and biochemical reactivity (Schmidt and Noack, 2000).

Harris et al. (2013) conducted a laboratory study on characterization and mineralization rates of low temperature peanut hull and pine chip biochar. In their study, they amended Tifton soil (fine-loamy, siliceous, thermic Plinthic Kandiudults) with peanut hull and pine chip biochar, which did not significantly affect N mineralization and immobilization after mineralization. Net mineralization of N in control was higher than in biochar treatments. Similar rates of mineralization were seen in pine chip and control. The majority of N was from native soil which may account for similar rates. Due to the high C:N ratio of pine chip biochar (214:1), N immobilization was expected. While PH biochar had a favorable C:N ratio (37:1), they did not see any significant sign of immobilization. They concluded that biochar derived from plant feedstock did not have significant effects on N mineralization likely due to binding in thermally stable compounds that are unavailable to soil microbes. Further research to investigate biochar with a range of C:N ratios should be conducted, including biochars derived from manure.

A study from Nguyen et al. (2017) showed that biochar reduced soil inorganic N including \( \text{NH}_4^+ \) – N and \( \text{NO}_3^- \) – N. They conducted a review and meta-analysis on effects of biochar on soil inorganic N. They analyzed 56 studies and 1080 experimental cases from manuscripts published between 2010 and 2015. Regardless of experimental
conditions, biochar reduced soil inorganic N. They found that biochar application reduced $\text{NH}_4^+ - N$ by 9-13 % and $\text{NO}_3^- - N$ by 8.4-11.6 %. Ninety-five percent of cases were assessed within one year after application of biochar. Factors influencing soil inorganic N after biochar application are residence time of biochar, pyrolysis temperature (Gundale and DeLuca, 2006), application rate, fertilizer type, soil pH, and environmental factors (Nguyen et al., 2017). Biochar application has complicated interactions with environmental factors (Nguyen et al., 2017). Woody biochar did not decrease soil inorganic N as much as other plant-based biochars. According to DeLuca et al. (2015), there is still limited understanding of the influences of charcoal on soil processes and N transformation. Cao et al. (2017) found that different soil types and biochar characteristics influence effects of biochar on soil inorganic N. Soil type influenced effect of biochar on $\text{NH}_4^+ - N$ and $\text{NO}_3^- - N$. The underlying mechanisms controlling the transformation of biochar and its effects on soil properties are poorly understood (Sohi et al., 2010 as cited in Bruun et al., 2012) It is difficult to compare between studies as soil, biochar, feedstock, climate, and methodology are different (Bruun et al., 2012).

After applying biochar, some soil N processes are impacted (Joseph et al., 2010; Prommer et al., 2014). These are related to biochar feedstock, pyrolysis conditions, soil properties, local environment, and climate (Joseph et al., 2010; Prommer et al., 2014). In addition, calcareous soil has impacts on N transformation (Imas, 2000). Since studies on biochar effects on N dynamics in calcareous soil are limited, it is difficult to make comparisons or provide thorough explanations. Biochar produced using different feedstock or pyrolysis conditions influence physical and chemical properties of soil in
different ways; consequently, biochar may be designed to selectively improve chemical and physical properties by altering feedstock or pyrolysis conditions (Novak et al., 2009b)

Effects of Biochar on Organic Matter

In this experiment, biochar did not have a significant impact on OM in either depth test (0-15 cm or 15-30 cm) (Table 2-9 and 2-10). The neutral effects of biochar on OM may result from the sorptive property of biochar. Biochar has high sorption affinity for OM because it contains nanopores (Kasozi et al., 2010; Sobek et al., 2009). The sorptive property of biochar serves two functions. It absorbs excess moisture and shields OM from enzymatic attacks (Kasozi et al., 2010). This leads to negative or neutral priming effects that protect OM from degradation through microbial-produced enzymes and abiotic oxidation (Zimmerman et al., 2011). Priming effects can influence OM as well. Negative priming effects, lower than expected C mineralization, occur when hardwood biochars are produced at high temperatures (525 and 650 °C). In contrast, biochars produced from grasses pyrolyzed at low temperatures (250 and 400 °C) have positive priming effects (higher than expected C mineralization) in the soil. Priming effects occur depending on biochar type and pyrolysis temperatures. Spokas & Reicosky (2009) conducted a study on the impacts of sixteen different biochars on greenhouse gas production from two soil types. The results showed that five biochars increased, three biochars decreased, and eight had no significant impacts on soil organic carbon (SOC) respiration. Biochar and soil type are the main factors influencing SOC respiration.

Effects of Biochar on Total Carbon
Biochar increased TC in this study. Biochar 40 Mg ha$^{-1}$ increased TC in the topsoil profile (0-15cm) (Table 2-9 and Fig. 2-5), but not in the deep profile (15-30 cm) (Table 2-10). Van Zwieten et al. (2010) conducted a study to quantify the agronomic response of papermill biochar additions to two soils in greenhouse conditions. There were two biochars and two soils in their study. Biochar significantly increased TC in both soils. Biochar 1 was made from 32.6 % (by mass) enhanced solids reduction (ESR) sludge, 18.8 % clarifier sludge, and 48.6 % wood chips. Biochar 2 was made from 19.5 % ESR sludge, 11.2 % clarifier sludge, and 69.3 % waste wood chips. The pyrolysis temperature for both biochars was 550 °C. Two soils, Ferrosol and Calcarosol, were collected. Biochar application was 10 ton ha$^{-1}$. In Ferrosol, biochar 1 increased TC 0.5 %, while biochar 2 elevated TC close to 1 %. In Calcarosol, TC increased 0.7 % in the biochar 1 treatment, and 2.53 % for biochar 2 (Van Zwieten et al., 2010).

Abdullaeva & Mankasingh (2014) conducted a pot experiment on biochar effects on fertility of saline and alkaline soils. Their study found that biochar made from apple wood (pH 8.67 and C 75 %) had significant impacts on increasing TC in the alkaline soil (pH 8.075). There were four rates of biochar used: 0, 20, 25, and 30g of biochar kg$^{-1}$ of soil. They found increases in OM (1.18, 1.49, 1.50, 1.58 %) and TC (3.6, 4.2, 4.7, 5.0 %) with each treatment. Studies by Van Zwieten et al. (2010) and Abdullaeva and Mankasingh (2014) both show increased TC with use of biochar in controlled environments. Total carbon was influenced by biochar and soil type in both instances.
Biochar Effects on Soil pH

In this study, applying biochar at 40 ton ha\(^{-1}\) soil increased pH from 7.73 (biochar0) to 7.83 (biochar40) (Fig. 2-6). Despite a slight increase, both levels fell within the baseline range of 7.7-8.0. In humid areas, biochar can increase soil pH in highly weathered soil (Jien & Wang, 2013; Obia et al., 2015). Using very acidic soil (pH 3.95) and alkaline biochar (pH 9.94), Jien and Wang (2013) conducted a study using three biochar application rates. After 105 days of incubation, the soil pH was 3.95, 4.65 and 5.07 with application rates of 0 %, 2.5 % and 5 % wt/wt, respectively. The soil pH increased with increasing application rate and suggests that biochar has the potential to increase soil pH in acidic soil (pH<4).

Chintala et al. (2013) found similar impacts of alkaline biochar on pH in acidic soils. Biochar from corn stover (pH 11.42) and switchgrass (pH 10.45) were used. After incubation, they found that soil pH (initially 4.78) increased in all treatments with biochar at different rates. Application rates of 52, 104, and 156 Mg ha\(^{-1}\) corn stover biochar increased soil pH 0.73, 0.99, and 1.366 units, respectively. Switchgrass biochar increased soil pH 0.49, 0.74, and 0.91 units, respectively. This study illustrates that corn stover biochar increased soil pH more than switchgrass and ameliorated the effect of biochar on soil pH. At the same rates, application of lime powder showed that soil pH was significantly increased by 2.71, 2.73 and 2.80 units, respectively.

Although biochar may have potential liming effects on acidic soil, some studies have indicated that biochar can decrease soil pH. Liu & Zhang (2012) and Wu et al. (2014) found that applying lower pH biochar to higher pH soil resulted in decreased soil
Liu & Zhang (2012) conducted a study on biochar effects on alkaline soil pH. In their study, they applied biochar with a pH of 8.38 to soil with a pH of 8.66-9.00. In all treatments, soil pH tended to decrease within 0.20 pH units. The largest decrease (0.17 pH units) was seen in soil with pH 9 and a biochar application rate of 16 g kg\(^{-1}\) while soil with pH 8.05 decreased 0.04 pH units. They concluded that biochar with lower pH than the target soil had the potential to decrease soil pH at the initial phase when biochar was mixed with soil. Their study confirmed a study done by Wu et al. (2014). After 56 days of incubation, Wu et al. (2014) found that 5% furfural (pH 2.9) and 5% biochar (pH 4.5) decreased the soil pH by 0.5-0.8 unit and 0.3-0.4 unit, respectively. The far lower pH of furfural and biochar compared with the soil pH may be what brought the soil pH down. In comparison to biochar, furfural had higher acidity and may have lowered the soil pH more significantly (Wu et al., 2014).

A review study from Al-Wabel et al. (2017) on the impact of biochar properties on soil conditions and agricultural sustainability illustrated that biochar had the potential to increase pH of acidic soil but did not alter pH of alkaline soil. This is because of the buffering capacity of alkaline soils which hinder the alkaline effects of biochar. It is worth considering that soil pH changes resulting from biochar application may result from the biochar’s own buffering capacity and may not permanently affect soil pH. Application rates of biochar, types of feedstocks, and pyrolysis conditions are the main factors influencing biochar potential in altering soil pH (Al-Wabel et al., 2017).
Fig. 2-5. Biochar effects on total carbon.

Total Carbon for Biochar treatments. Boxes indicate the LS mean. Error bars indicate the 95% confidence interval of the LS mean. Means sharing a letter are not significantly different (LSD comparisons).
Fig. 2-6. Biochar effects on soil pH.
Table 2-9. Effects of biochar on soil nutrients at 0-15 cm.

pH, Soil Electrical Conductivity (EC), Nitrate Nitrogen (NO$_3^-$ – N), Total Nitrogen (TN), Organic Matter (OM), Total Carbon (TC), Phosphorus (P), Potassium (K), Iron (Fe), Copper (Cu), Manganese (Mn), Zinc (Zn), Sulfate-Sulfur (S)

<table>
<thead>
<tr>
<th>Treatment</th>
<th>pH</th>
<th>EC</th>
<th>NO$_3^-$N</th>
<th>TN %</th>
<th>OM %</th>
<th>TC %</th>
<th>P mg/kg</th>
<th>K mg/kg</th>
<th>Fe mg/kg</th>
<th>Cu mg/kg</th>
<th>Mn mg/kg</th>
<th>Zn mg/kg</th>
<th>S mg/kg</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biochar0</td>
<td>7.78</td>
<td>0.50</td>
<td>1.27</td>
<td>0.10</td>
<td>2.10</td>
<td>2.01ab</td>
<td>10.90</td>
<td>614.20</td>
<td>3.40</td>
<td>1.20</td>
<td>4.20</td>
<td>0.34</td>
<td>3.37</td>
</tr>
<tr>
<td>Biochar2</td>
<td>7.78</td>
<td>0.50</td>
<td>1.54</td>
<td>0.10</td>
<td>2.10</td>
<td>1.84ab</td>
<td>14.10</td>
<td>621.20</td>
<td>3.40</td>
<td>1.20</td>
<td>4.10</td>
<td>0.36</td>
<td>3.52</td>
</tr>
<tr>
<td>Biochar10</td>
<td>7.75</td>
<td>0.50</td>
<td>1.19</td>
<td>0.10</td>
<td>2.00</td>
<td>2.06a</td>
<td>12.00</td>
<td>579.00</td>
<td>3.00</td>
<td>1.20</td>
<td>3.70</td>
<td>0.28</td>
<td>3.45</td>
</tr>
<tr>
<td>Biochar40</td>
<td>7.83</td>
<td>0.50</td>
<td>1.57</td>
<td>0.10</td>
<td>2.00</td>
<td>2.66b</td>
<td>9.00</td>
<td>566.50</td>
<td>3.30</td>
<td>1.00</td>
<td>3.60</td>
<td>0.32</td>
<td>3.93</td>
</tr>
<tr>
<td>Std E</td>
<td>0.02</td>
<td>0.02</td>
<td>0.29</td>
<td>0.10</td>
<td>0.10</td>
<td>0.10</td>
<td>1.43</td>
<td>23.60</td>
<td>0.20</td>
<td>0.05</td>
<td>0.20</td>
<td>0.04</td>
<td>0.45</td>
</tr>
<tr>
<td>P value</td>
<td>0.04*</td>
<td>0.30</td>
<td>0.75</td>
<td>0.70</td>
<td>0.90</td>
<td>0.009**</td>
<td>0.10</td>
<td>0.30</td>
<td>0.40</td>
<td>0.10</td>
<td>0.20</td>
<td>0.60</td>
<td>0.80</td>
</tr>
</tbody>
</table>

Biocahr0 (0 of biochar ha$^{-1}$), Biochar2 (2 ton of biochar ha$^{-1}$), Biochar10 (10 ton of biochar ha$^{-1}$), and Biochar40 (40 ton of biochar ha$^{-1}$).

* significantly different at $p <0.05$
** significantly different at $p< 0.01$
*** significantly different at $p<0.001$
**** significantly different at $p<0.0001$
Table 2-10. Effects of biochar on soil nutrients at 15-30 cm.

Table 2-10. Effects of biochar on soil nutrients at 15-30 cm.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>pH</th>
<th>EC</th>
<th>NO$_3$N</th>
<th>TN</th>
<th>OM</th>
<th>TC</th>
<th>P</th>
<th>K</th>
<th>Fe</th>
<th>Cu</th>
<th>Mn</th>
<th>Zn</th>
<th>S</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>dS/m</td>
<td>mg/kg</td>
<td>%</td>
<td>%</td>
<td>%</td>
<td>%</td>
<td>mg/kg</td>
<td>mg/kg</td>
<td>mg/kg</td>
<td>mg/kg</td>
<td>mg/kg</td>
<td>mg/kg</td>
<td>mg/kg</td>
</tr>
<tr>
<td>Biochar0</td>
<td>7.9</td>
<td>0.6</td>
<td>4.8</td>
<td>0.7</td>
<td>1.5</td>
<td>3.1</td>
<td>3.8</td>
<td>524.5</td>
<td>2.2</td>
<td>0.8</td>
<td>3.0</td>
<td>0.1</td>
<td>4.5</td>
</tr>
<tr>
<td>Biochar2</td>
<td>7.9</td>
<td>0.6</td>
<td>4.4</td>
<td>0.7</td>
<td>1.4</td>
<td>2.8</td>
<td>4.6</td>
<td>532.5</td>
<td>3.0</td>
<td>0.8</td>
<td>3.2</td>
<td>0.1</td>
<td>4.7</td>
</tr>
<tr>
<td>Biochar10</td>
<td>7.9</td>
<td>0.6</td>
<td>6.1</td>
<td>0.6</td>
<td>1.4</td>
<td>3.1</td>
<td>3.1</td>
<td>510.3</td>
<td>2.9</td>
<td>0.7</td>
<td>2.5</td>
<td>0.1</td>
<td>4.5</td>
</tr>
<tr>
<td>Biochar40</td>
<td>7.8</td>
<td>0.6</td>
<td>5</td>
<td>0.7</td>
<td>1.6</td>
<td>2.9</td>
<td>6.3</td>
<td>579.7</td>
<td>3.0</td>
<td>0.9</td>
<td>3.1</td>
<td>0.2</td>
<td>5.5</td>
</tr>
<tr>
<td>Std E</td>
<td>0.04</td>
<td>0.04</td>
<td>0.6</td>
<td>0.004</td>
<td>0.2</td>
<td>1.04</td>
<td>30.4</td>
<td>0.3</td>
<td>0.05</td>
<td>0.1</td>
<td>0.03</td>
<td>0.6</td>
<td></td>
</tr>
<tr>
<td>P value &lt;0.05</td>
<td>0.7</td>
<td>0.2</td>
<td>0.09</td>
<td>0.08</td>
<td>0.6</td>
<td>0.2</td>
<td>0.4</td>
<td>0.2</td>
<td>0.04*</td>
<td>0.03*</td>
<td>0.2</td>
<td>0.6</td>
<td></td>
</tr>
</tbody>
</table>

Biochar0 (0 of biochar ha$^{-1}$), Biochar2 (2 ton of biochar ha$^{-1}$), Biochar10 (10 ton of biochar ha$^{-1}$) and Biochar40 (40 ton of biochar ha$^{-1}$).

* significantly different at $p < 0.05$
** significantly different at $p < 0.01$
*** significantly different at $p < 0.001$
**** significantly different at $p < 0.0001$
Biochar Effects on Soil Moisture

In this study, soil moisture increased with increased rate of biochar application in the topsoil profile (Fig. 2-7). However, there was no significant difference in soil moisture among different rates of biochars. Only biochar40 in topsoil showed a significantly different soil moisture with an increase from 2.5 (control) to 3.1 (biochar40). Biochar did not increase soil moisture in 15-30 cm depth (Table 2-12).

Biochar has the capacity to maintain soil moisture because of its surface area and porous nature (Pandian et al., 2016). Novak et al. (2012) conducted a study on the impact of biochar on soil moisture storage in ultisol (Norfork loamy sand) and two aridisols (silt loams) from an arid location. The aridisols needed improved water holding capacity. Nine biochars were pyrolyzed from different feedstocks (peanut hull, pecan shells, poultry litter, switch grass, and hardwood waste products) at two temperatures (low pyrolysis <400 °C or high pyrolysis >500 °C). Switchgrass biochar had the most significant impact on improving soil moisture storage. They found improved moisture storage in Norfolk loamy sand in 2 % switchgrass pyrolyzed at 250 °C, switchgrass pyrolyzed at 500 °C, and hardwood biochar after four leaching events. Soil containing switchgrass biochar could improve water storage two-fold compared to control. The other biochars had small, but significant, impacts on soil moisture content. They concluded that types of feedstock and pyrolysis conditions influence water storage in the soil. Biochar made from switchgrass and hardwood (fast pyrolysis) have optimum impact on improving soil moisture in sandy ultisol and biochar made from switchgrass can improve the moisture holding capacity for silt loam aridisols. Different types of biochar (materials
and pyrolysis temperatures) can result in diverse interactions between water and soil particles.

In the present study, the soil moisture was measured twice: first during the stem elongation, (Zadoks 31 and 33, 09 May 2017) and second during the milk stage, (Zadoks 73 and 75, 23 July 2017) (Zadoks et al., 1974). The soil water content was higher during the milk stage than during stem elongation due to water use of the plant (Table 2-12). Water use gradually increased until late May or early June when the spring green-up occurred (Yonts et al., 2009).

Neither biochar nor compost had an impact on the first measure of soil moisture (Table 2-12). However, during the milk stage, soil water content significantly increased in biochar40 treatment (Table 2-12, Fig. 2-7.). In a similar study by Vitkova et al. (2017), water content and crop yield were measured after applying biochar in field conditions. The experiment was located in Malanta, Slovakia. Water content was measured at 5-10 cm depth in plots treated with 20 ton ha$^{-1}$ and 0 ton ha$^{-1}$ of biochar amendment. There were two types of crops (maize in 2015 and spring wheat in 2016) used in the study. They found that biochar increased water content in wheat production in 2016. However, in 2015, when the field was cultivated with maize, biochar did not increase the soil moisture content and was lower than in control. They suspected a precipitation event contributed to the soil moisture content in the study. In 2015, regardless of a high or low water content in the soil, soil water content was always higher in the control treatment than with biochar. While they did not have a firm explanation for this phenomenon, they mentioned some possible factors: characteristics of biochar such as pyrolysis conditions.
or surface type, different root zones of crops influencing water content, different soil water evaporation patterns, or water use of wheat at different growth stages. Positive impacts of biochar on soil water content were due to the strong relationship between soil water content and type of crop. Soil-plant-atmosphere system interactions are complicated. In order to assess the impact of biochar on soil water content, hypothesis testing in long-term field conditions is necessary.
Table 2-11. Effects of compost on soil water content in soil depths of 0-15 cm and 15-30 cm.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Moisture (%)</th>
<th>09 May 2017</th>
<th>23 June 2017</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0-15 cm</td>
<td>15-30 cm</td>
<td>0-15 cm</td>
</tr>
<tr>
<td>Compost0</td>
<td>10.2</td>
<td>15.6</td>
<td>2.9</td>
</tr>
<tr>
<td>Compost8</td>
<td>9.8</td>
<td>13.5</td>
<td>2.6</td>
</tr>
<tr>
<td>Std E</td>
<td>0.4</td>
<td>0.5</td>
<td>0.1</td>
</tr>
<tr>
<td>P value &lt;0.05</td>
<td>0.1</td>
<td>0.1</td>
<td>0.2</td>
</tr>
</tbody>
</table>

Compost0 (0 ton of compost ha$^{-1}$) and Compost8 (18 ton of compost ac$^{-1}$).
* significantly different at $p < 0.05$
** significantly different at $p < 0.01$
*** significantly different at $p < 0.001$
**** significantly different at $p < 0.0001$

Table 2-12. Effects of biochar on soil water content in soil depths of 0-15 cm and 15-30 cm.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Moisture (%)</th>
<th>09 May 2017</th>
<th>23 June 2017</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0-15 cm</td>
<td>15-30 cm</td>
<td>0-15 cm</td>
</tr>
<tr>
<td>Biochar0</td>
<td>9.8</td>
<td>14.7</td>
<td>2.5a</td>
</tr>
<tr>
<td>Biochar2</td>
<td>10.1</td>
<td>14.9</td>
<td>2.5ab</td>
</tr>
<tr>
<td>Biochar10</td>
<td>10.0</td>
<td>14.5</td>
<td>2.9ab</td>
</tr>
<tr>
<td>Biochar40</td>
<td>10.2</td>
<td>14.0</td>
<td>3.1b</td>
</tr>
<tr>
<td>Std E</td>
<td>0.4</td>
<td>0.4</td>
<td>0.1</td>
</tr>
<tr>
<td>P value &lt;0.05</td>
<td>0.4</td>
<td>0.4</td>
<td>0.02*</td>
</tr>
</tbody>
</table>

Biochar0 (0 of biochar ha$^{-1}$), Biochar2 (2 ton of biochar ha$^{-1}$), Biochar10 (10 ton of biochar ha$^{-1}$) and Biochar40 (40 ton of biochar ha$^{-1}$)
* significantly different at $p < 0.05$
** significantly different at $p < 0.01$
*** significantly different at $p < 0.001$
**** significantly different at $p < 0.0001$
Table 2-13. Effects of interaction between compost and biochar on soil water content in depths of 0-15 cm and 15-30 cm.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>Moisture 09 May 2017</th>
<th>Moisture 23 June 2017</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>0-15 cm</td>
<td>15-30 cm</td>
</tr>
<tr>
<td>C0B0</td>
<td>10.1</td>
<td>15.7</td>
</tr>
<tr>
<td>C0B2</td>
<td>10.5</td>
<td>16.3</td>
</tr>
<tr>
<td>C0B10</td>
<td>9.9</td>
<td>15.1</td>
</tr>
<tr>
<td>C0B40</td>
<td>10.5</td>
<td>15.2</td>
</tr>
<tr>
<td>C8B0</td>
<td>9.6</td>
<td>13.6</td>
</tr>
<tr>
<td>C8B2</td>
<td>9.7</td>
<td>13.5</td>
</tr>
<tr>
<td>C8B10</td>
<td>10.1</td>
<td>13.9</td>
</tr>
<tr>
<td>C8B40</td>
<td>9.9</td>
<td>12.9</td>
</tr>
<tr>
<td>Std E</td>
<td>0.6</td>
<td>0.5</td>
</tr>
<tr>
<td>P value &lt;0.05</td>
<td>0.6</td>
<td>0.6</td>
</tr>
</tbody>
</table>

C0BO (0 ton of compost ha⁻¹ and 0 ton of biochar ha⁻¹), C0B2 (0 ton of compost ha⁻¹ and 2 ton of biochar ha⁻¹), C0B10 (0 ton of compost ha⁻¹ and 10 ton of biochar ha⁻¹), C0B40 (0 ton of compost ha⁻¹ and 40 ton of biochar ha⁻¹), C8B0 (18 ton of compost ha⁻¹ and 0 ton of biochar ha⁻¹), C8B2 (18 ton of compost ha⁻¹ and 2 ton of biochar ha⁻¹), C8B10 (18 ton of compost ha⁻¹ and 10 ton of biochar ha⁻¹), C8B40 (18 ton of compost ha⁻¹ and 40 ton of biochar ha⁻¹)

* significantly different at p <0.05
** significantly different at p< 0.01
*** significantly different at p <0.001
**** significantly different at p <0.0001
Fig. 2-7. Biochar effects on soil moisture in milk stage.

SOIL MOISTURE for Biochar treatments. Boxes indicate the LS mean. Error bars indicate the 95% confidence interval of the LS mean. Means sharing a letter are not significantly different (LSD comparisons).
Table 2-14. Effects of interaction between biochar and compost on soil nutrients in depth 0-15 cm.

pH, Soil Electrical Conductivity (EC), Nitrate Nitrogen (NO$_3^-$ − N), Total Nitrogen (TN), Organic Matter (OM), Total Carbon (TC), Phosphorus (P), Potassium (K), Iron (Fe), Copper (Cu), Manganese (Mn), Zinc (Zn), Sulfate-Sulfur (S)

<table>
<thead>
<tr>
<th>Treatment</th>
<th>pH</th>
<th>EC</th>
<th>NO$_3$-N</th>
<th>TN</th>
<th>OM</th>
<th>TC</th>
<th>P</th>
<th>K</th>
<th>Fe</th>
<th>Cu</th>
<th>Mn</th>
<th>Zn</th>
<th>S</th>
</tr>
</thead>
<tbody>
<tr>
<td>C0B0</td>
<td>7.8</td>
<td>0.5</td>
<td>2.0</td>
<td>0.1</td>
<td>2.0</td>
<td>2.1</td>
<td>8.4</td>
<td>579.3</td>
<td>3.5</td>
<td>1.2</td>
<td>4.2</td>
<td>0.3</td>
<td>2.6</td>
</tr>
<tr>
<td>C0B2</td>
<td>7.8</td>
<td>0.4</td>
<td>1.9</td>
<td>0.1</td>
<td>2.0</td>
<td>2.0</td>
<td>6.9</td>
<td>575.3</td>
<td>3.0</td>
<td>1.1</td>
<td>3.6</td>
<td>0.2</td>
<td>2.5</td>
</tr>
<tr>
<td>C0B10</td>
<td>7.7</td>
<td>0.5</td>
<td>2.0</td>
<td>0.1</td>
<td>2.1</td>
<td>1.9</td>
<td>8.9</td>
<td>562.3</td>
<td>2.8</td>
<td>1.2</td>
<td>3.5</td>
<td>0.2</td>
<td>2.6</td>
</tr>
<tr>
<td>C0B40</td>
<td>7.8</td>
<td>0.4</td>
<td>2.6</td>
<td>0.1</td>
<td>2.0</td>
<td>2.7</td>
<td>6.3</td>
<td>545.7</td>
<td>3.1</td>
<td>1.0</td>
<td>3.2</td>
<td>0.2</td>
<td>2.9</td>
</tr>
<tr>
<td>C8B0</td>
<td>7.8</td>
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<td>0.5</td>
<td>0.1</td>
<td>2.1</td>
<td>1.9</td>
<td>13.3</td>
<td>649.0</td>
<td>3.2</td>
<td>1.1</td>
<td>4.3</td>
<td>0.4</td>
<td>4.1</td>
</tr>
<tr>
<td>C8B2</td>
<td>7.7</td>
<td>0.7</td>
<td>1.2</td>
<td>0.1</td>
<td>2.2</td>
<td>1.6</td>
<td>21.2</td>
<td>667.0</td>
<td>3.9</td>
<td>1.2</td>
<td>4.7</td>
<td>0.4</td>
<td>4.6</td>
</tr>
<tr>
<td>C8B10</td>
<td>7.7</td>
<td>0.5</td>
<td>0.4</td>
<td>0.1</td>
<td>2.0</td>
<td>2.2</td>
<td>15.1</td>
<td>595.7</td>
<td>3.1</td>
<td>1.2</td>
<td>3.8</td>
<td>0.3</td>
<td>4.3</td>
</tr>
<tr>
<td>C8B40</td>
<td>7.8</td>
<td>0.5</td>
<td>0.5</td>
<td>0.1</td>
<td>2.0</td>
<td>2.6</td>
<td>11.8</td>
<td>587.3</td>
<td>3.6</td>
<td>1.0</td>
<td>4.1</td>
<td>0.4</td>
<td>5.0</td>
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<td>0.4</td>
<td>0.008</td>
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<td>33.3</td>
<td>0.3</td>
<td>0.1</td>
<td>0.316</td>
<td>0.06</td>
<td>0.6</td>
</tr>
</tbody>
</table>

P value <0.05

C0BO (0 ton of compost ha$^{-1}$ and 0 ton of biochar ha$^{-1}$), COB2 (0 ton of compost ha$^{-1}$ and 2 ton of biochar ha$^{-1}$), C0B10 (0 ton of compost ha$^{-1}$ and 10 ton of biochar ha$^{-1}$), COB40 (0 ton of compost ha$^{-1}$ and 40 ton of biochar ha$^{-1}$), C8B0 (18 ton of compost ha$^{-1}$ and 0 ton of biochar ha$^{-1}$), C8B2 (18 ton of compost ha$^{-1}$ and 2 ton of biochar ha$^{-1}$), C8B10 (18 ton of compost ha$^{-1}$ and 10 ton of biochar ha$^{-1}$), C8B40 (18 ton of compost ha$^{-1}$ and 40 ton of biochar ha$^{-1}$)

* significantly different at $p <0.05$

** significantly different at $p< 0.01$

*** significantly different at $p<0.001$

**** significantly different at $p<0.0001$
Table 2-15. Effects of interaction between biochar and compost on soil nutrients in depth 15-30 cm.

| Treatment | pH | Ec (dS/m) | NO$_3$-N (mg/kg) | TN (%) | OM (%) | TC (%) | P (mg/kg) | K (mg/kg) | Fe (mg/kg) | Cu (mg/kg) | Mn (mg/kg) | Zn (mg/kg) | S (mg/kg) |
|-----------|----|-----------|------------------|--------|--------|--------|-----------|-----------|-----------|------------|------------|------------|------------|-----------|
| C0B0      | 7.9| 0.6       | 7.2              | 0.07   | 1.4    | 3.4    | 3         | 512.7     | 3.6       | 0.8        | 3          | 0.1        | 3.5        |
| C0B2      | 8.0| 0.6       | 6.9              | 0.06   | 1.3    | 3.0    | 2.8       | 569.7     | 2.8       | 0.7        | 2.6        | 0.1        | 3.3        |
| C0B10     | 7.9| 0.6       | 8.0              | 0.07   | 1.4    | 3.0    | 2.6       | 516.0     | 2.8       | 0.7        | 2.5        | 0.1        | 3.7        |
| C0B40     | 7.9| 0.6       | 8.7              | 0.07   | 1.4    | 3.1    | 3.3       | 566.0     | 2.8       | 0.8        | 2.5        | 0.1        | 5.3        |
| C8B0      | 7.8| 0.6       | 2.3              | 0.08   | 1.5    | 2.7    | 4.6       | 536.3     | 2.9       | 0.8        | 3.1        | 0.1        | 5.5        |
| C8B2      | 7.7| 0.7       | 2.7              | 0.07   | 1.5    | 2.6    | 6.3       | 495.3     | 3.1       | 0.9        | 3.7        | 0.1        | 6          |
| C8B10     | 7.9| 0.7       | 4.3              | 0.05   | 1.3    | 3.1    | 3.7       | 504.7     | 3.1       | 0.7        | 2.5        | 0.1        | 5.4        |
| C8B40     | 7.7| 0.6       | 1.2              | 0.09   | 1.9    | 2.7    | 9.2       | 593.3     | 3.1       | 1.0        | 3.6        | 0.2        | 5.7        |

| Std E | 0.6 | 0.05 | 0.8 | 0.007 | 0.1 | 0.3 | 1.5 | 43 | 0.4 | 0.05 | 0.2 | 0.05 | 0.8 |

| P value <0.05 | 7.9 | 0.4 | 0.2 | 0.3 | 0.1 | 0.5 | 0.4 | 0.6 | 0.2 | 0.07 | 0.03* | 0.2 | 0.6 |

C0BO (0 ton of compost ha$^{-1}$ and 0 ton of biochar ha$^{-1}$), C0B2 (0 ton of compost ha$^{-1}$ and 2 ton of biochar ha$^{-1}$), C0B10 (0 ton of compost ha$^{-1}$ and 10 ton of biochar ha$^{-1}$), C0B40 (0 ton of compost ha$^{-1}$ and 40 ton of biochar ha$^{-1}$), C8B0 (18 ton of compost ha$^{-1}$ and 0 ton of biochar ha$^{-1}$), C8B2 (18 ton of compost ha$^{-1}$ and 2 ton of biochar ha$^{-1}$), C8B10 (18 ton of compost ha$^{-1}$ and 10 ton of biochar ha$^{-1}$), C8B40 (18 ton of compost ha$^{-1}$ and 40 ton of biochar ha$^{-1}$)

* significantly different at $p < 0.05$

** significantly different at $p < 0.01$

*** significantly different at $p < 0.001$

**** significantly different at $p < 0.000$
CHAPTER III:
WHEAT YIELD QUALITY

Introduction

There are many studies on the effects of compost and biochar on crop yield and quality. Some studies show positive effects, some show neutral effects, while others show negative effects. Some studies illustrate the positive effects of compost on increasing production of organic winter wheat in dryland conditions (Stukenholtz et al., 2002; Reeve et al., 2012). The study from Calderón et al. (2018) showed positive effects of compost application on wheat test weight, but did not increase the wheat yield.

According to Spokas et al. (2012), adding black carbon (C) or biochar to soil can increase, decrease, or have no significant impacts on crop yield. They did a review study on impacts of biochar beyond carbon sequestration. In their study, they found that 50% of articles reviewed showed short term positive impacts of biochar on crop yield or plant growth; 30% showed no significant impact on crop yield or plant growth and the remaining 20% showed negative impacts on crop yield or plant growth. The methods of biochar production (feedstock and pyrolysis conditions) and the postproduction conditions (storage and activation) are factors which affect yield responses of biochar (Spokas et al., 2012).
Material and Methods

Yield

The plot was harvested using a small plot combine to measure the yield. After harvesting, the grain was weighed by using an electronic balance (TL-12001, Denver Instrument Company). After harvesting, 500 g of wheat from each plot were sent to Western Wheat Quality Laboratory (WWQL) for wheat quality analysis. Wheat was also analyzed at the Utah State University Cereal Laboratory (USUCL).

Grain Quality Analysis From Utah State University Cereal Laboratory

Grain Protein

The protein and water content of the grain were measured using a near-infrared spectrometer (Bran+Luebbe InfraAlyzer 2000) using AACC Method 39-11.01 (AACC Methods, 2009).

Test Weight

The grain was cleaned using the Pfeuffer Rationel Kornservice SLN3. Test weight was measured by filling a one quart container (32 qts to a bushel) that meets the specifications of the United States Department of Agriculture – Federal Grain Inspection Service (USDA-FGIS) and Grain Inspection, Packers and Stockyards Administration (GIPSA). The quart with grain was weighed by electronic balance, (TL-12001, Denver Instrument Company) and bushel weight was calculated. Test weight unit was lbs bu$^{-1}$.

Mixograph

A mixograph was used to measure the mixing characteristics of flour. Mixograph data were used to differentiate baking quality of wheat flour (Chung et al., 2001). The
method is based on AACCI Method 54-10A (1),(8). First, whole wheat grain was ground into flour and 1.89 g of flour were weighed on a precision balance. Then, flour was transferred to the mixograph bowl and 1.6 ml of water were added. The mixograph ran approximately 7 minutes and used Mixsmart software for analyzing the mixograph data (National Manufacturing TMCO, Lincoln, NE). At the end of the mixing, the trace was automatically recorded and analyzed using the Mixsmart software program. The Mixsmart software constructs a midline curve from the recorded mixing trace and the upper and lower envelope.

Grain Quality Analysis From Western Wheat Quality Laboratory

Grain Wheat Protein


Test Weight

Test weight (TW) was measured after cleaning. Weights were measured in lbs bu⁻¹. based on AACCI Method 55-10.01.

Mixograph

A 10-g instrument was used to characterize the market class and estimate mixing and baking properties of flours. To reduce the time and expense, a reference chart was developed to characterize each curve ranging from very weak to exceptionally long and
strong. The chart and instructions for use are found in the Mixograph Reference Chart (AACCI Method 54-10A (1),(8)) (Fig. 3-6).

Loaf Volume

Loaf volume was determined by rapeseed displacement.

Predicted Loaf Volume

Predicted loaf volume was calculated based on the relationship between protein and loaf volume.

Bread Crumb Grain

Bread crumb grain is visually evaluated by trained bakers.

Statistical Analysis

The data analyses were done using R-Studio (model R version 3.3.1 (2016)) for compost and biochar effects and interactions. The experimental design was comprised of split plots with two compost treatments comprising the whole plot: compost0 (0 ton of compost ha\(^{-1}\)) and compost8 (18 ton of compost ha\(^{-1}\)). There were three replications of the whole plot compost treatment and control. The split-plot included four application rates of biochar, 0, 2, 10 and 40 ton of biochar ha\(^{-1}\), which were randomized on each replication. Compost, biochar, and replication were the three factors in the experiments. Biochar is equivalent to the interaction between compost and replication. The goal of the study was to assess whether there was an interaction between compost and biochar or whether they would produce any effects.
Results

After harvesting, 500 g of wheat from each plot were sent to the WWQL to do analyses on wheat quality. Meanwhile, similar analyses were performed at the USUCL. The results obtained from the WWQL were slightly different than those from USUCL for WP, TW, and the mixograph. Differences will be discussed in more detail in the following sections.

Effects of Compost and Biochar on Wheat Protein and Test Weight

The TW and WP obtained from WWQL and USUCL were slightly different. The grand mean of TW and WP from WWQL were 61.2 lbs bu$^{-1}$ and 13.1 %, respectively (Table 3-1 and 3-2). The grand mean of TW and WP from USUCL were 59.9 lbs bu$^{-1}$ and 13.6 %, respectively (Table 3-1 and 3-2). After running the statistical analysis on both of the results, we did not see significant impacts of either compost or biochar on TW and WP (Table 3-1 and 3-2). There was no significant interaction between compost and biochar on TW and WP (Table 3-3).
Table 3-1. Effects of compost on yield, test weight (TW), and wheat protein (WP) from Western Wheat Quality Laboratory (WWQL) and USU Cereal Laboratory (USUCL).

<table>
<thead>
<tr>
<th>Treatment</th>
<th>WWQL</th>
<th>USUCL</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Yield</td>
<td>TW</td>
</tr>
<tr>
<td></td>
<td>bu/ac</td>
<td>lbs/bu</td>
</tr>
<tr>
<td>Compost0</td>
<td>10.8</td>
<td>60.7</td>
</tr>
<tr>
<td>Compost8</td>
<td>18.0</td>
<td>61.7</td>
</tr>
<tr>
<td>Grand mean</td>
<td>14.4</td>
<td>61.2</td>
</tr>
<tr>
<td>Std E</td>
<td>0.9</td>
<td>0.16</td>
</tr>
<tr>
<td>P&lt;0.05</td>
<td>0.03*</td>
<td>0.052</td>
</tr>
</tbody>
</table>

Compost0 (0 ton of compost ha⁻¹) and Compost8 (18 ton of compost ha⁻¹).
* significantly different at \( p < 0.05 \)
** significantly different at \( p < 0.01 \)
*** significantly different at \( p < 0.001 \)
**** significantly different at \( p < 0.0001 \)

Table 3-2. Effects of biochar on yield, test weight (TW), and wheat protein (WP) from Western Wheat Quality Laboratory (WWQL) and USU Cereal Laboratory (USUCL).

<table>
<thead>
<tr>
<th>Treatment</th>
<th>WWQL</th>
<th>USUCL</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Yield</td>
<td>TW</td>
</tr>
<tr>
<td></td>
<td>bu/ac</td>
<td>lbs/bu</td>
</tr>
<tr>
<td>Biochar0</td>
<td>13.3</td>
<td>61.4</td>
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<tr>
<td>Biochar2</td>
<td>15.1</td>
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<tr>
<td>Biochar10</td>
<td>13.5</td>
<td>61.2</td>
</tr>
<tr>
<td>Biochar40</td>
<td>15.7</td>
<td>61.1</td>
</tr>
<tr>
<td>Grand Mean</td>
<td>14.4</td>
<td>61.2</td>
</tr>
<tr>
<td>Std E</td>
<td>1.2</td>
<td>0.2</td>
</tr>
<tr>
<td>P value&lt;0.05</td>
<td>0.4</td>
<td>0.8</td>
</tr>
</tbody>
</table>

Biochar0 (0 of biochar ha⁻¹), Biochar2 (2 ton of biochar ha⁻¹), Biochar10 (10 ton of biochar ha⁻¹) and Biochar40 (40 ton of biochar ha⁻¹).
* significantly different at \( p < 0.05 \)
** significantly different at \( p < 0.01 \)
*** significantly different at \( p < 0.001 \)
**** significantly different at \( p < 0.0001 \)
Table 3-3. Effects of interaction between biochar and compost on test weight (TW) and wheat protein (WP) from Western Wheat Quality Laboratory (WWQL) and USU Cereal Laboratory (USUCL).

<table>
<thead>
<tr>
<th>Treatment</th>
<th>WWQL</th>
<th>USUCL</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Yield</td>
<td>TW</td>
</tr>
<tr>
<td></td>
<td>bu/ac</td>
<td>lbs/bu</td>
</tr>
<tr>
<td>C0B0</td>
<td>8.9</td>
<td>60.5</td>
</tr>
<tr>
<td>C0B2</td>
<td>11.9</td>
<td>60.9</td>
</tr>
<tr>
<td>C0B10</td>
<td>9.8</td>
<td>60.9</td>
</tr>
<tr>
<td>C0B40</td>
<td>12.5</td>
<td>60.7</td>
</tr>
<tr>
<td>C8B0</td>
<td>17.7</td>
<td>61.8</td>
</tr>
<tr>
<td>C8B2</td>
<td>18.3</td>
<td>61.6</td>
</tr>
<tr>
<td>C8B10</td>
<td>17.2</td>
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<td>C8B40</td>
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<td>62.0</td>
</tr>
<tr>
<td>Grand Mean</td>
<td>14.4</td>
<td>61.2</td>
</tr>
</tbody>
</table>

Std E 0.80.50.20.30.2
P value < 0.05

C0B0 (0 ton of compost ha$^{-1}$ and 0 ton of biochar ha$^{-1}$), C0B2 (0 ton of compost ha$^{-1}$ and 2 ton of biochar ha$^{-1}$), C0B10 (0 ton of compost ha$^{-1}$ and 10 ton of biochar ha$^{-1}$), C0B40 (0 ton of compost ha$^{-1}$ and 40 ton of biochar ha$^{-1}$), C8B0 (18 ton of compost ha$^{-1}$ and 0 ton of biochar ha$^{-1}$), C8B2 (18 ton of compost ha$^{-1}$ and 2 ton of biochar ha$^{-1}$), C8B10 (18 ton of compost ha$^{-1}$ and 10 ton of biochar ha$^{-1}$), C8B40 (18 ton of compost ha$^{-1}$ and 40 ton of biochar ha$^{-1}$),

* significantly different at $p < 0.05$
** significantly different at $p < 0.01$
*** significantly different at $p < 0.001$
**** significantly different at $p < 0.0001$
Effects of Compost and Biochar on Wheat Yield

Compost significantly increased wheat yield. The wheat yields were 10.8 bu ac\(^{-1}\) and 18.0 bu ac\(^{-1}\) in compost0 and compost8, respectively. The wheat yield was 1.7 times higher in compost8 (Table 3-1 and Fig. 3-1). Biochar did not significantly increase the wheat yield (Table 3-2).

Yield Response Compost Application

Two compost experiments were conducted in Snowville, Utah from 1994 to 1998. The first experiment was conducted on the south side of the dividing road on a cooperator’s dryland organic wheat farm in the fall of 1994. The second experiment was conducted on the north side of the dividing road in the fall of 1995. Both experiments applied compost treatments at rates of 0, 10, 25, 50, and 70 Mg ha\(^{-1}\). The annual precipitation in the study area was 30 cm. However, the precipitation during the first experiment (south side) was 56 cm (186 % of average) during the winter wheat growing season. In the second experiment (north), they received 26 cm of precipitation (87% of average) during the growing season. The wheat yield from the first experiment (south side) increased 242% (1,510 to 3,649 kg ha\(^{-1}\)) and from the second experiment (north side) yield increased 254% (860 to 2,184 kg ha\(^{-1}\)) in comparison to the control plots. Wheat yield increased significantly with application of compost in both experiments (Stukenholtz et al., 2002). They concluded that compost and soil moisture played important roles in increasing crop productivity in dryland conditions. Dr. Hole and his team continue to harvest the plots where composts were applied in 1995 (Personal communication, 2018). The team found that compost still has significant impacts on
wheat yield (Fig. 3-2). To determine whether compost still has significant impacts on the wheat yield and soil quality, Reeve et al. (2012) sampled the soil on the south side and determined the residual effects of compost on soil quality and wheat yield. They found that residual effects of compost applied in 1995 have long-term carryover effects and improve organic wheat yield, microbial biomass, and soil quality.

Wheat Yield Response to Biochar Treatments

Wheat yield in biochar treatment was 13.3, 15.1, 13.5, and 15.7 bu ac$^{-1}$ in biochar0, biochar2, biochar10, and biochar40, respectively (Table 3-2). Interactions between biochar and compost did not have significant effects on wheat yield (Table 3-3). Spokas et al. (2012) did a review on impacts of biochar. In their study, they found that 50% of studies showed short term positive impacts of biochar, 30 % illustrated no significant impact, and the other 20 % showed negative impacts on crop yield or plant growth (Spokas et al., 2012). The methods of biochar production (feedstocks and pyrolysis conditions) and the postproduction conditions (storage and activation) are factors which result in different crop yields or plant growth (Spokas et al., 2012).

Biochar had promising effects on crop yield when it was combined with mineral fertilizer (Asai et al., 2009; Alburquerque et al., 2013). Asai et al. (2009) conducted an experiment on biochar amendment techniques for upland rice production in northern Laos. The results showed that biochar and fertilizers had the potential to improve plant response and increase yield in soil with low phosphorous (P) availability. They suggested that, for rice production in upland areas, the positive effects of biochar are highly dependent on soil fertility and fertilizer management. A growth chamber study conducted
by Alburquerque et al. (2013) showed slight effects of biochar on Durum wheat in a low-nutrient, slightly acidic, loamy sand from Southern Spain. A 20-30 % increase in grain yield was observed in the treatment containing biochar and mineral fertilizer compared to the treatment that had only mineral fertilizer. However, only a slight increase was seen for the use of biochar alone. Biochar is carbon-rich but has poor nutrient availability. Because of this, biochar alone is often insufficient to meet plant needs but can have a range of effects dependent on characteristics and conditions.
Fig. 3-1. Compost effects on wheat yield
Compost8 (18 ton of compost ha\(^{-1}\))
Compost0 (0 ton of compost ha\(^{-1}\)).
Fig. 3-2. Compost effects on dryland wheat yield after single application in 1995. Adapted from Miller et al., 2018

Compost 50 (50 ton of compost ha$^{-1}$)
Compost0 (0 ton of compost ha$^{-1}$).
Biochar and Compost Effects on Wheat Quality

Mixograph from Western Wheat Quality Laboratory

Data from WWQL reports 11 indicators that describe wheat flour quality. Those parameters are mixing time, midline peak time, midline peak height, midline peak value under the curve to peak mixing time, Midline peak width tail at 2 min after peak time, mixing absorption, baking absorption, loaf volume, predicted loaf volume, bread crumb grain rating, and mixing type.

Mixing time is the time in minutes required to mix the flour and the other bread dough constituents to the optimum condition as judged by an experienced baker (Washington State University, 2018). In the present study, only compost8 had significant impacts on mixing time (P=0.02). Mixing time of compost8 was 3.6 min, while mixing time of the compost0 was 3.1 min (Fig. 3-3). Biochar did not have significant impacts on mixing time (Table 3-6) and there was no significant interaction between biochar and compost on mixing time (Table 3-7).

Midline peak time is the time required for dough to reach its maximum elasticity and extension (Washington State University, 2018). Midline peak time is recorded from the time the mixer started until the dough reached its maximum capacity and consistency (Wheat Marketing Center, Inc. (2004)). Midline peak time is influenced by environment, nitrogen, seeding rate, and genotype (Bhatta, 2015). The midline peak time in this study was significantly impacted by compost (P=0.04). Midline peak time in compost0 and compost8 were 3.5 and 4.0 min (Table 3-5 and Fig. 3-4).

Midline peak height is calculated as the height on the curve at midline peak time
and indicates the dough strength (maximum capacity of dough elasticity) (Bhatta, 2015; Labuschagne and Moloi, 2015). Midline peak height is influenced by nitrogen, seeding rate, and genotype (Bhatta, 2015). There was a significant positive correlation between protein concentration and midline peak height. Compost had significant impacts on midline peak height but biochar did not (Table 3-5 and Table 3-6). There was no significant interaction between biochar and compost on midline peak height (Table 3-7).

Midline peak value under the curve to peak mixing time, or midline peak integral value, is the mid-point work value from the mixograph. This is the area under the curve to the peak mixing time. Midline peak integral value represents the work put into the flour and water dough in order to develop it. The unit is the vertical axis (% torque) multiplied by the horizontal axis (minute) (%TQxmin). Compost and biochar did not have a significant impact on midline peak integral value (Table 3-5 and 3-6). There was no significant interaction between biochar and compost (Table 3-7). The grand mean of midline peak integral value was 170.8 %TQxmin.

Midline peak width tail at 2 min after peak time, sometimes referred to as tail slope width or end-width, is measured two minutes after the midline peak time. Midline peak width tail at 2 min after peak time measures dough extensibility and mixing tolerance (Labuschagne and Moloi, 2005). In this study, Midline peak width tail at 2 min after peak time was significantly influenced by compost (P=0.038). Midline peak width tail at 2 min after peak time of compost0 and compost8 were 4.8 and 10.5, respectively (Fig. 3-5). The biochar did not have a significant impact on Midline peak width tail at 2 min after peak time and there was no significant interaction between biochar and compost.
According to Washington State University (2018), mixing absorption is the optimum flour water absorption and is reported as percent (%) by weight, corrected to a 14 % flour measure basis. Mixing absorption is a function of protein content, variety, flour moisture, and environment. For bread-type wheat flour, mixing absorption is used to estimate bread baking absorption. In this study, neither biochar nor compost had significant impacts on mixing absorption or baking absorption (Table 3-5 and 3-6).

The interaction between biochar and compost did not have a significant impact on loaf volume of bread (P= 0.09) (Table 3-7). In the plot without compost, biochar0 resulted in a loaf volume of 1003.3 cc while biochar2 resulted in 1078.3 cc (Table 3-7). The interaction between biochar and compost had a significant impact on predicted loaf volume of the bread (P=0.032). Predicted loaf volume of biochar0 with compost was 174 while predicted loaf volume of biochar40 without compost was 87. Loaf volume and dough quality are highly dependent on weather conditions (Karki et al., 2016).

According to Hayman et al. (1998), the baking industry is interested in crumb grain quality and texture of bread in addition to the protein content and potential loaf volume. Bread crumb grain rating plays an important role in contributing to the textural properties of fresh bread (Zghal et al., 1999). Cell size, shape, and wall thickness are the main characteristics used to evaluate the crumb grain (Hayman et al., 1998). If bread consists of intermediate to large gas cells, it is characterized as open. If it consists of small gas cells, it is characterized as closed. In bread, elongated gas cells are preferred over round. The elongated cells result from the dough’s elastic properties (Hayman et al.,
Crumb grain quality is decided by a group of experienced bakers (Washington State University, 2018). The quality of crumb grain in the present study was determined using a table from Washington State University (2018) (Table 3-4). Crumb grain was rated on a scale of 1-9 with 1 being excellent and 9 being unsatisfactory. Results showed that the crumb grain of compost0 ranged from 4-7 and compost8 ranged from 2-5 (Table 3-5). Crumb grain of biochar0 ranged from 4-7, biochar2 ranged from 4-5, biochar10 ranged from 4-6, and biochar40 ranged from 2-6 (Table 3-6). For the interaction between biochar and compost, the crumb grain of biochar40 with compost ranged from 2-4, while biochar0 without compost ranged from 5-7 (Table 3-7).

According to Washington State University (2018), the mixograph type is based on protein content of flour and mixograph curve, and typed according to the Mixograph Reference Chart (Fig. 3-6). Flour protein in the present study ranged from 12.6-13.8 % (Table 3-1-3-3). The Mixograph Reference Chart (Fig. 3-6) was used to identify the curve characteristics that most closely resembled the sample chart identifier, for instance, 1L (low), 1M (medium), 1H (high) through 8H are reported as mixograph types (Fig. 3-6). The mixograph type in the current study varied from one treatment to another. The mixograph type of compost0 ranged from 3M-4H (Table 3-5). The mixograph type of compost8 ranged from 3H-5H (Table 3-5). The mixograph type of biochar was not uniform. The mixograph type of biochar10 ranged from 3H-5H (Table 3-6). Wide variability of mixograph type was observed for the interaction between biochar and compost (Table 3-7). The mixograph type for the interaction between biochar and no compost ranged from 3M-4H, with the exception of biochar10 that ranged from 3H-4H.
However, for different rates of biochar with compost, mixograph type ranged from 3H-5H. Desirable mixograph characteristics of bread flours are characterized as H, with a preference for 3H-6H (Washington State University, 2018) (Fig. 3-6). In this study, application of compost resulted in mixograph types in the preferred range.
Fig. 3-3. Compost effects on mixing time
Compost 0 (0 ton of compost ha$^{-1}$)
Compost 8 (18 ton of compost ha$^{-1}$)
Fig. 3-4. Compost effects on midline peak time
Compost 0 (0 ton of compost ha$^{-1}$)
Compost 8 (18 ton of compost ha$^{-1}$)
Fig. 3-5. Compost effects on midline peak width tail at 2 min after peak time
Compost 0 (0 ton of compost ha$^{-1}$)
Compost 8 (18 ton of compost ha$^{-1}$)
Fig. 3-6. Mixograph reference chart
Adapted from: http://wwql.wsu.edu/wp-content/uploads/2017/03/Appendix-6-Mixogram-Chart.pdf
Table 3-4. Code and meaning of bread crumb grain rating.

<table>
<thead>
<tr>
<th>Code</th>
<th>Meaning</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Excellent</td>
</tr>
<tr>
<td>2</td>
<td>Satisfactory</td>
</tr>
<tr>
<td>3</td>
<td>(Intermediate)</td>
</tr>
<tr>
<td>4</td>
<td>Questionable - Satisfactory</td>
</tr>
<tr>
<td>5</td>
<td>(Intermediate)</td>
</tr>
<tr>
<td>6</td>
<td>Questionable</td>
</tr>
<tr>
<td>7</td>
<td>Intermediate</td>
</tr>
<tr>
<td>8</td>
<td>Questionable - Unsatisfactory</td>
</tr>
<tr>
<td>9</td>
<td>Unsatisfactory</td>
</tr>
</tbody>
</table>

Adapted from: http://wwql.wsu.edu/wheat-was/wheat-was-inter-txt/
Mixograph from Utah State University Cereal Laboratory

In addition to the testing at WWQL, analyses were also run at the USUCL. The USUCL ran a 2 g mixograph to assess wheat flour quality. Ten parameters in the computer analyzed mixograph were used in this study: midline peak time, midline peak value, midline left slope, midline right slope, midline peak width value, midline tail width value at 7 min, midline tail value, weakening slope value, midline peak integral value, midline tail integral value. According to Ma et al. (2013), midline peak time, midline peak value and midline tail integral value are positively correlated with dough strength. In general, weaker dough has higher weakening slope, shorter midline peak time, lower midline peak value, and smaller midline tail integral value when compared to stronger dough.

Midline peak time is the time required for dough to reach its maximum elasticity and extension (Washington State University, 2018). Midline peak time is determined by measuring the number of minutes from when the mixer starts until the dough reaches its maximum capacity and consistency (elasticity and extensibility) (Wheat Marketing Center, Inc., 2004)). Mixing time is influenced by environment, nitrogen (N), seeding rate, and genotype (Bhatta, 2015). Neither compost nor biochar had significant impacts on midline peak time (Table 3-8 and 3-9). There was no interaction between biochar and compost on midline peak time (Table 3-10). The grand mean of midline peak time was 3.2 min (Table 3-8, 3-9, and 3-10).

Midline peak value is calculated as the height of the curve at midline peak time and indicates the dough strength (maximum capacity of dough elasticity) (Bhatta, 2015;
Labuschagne and Moloi, 2015). Midline peak value is influenced by N, seeding rate, and genotype (Bhatta, 2015). In this study, the grand mean of midline peak value was 47 %. Neither compost nor biochar had significant impacts on midline peak value (Table 3-8 and 3-9). The interaction between compost and biochar did not have a significant impact on midline peak value (Table 3-10).

Midline left slope denotes the slope of the midline that appears between the starting point and midline peak time. Midline left slope is used to predict the mixing tolerance of dough (Chung et al., 2001). The grand mean of midline left slope in this study was 9.7 % min$^{-1}$. Neither compost, biochar, nor interaction between biochar and compost had a significant impact on midline left slope (Table 3-8, 3-9, and 3-10).

Midline peak width is the width of the curve at midline peak time (Pistón et al., 2011). Midline peak width is used to predict the maximum capacity of dough extensibility. The grand mean of midline peak width in this study was 20.3 %. Neither compost nor biochar had a significant impact on midline peak width (Table 3-8, 3-9, and 3-10).

Midline right slope is used to predict mixing tolerance, typically one minute after midline peak time. In this study, the grand mean of midline right slope was -5.6 % min$^{-1}$. Neither compost nor biochar had a significant impact on midline right slope (Table 3-8-3, 3-9, and 3-10).

Tail slope width, or end-width, is one of the indicators for dough extensibility and is used as one of the parameters for mixing tolerance (Labuschagne and Moloi, 2015). It can also be used to predict the gluten and protein of the dough. The tail area has
significant interactions with environment, nitrogen, seeding rate, and genotype (Bhatta, 2015). In this study, tail slope width is the value of midline bandwidth at 7 min. The grand mean of tail slope width in this study was 4.9%. Neither compost nor biochar had a significant impact on tail slope width (Table 3-8, 3-9 and 3-10).

Weakening slope indicates the rate of breakdown while mixing and is an indicator of mixing tolerance. Weakening slope is the difference between midline peak value and midline tail value calculated at 7 min (Table 3-8, 3-9, and 3-10). Weakening slope is affected by environment, nitrogen, and genotype. Weakening slope varies dependent on environment (Bhatta, 2015). The larger the value of weakening slope, the lower the quality of dough. The grand mean of weakening slope in our study was 22.4%. Neither compost nor biochar had a significant impact on weakening slope (Table 3-8, 3-9 and 3-10).

According to Walker and Walker (1992), the integral values are the areas beneath the midline from time zero to the point in question. These values represent the work put into the flour and water dough in order to develop it. The unit is the vertical axis (% torque) multiplied by the horizontal axis (minute) (%TQxmin). In this study midline peak integral value and midline tail integral value are the total areas under the mixograph midline curve from the starting point to peak time and 7 min of mixing time, respectively. According to Labuschagne et al. (2016), midline tail integral value is used as one parameter for predicting flour protein and bread volume. Midline tail integral value is an indicator of the resistance to extension (Bhatta, 2015). Higher value of midline tail integral value indicates better dough quality. The grand mean of midline peak integral
value and midline tail integral value were 109 and 249.4 %TQxmin, respectively. Neither compost nor biochar had a significant impact on midline tail integral value (Table 3-8, 3-9 and 3-10).

The Mixograph Reference Chart (Fig. 3-6) was used to determine the type of wheat flour present in the study. Flour is categorized according to the Mixograph Reference Chart dependent upon the shape of the curve and protein content (Washington State University, 2018). Protein content is divided into three categories: low (<9 %), medium (9-11 %), and high (11-13 %). Mixograph types from the study obtained from USUCL were characterized as medium quality dough and ranged from 2M-6M. The grand mean of wheat protein from the samples was 13.1 % (Table 3-1, 3-2, and 3-3) and would fall in the H category of the Mixograph Reference Chart (Fig. 3-6). However, based on the shape of the curve, the mixograph type would fall into the M category (Appendix C and D). The mixograph of an 11 % wheat protein flour may be classified as high if the shape of the curve reflects that of a flour with at least 13 % protein, meaning the protein in the flour is of higher quality (Montana State University, n.d). Although the wheat protein level we got from USUCL was high (13 %), the protein may not be high quality.

Discussion

Results from WWQL showed that compost had a significant impact on midline peak time, while USUCL showed no significant impact of compost on midline peak time. The data from WWQL showed the mixograph types ranged from 3M-5H, while USUCL showed the mixograph types in medium. There were some factors that contributed to
these differences. WWQL found that compost significantly increased midline peak time from 3.5 (control) to 4.0 (compost) min while USUCL found midline peak time increased from 2.8 to 3.6 min. The values for midline peak time were still in the desirable time frame and considered good for bread.

When judging mixograph types, assignment of mixing curves is highly subjective due to operator interpretation of the curve (Dobraszczyk & Schofield, 2000). Differences in results may also be attributed to the use of different mixograph models (10g at WWQL, 2 g at USUCL) The 2 g model mixograph was adjusted to 88.0 (±1.0) rotations per minute (RPM). The settings of the mixograph at WWQL are unknown and may have impacted results.

According to Park et al. (2014), yield and bread-making quality of wheat in the United States Northern Great Plains are directly impacted by wide seasonal variation in rainfall and temperature. In dryland environments, metabolic activity and protein composition are influenced by water and nitrogen management (French and Schultz, 1984; Park et al., 2014). Management practices, environment, and genetic interactions influence wheat quality (Kraljevic-Balallic et al., 2001). Those factors shorten the grain-filling period, which directly impacts the types and amounts of proteins transported to the kernel (Kraljevic-Balallic et al., 2001; Park et al., 2014). Soil and climate variability can impact yields, protein composition, and dough quality (Park et al., 2014). There is a complex relationship between soil variability and climate condition that should be further studied to understand the impacts on wheat yield and quality.
Table 3-5. Effects of compost on wheat flour quality from Western Wheat Quality Laboratory (WWQL). Midline Peak Time (MPTIME), Mixing Time (MTIME), Midline Peak Height (MPH), Midline Peak Value Under the Curve to Peak Mixing Time (MPW1), Midline Peak Width Tail at 2 min After Peak Time (MPW2), Mixing Absorption (MABS), Baking Absorption (BABS), Loaf Volume (LVOL), Predicted Loaf Volume (PLVOL), Bread Crumb Grain Rating (BCRGR), and Mixograph Type (MTYPE).

<table>
<thead>
<tr>
<th>Treatment</th>
<th>MPTIME min</th>
<th>MTIME min</th>
<th>MPH</th>
<th>MPW1 %TQ×min</th>
<th>MPW2 %</th>
<th>MABS %</th>
<th>BABS %</th>
<th>LVOL cc</th>
<th>PLVOL cc</th>
<th>BCRGR</th>
<th>MTYPE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Compost0</td>
<td>3.5</td>
<td>3.1</td>
<td>58.6</td>
<td>156.4</td>
<td>4.8</td>
<td>63.3</td>
<td>67.1</td>
<td>1045.8</td>
<td>122.3</td>
<td>4,5,6,7</td>
<td>3M,4M,3H,4H</td>
</tr>
<tr>
<td>Compost8</td>
<td>4</td>
<td>3.6</td>
<td>59.3</td>
<td>185.1</td>
<td>10.6</td>
<td>62.6</td>
<td>67.2</td>
<td>1028.3</td>
<td>146.4</td>
<td>2,4,5</td>
<td>3H,4H,5H</td>
</tr>
<tr>
<td>Grand mean</td>
<td>3.8</td>
<td>3.4</td>
<td>58.9</td>
<td>170.8</td>
<td>7.7</td>
<td>63</td>
<td>67.2</td>
<td>1037.1</td>
<td>134.4</td>
<td></td>
<td></td>
</tr>
<tr>
<td>StE</td>
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<td>0.05</td>
<td>0.9</td>
<td>5.4</td>
<td>0.8</td>
<td>0.4</td>
<td>0.2</td>
<td>18.5</td>
<td>15.6</td>
<td></td>
<td></td>
</tr>
<tr>
<td>P value &lt;0.05</td>
<td>0.04*</td>
<td>0.02*</td>
<td>0.6</td>
<td>0.06</td>
<td>0.03*</td>
<td>0.3</td>
<td>0.8</td>
<td>0.5</td>
<td>0.4</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Compost0 (0 ton of compost ha⁻¹) and Compost8 (18 ton of compost ha⁻¹).

* significantly different at $p<0.05$
** significantly different at $p<0.01$
*** significantly different at $p<0.001$
**** significantly different at $p<0.0001$
Table 3-6. Effects of biochar on wheat flour quality from Western Wheat Quality Laboratory (WWQL). Midline Peak Time (MPTIME), Mixing Time (MTIME), Midline Peak Height (MPH), Midline Peak Value Under the Curve to Peak Mixing Time (MPW1), Midline Peak Width Tail at 2 min After Peak Time (MPW2), Mixing Absorption (MABS), Baking Absorption (BABS), Loaf Volume (LVOL), Predicted Loaf Volume (PLVOL), Bread Crumb Grain Rating (BCRGR), and Mixograph Type (MTYPE).

<table>
<thead>
<tr>
<th>Treatment</th>
<th>MPTIME</th>
<th>MTIME</th>
<th>MPH</th>
<th>MPW1</th>
<th>MPW2</th>
<th>MABS</th>
<th>BABS</th>
<th>LVOL</th>
<th>PLVOL</th>
<th>BCRGR</th>
<th>MTYPE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Biochar0</td>
<td>3.6</td>
<td>3.2</td>
<td>58.2</td>
<td>164.9</td>
<td>7.6</td>
<td>62.8</td>
<td>66.9</td>
<td>1025.8</td>
<td>138.5</td>
<td>4,5,7</td>
<td>3M, 3H,4H</td>
</tr>
<tr>
<td>Biochar2</td>
<td>3.8</td>
<td>3.2</td>
<td>59.6</td>
<td>173.5</td>
<td>7</td>
<td>62.8</td>
<td>66.9</td>
<td>1046.7</td>
<td>143</td>
<td>4</td>
<td>3H,4M,5H</td>
</tr>
<tr>
<td>Biochar10</td>
<td>3.8</td>
<td>3.5</td>
<td>59.1</td>
<td>168.9</td>
<td>8.1</td>
<td>62.9</td>
<td>67.1</td>
<td>1033.3</td>
<td>125.5</td>
<td>4,5</td>
<td>3H,4H,5H</td>
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<td>1042.5</td>
<td>130.3</td>
<td>2,4</td>
<td>4M, 3H,4H</td>
</tr>
<tr>
<td>Grand mean</td>
<td>3.8</td>
<td>3.4</td>
<td>58.9</td>
<td>170.8</td>
<td>7.7</td>
<td>63.0</td>
<td>67.2</td>
<td>1037.1</td>
<td>134.4</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

StE: 0.1 0.12 0.7 5.6 0.6 0.3 0.5 19.2 16.8

P value: <0.05

* significantly different at p <0.05
** significantly different at p < 0.01
*** significantly different at p <0.001
**** significantly different at p <0.0001

Biochar0 (0 of biochar ha⁻¹), Biochar2 (2 ton of biochar ha⁻¹), Biochar10 (10 ton of biochar ha⁻¹), and Biochar40 (40 ton of biochar ha⁻¹).
Table 3-7. Effects of interaction between biochar and compost on wheat flour quality from Western Wheat Quality Laboratory (WWQL).
Midline Peak Time (MPTIME), Mixing Time (MTIME), Midline Peak Height (MPH), Midline Peak Value Under the Curve to Peak Mixing Time (MPW1), Midline Peak Width Tail at 2 min After Peak Time (MPW2), Mixing Absorption (MABS), Baking Absorption (BABS), Loaf Volume (LVOL), Predicted Loaf Volume (PLVOL), Bread Crumb Grain Rating (BCRGR), and Mixograph Type (MTYPE).

<table>
<thead>
<tr>
<th>Treatment</th>
<th>MPTIME</th>
<th>MTIME</th>
<th>MPH</th>
<th>MPW1</th>
<th>MABS</th>
<th>BABS</th>
<th>LVOL</th>
<th>PLVOL</th>
<th>BCRGR</th>
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</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>min</td>
<td>min</td>
<td>%</td>
<td>%TQ×min</td>
<td>%</td>
<td>%</td>
<td>%</td>
<td>cc</td>
<td>cc</td>
<td></td>
</tr>
<tr>
<td>C0B0</td>
<td>3.5</td>
<td>2.9</td>
<td>57</td>
<td>154</td>
<td>4.4</td>
<td>63.1</td>
<td>67.1</td>
<td>1003.3</td>
<td>103</td>
<td>5,7</td>
</tr>
<tr>
<td>C0B2</td>
<td>3.6</td>
<td>3.1</td>
<td>58.7</td>
<td>164.7</td>
<td>5.5</td>
<td>63.1</td>
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C0BO (0 ton of compost ha\(^{-1}\) and 0 ton of biochar ha\(^{-1}\)), C0B2 (0 ton of compost ha\(^{-1}\) and 2 ton of biochar ha\(^{-1}\)), C0B10 (0 ton of compost ha\(^{-1}\) and 10 ton of biochar ha\(^{-1}\)), C0B40 (0 ton of compost ha\(^{-1}\) and 40 ton of biochar ha\(^{-1}\)), C8B0 (18 ton of compost ha\(^{-1}\) and 0 ton of biochar ha\(^{-1}\)), C8B2 (18 ton of compost ha\(^{-1}\) and 2 ton of biochar ha\(^{-1}\)), C8B10 (18 ton of compost ha\(^{-1}\) and 10 ton of biochar ha\(^{-1}\)), and C8B40 (18 ton of compost ha\(^{-1}\) and 40 ton of biochar ha\(^{-1}\)).

* significantly different at \(p < 0.05\)
** significantly different at \(p < 0.01\)
*** significantly different at \(p < 0.001\)
**** significantly different at \(p < 0.0001\)
Data from USU Cereal Laboratory

Table 3-8. Effects of compost wheat flour quality from Utah State University Cereal Laboratory (USUCL). Midline Peak Time (MPTIME), Midline Peak Value (MPV), Midline Left Slope (MLP), Midline Right Slope (MRS), Midline Peak Width Value (MPW), Midline Tail Width Value at 7 min (MTW7), Midline Tail Value (MTV), Weakening Slope Value (WS), Midline Peak Integral Value (MLPIQ), Midline Tail Integral Value (MLTIQ)

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<td>0.7</td>
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Compost0 (0 ton of compost ha\(^{-1}\)) and Compost8 (18 ton of compost ha\(^{-1}\)).

* significantly different at \(p < 0.05\)
** significantly different at \(p < 0.01\)
*** significantly different at \(p < 0.001\)
**** significantly different at \(p < 0.0001\)
Table 3-9. Effects of biochar wheat flour quality from Utah State University Cereal Laboratory (USUCL).
Midline Peak Time (MPTIME), Midline Peak Value (MPV), Midline Left Slope (MLP), Midline Right Slope (MRS), Midline Peak Width Value (MPW), Midline Tail Width Value at 7 min (MTW7), Midline Tail Value (MTV), Weakening Slope Value (WS), Midline Peak Integral Value (MLPIQ), Midline Tail Integral Value (MLTIQ)

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<th>MLS (%/min)</th>
<th>MRS (%/min)</th>
<th>MPW (%)</th>
<th>MTW7 (%)</th>
<th>MTV (%)</th>
<th>WS (%)</th>
<th>MLPIQ (%TQ×min)</th>
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</table>

* significantly different at $p < 0.05$
** significantly different at $p < 0.01$
*** significantly different at $p < 0.001$
**** significantly different at $p < 0.0001$

Biocahr0 (0 of biochar ha$^{-1}$), Biochar2 (2 ton of biochar ha$^{-1}$), Biochar10 (10 ton of biochar ha$^{-1}$), and Biochar40 (40 ton of biochar ha$^{-1}$).
Table 3-10. Effects of interaction between compost and biochar on wheat flour quality from Utah State University Cereal Laboratory (USUCL).
Midline Peak Time (MPTIME), Midline Peak Value (MPV), Midline Left Slope (MLP), Midline Right Slope (MRS), Midline Peak Width Value (MPW), Midline Tail Width Value at 7 min (MTW7), Midline Tail Value (MTV), Weakening Slope Value (WS), Midline Peak Integral Value (MLPIQ), Midline Tail Integral Value (MLTIQ)

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<th>MRS (%/min)</th>
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<th>MTV (%)</th>
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C0B0 (0 ton of compost ha⁻¹ and 0 ton of biochar ha⁻¹), C0B2 (0 ton of compost ha⁻¹ and 2 ton of biochar ha⁻¹), C0B10 (0 ton of compost ha⁻¹ and 10 ton of biochar ha⁻¹), C0B40 (0 ton of compost ha⁻¹ and 40 ton of biochar ha⁻¹), C8B0 (18 ton of compost ha⁻¹ and 0 ton of biochar ha⁻¹), C8B2 (18 ton of compost ha⁻¹ and 2 ton of biochar ha⁻¹), C8B10 (18 ton of compost ha⁻¹ and 10 ton of biochar ha⁻¹), and C8B40 (18 ton of compost ha⁻¹ and 40 ton of biochar ha⁻¹)

* significantly different at $p < 0.05$
** significantly different at $p < 0.01$
*** significantly different at $p < 0.001$
**** significantly different at $p < 0.0001$
Suggestions

To gain better understanding of soil responses to compost and biochar, soil samples should be taken three times. Pre-experiment soil samples should be taken to gather preliminary information about the soil. A second set of samples should be taken during spring to understand the performance of plants and soils in response to the applications of compost and biochar. Lastly, soil samples should be taken shortly after harvesting in order to determine plant nutrient uptake and remaining soil quality. In addition to nitrate nitrogen ($\text{NO}_3^- - N$) analysis, ammonium ($\text{NH}_4^+ - N$), organic C, inorganic C, and TC should be analyzed in each phase to better understand effects of treatments on soil and plant production.

Soil disturbance should be a serious consideration. Severe soil disturbance can cause error in study results. The extensive disturbance can cause loss of soil moisture, microbes, and nutrient transformation, which can affect wheat yield and quality.

Plant tissue analysis should be conducted to better understand the impacts of treatments on plant nutrient uptake. Characterization of wheat protein should be conducted to better understand impacts on wheat quality. More research on 2 g versus 10 g model mixographs should be conducted to determine whether they yield consistent results.
CONCLUSIONS

This experiment was conducted in a rain-fed dryland area with limited soil moisture and precipitation, which lacks nutrients such as nitrogen (N), P, zinc (Zn), sulfur (S), and iron (Fe). The soil is Thiokol silt loam with 1-6 % slope and contains approximately 40 % native calcium carbonate (calcareous soil). There were three different types of soil textures in the experimental area: silt loam, sandy loam, and sandy clay loam.

Nutrient management in calcareous soil is different than in non-calcareous soil. The pH of calcareous soil has effects on nutrient availability and chemical reactions that affect the loss or fixation of nutrients. The rate of N transformations in calcareous soil is affected by the alkaline pH which influences efficiency of N use by plants. In addition, P availability in calcareous soil is usually restricted. Other Nutrients such as Fe, Zn, and copper (Cu) are deficient in the calcareous soil because of the reduced solubility at alkaline pH values.

Compost had a significant impact on increasing potassium (K) in the topsoil, manganese (Mn) in deep soil, S in both depths, and NO$_3^-$ – N in the topsoil. The amount of NO$_3^-$ – N in the compost treatment was significantly lower than with no compost. Although NO$_3^-$ – N was lower in the compost treatment, it does not mean that compost had a negative impact on plant available N. There was no significant difference in total nitrogen (TN) between compost and control. This could mean that NO$_3^-$ – N was lower in the compost treatment but other forms of available N were higher. Lower NO$_3^-$ – N in compost could also be caused by plant uptake due to increased wheat yield in compost
versus no compost. Timing of soil samples may have contributed to $\text{NO}_3^-$ — N levels. Soil samples were taken on 09 May 2017, which was when wheat was in the stem elongation stage and would use extra N. Limited precipitation, soil moisture, non-uniform soil texture, and sloped topography may have impacted N levels as well. Due to these factors, it cannot be concluded that applying compost reduces the N available for plant uptake. Future research should take soil samples three times (pre-experiment, during plant growth, and after harvesting) to gain better information about the response to compost application.

Compost increased dehydrogenase activity (DHA) in the deep soil profile. Reasons for DHA being significantly impacted by compost in the deep soil profile are complex. Sensitive soil enzymes, such as DHA, are easily influenced by sample timing, soil disturbance, crop type, precipitation, and farming practices. Many factors may have impacted the increased DHA in the deep soil profile, but the specific cause is unknown.

Biochar40 significantly increased total carbon (TC) and soil moisture. Increases in pH between biochar0 and biochar40 fell within the range of the initial soil samples (7.7-8.2). Biochar may have increased soil pH slightly in this study because of biochar’s buffering capacity but this impact may not be permanent. Multiple studies report that initial biochar pH can alter soil pH. Many factors impact soil pH, such as feedstock type, pyrolysis conditions, and biochar pH.

Biochar increased soil moisture. During initial measures (stem elongation), neither compost nor biochar had significant impacts on soil water content. However, during the second measure (milking stages), we found that soil water content was
significantly higher in biochar40. While biochar characteristics, crop type, and soil water evaporation patterns may account for this finding, we do not have a specific explanation.

In this study, biochar did not have significant impacts on wheat quality. Compost increased midline peak time and midline tail width. Compost and biochar had a significant impact on predicted loaf volume. The bread crumb grain rating ranged from 2-7. The wheat flour quality ranged from 3M-5H. Applying compost resulted in the mixograph type being in the high category (3H-5H), which is favorable for bread baking. Mixograph types of wheat flour in the biochar applications ranged from 3M-4H. Interactions between compost and biochar resulted in wide variability on the mixograph. The mixograph types of wheat flour for the interaction between no compost and different rates of biochar ranged from 3M-4H, except biochar10 without compost, which ranged from 3H-4H. With compost, different rates of biochar resulted in mixograph types that ranged from 3H-5H.

Results in this study may be related to differences in chemical contents of the amendments (biochar and compost), different soil textures, and high calcium carbonate. Native calcium carbonate may have impacted nutrient transformation in the soil. This study found negligible impacts of biochar on soil quality and wheat production. This may be due to limited precipitation and soil moisture as well as high levels of calcium carbonate in the soil.

Although research on biochar and compost have been conducted worldwide, it is difficult to compare the results. Research has been conducted in controlled and field environments, used different biochars and composts, and used different experimental
conditions (crop type, soil type, and farm practice). Complex interactions between biochar and environmental factors make it difficult to fully explain the effects of biochar application.

To assess the impacts of biochar on soil quality and plant production under a rain-fed dryland farming system, testing in field conditions is required. Since soil moisture in dryland systems is limited, activities that result in soil disturbance should be carefully considered. In this study, application of compost had more significant impacts on wheat yield and soil quality than application of biochar. Further field research is needed to confirm these results.
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APPENDICES
Appendix: Observations and Lessons Learned

Soil Disturbance

Soil treated with biochar (2, 10, and 40 ton ha$^{-1}$) has been disturbed many times. Soil was tilled by the farmers and raked to incorporate the biochar into the soil (Fig. A-1). Wind blew the biochar off the ground so a tractor rotary tiller was used to incorporate the plots again. Surface crusting occurred particularly on plots with more biochar. This may be due to soil disturbance or characteristics of biochar particles. Rain may have contributed to surface crust as well. After planting, the seeds did not emerge, so the farmers replanted the plots.

Fig. A-1. Soil disturbance.
Incorporating biochar into the soil by hand (A).
Using rotary tiller to incorporate biochar (B)
Fig. A-2. Topographical characteristics of the study area. Plots had variable slopes (A and B).

Fig. A-3. Soil erosion and weeds. Fields underwent soil erosion. A creek ran diagonally across the field (A). The plots had many weeds (B).
Soil samples were taken using the AMS soil sampler and soil probe with hammer because the soil was too dry and hard to collect adequate samples with a normal soil probe.

To measure soil moisture, a HydroSense time domain reflectometry with 12 cm and 20 cm rods was used in the present study (A). Since the soil was dry and hard, inserting the rods would risk damage to the equipment. The lab technician came up with an idea to minimize risk of rod damage. He measured the diameter and length of rod as well as the distance between the two rods. He used a hand drill to drill holes in a wooden board then drilled into the ground through the holes in the board (B). After that, we inserted the HydroSense into the ground through the drilled holes (C).
Fig. A-6. Applying biochar to the soil. Biochar was weighed before applying to the plot (A) and applied to the soil by tractor or by hand. (B and C). Biochars were incorporated into the ground by raking and/or rotary tiller (D, E, F).
Fig. A-7. Mixograph of wheat flour from treatment C0B0.

Plot 111 (C0B0) (0 ton of compost ha\(^{-1}\) and 0 ton of biochar ha\(^{-1}\))

Plot 242 (C0B0) (0 ton of compost ha\(^{-1}\) and 0 ton of biochar ha\(^{-1}\))

Plot 311 (C0B0) (0 ton of compost ha\(^{-1}\) and 0 ton of biochar ha\(^{-1}\))
Fig. A-8. Mixograph of wheat flour from treatment C0B2.

Plot 121 (C0B2) (0 ton of compost ha\(^{-1}\) and 2 ton of biochar ha\(^{-1}\))

Plot 222 (C0B2) (0 ton of compost ha\(^{-1}\) and 2 ton of biochar ha\(^{-1}\))

Plot 321 (C0B2) (0 ton of compost ha\(^{-1}\) and 2 ton of biochar ha\(^{-1}\))
Fig. A-9. Mixograph of wheat flour from treatment C0B10.

Plot 131 (C0B10) (0 ton of compost ha\(^{-1}\) and 10 ton of biochar ha\(^{-1}\))

Plot 212 (C0B10) (0 ton of compost ha\(^{-1}\) and 10 ton of biochar ha\(^{-1}\))

Plot 341 (C0B10) (0 ton of compost ha\(^{-1}\) and 10 ton of biochar ha\(^{-1}\))
Fig. A-10. Mixograph of wheat flour from treatment C0B40.

Plot 141 (C0B40) (0 ton of compost ha$^{-1}$ and 40 ton of biochar ha$^{-1}$)

Plot 232 (C0B40) (0 ton of compost ha$^{-1}$ and 40 ton of biochar ha$^{-1}$)

Plot 331 (C0B40) (0 ton of compost ha$^{-1}$ and 40 ton of biochar ha$^{-1}$)
Fig. A-11. Mixograph of wheat flour from treatment C8B0.

Plot 142 (C8B0) (8 ton of compost ha\(^{-1}\) and 0 ton of biochar ha\(^{-1}\))

Plot 221 (C8B0) (8 ton of compost ha\(^{-1}\) and 0 ton of biochar ha\(^{-1}\))

Plot 332 (C8B0) (8 ton of compost ha\(^{-1}\) and 0 ton of biochar ha\(^{-1}\))
Fig. A-12. Mixograph of wheat flour from treatment C8B2.

Plot 112 (C8B2) (8 ton of compost ha\(^{-1}\) and 2 ton of biochar ha\(^{-1}\))

Plot 241 (C8B2) (8 ton of compost ha\(^{-1}\) and 2 ton of biochar ha\(^{-1}\))

312 (C8B2) (8 ton of compost ha\(^{-1}\) and 2 ton of biochar ha\(^{-1}\))
Fig. A-13. Mixograph of wheat flour from treatment C8B10.

Plot 132 (C8B10) (8 ton of compost ha$^{-1}$ and 10 ton of biochar ha$^{-1}$)

Plot 211 (C8B10) (8 ton of compost ha$^{-1}$ and 10 ton of biochar ha$^{-1}$)

Plot 331 (C8B10) (8 ton of compost ha$^{-1}$ and 10 ton of biochar ha$^{-1}$)
Fig. A-14. Mixograph of wheat flour from treatment C8B40.

Plot 122 (C8B40) (8 ton of compost ha\(^{-1}\) and 40 ton of biochar ha\(^{-1}\))

Plot 231 (C8B40) (8 ton of compost ha\(^{-1}\) and 40 ton of biochar ha\(^{-1}\))

Plot 322 (C8B40) (8 ton of compost ha\(^{-1}\) and 40 ton of biochar ha\(^{-1}\))
Appendix: Mixograph from Western Wheat Quality Laboratory

Fig. A-15. Mixograph of wheat flour from treatment C0B0.
Fig. A-16. Mixograph of wheat flour from treatment C0B2.
Fig. A-17. Mixograph of wheat flour from treatment C0B10.
Fig. A-18. Mixograph of wheat flour from treatment C0B40.

Plot 141

Plot 232

Plot 331
Fig. A-19. Mixograph of wheat flour from treatment C8B0.

Plot 142

Plot 221

Plot 332
Fig. A-20. Mixograph of wheat flour from treatment C8B2.
Fig. A-21. Mixograph of wheat flour from treatment C8B10.
Fig. A-22. Mixograph of wheat flour from treatment C8B40.
### Appendix: Replication Effects on Soil Nutrients

Table A-1. Replication effects on soil nutrients at soil depth 0-15 cm. pH, Soil Electrical Conductivity (EC), Nitrate Nitrogen (NO$_3^-$ - N), Total Nitrogen (TN), Organic Matter (OM), Total Carbon (TC), Phosphorus (P), Potassium (K), Iron (Fe), Copper (Cu), Manganese (Mn), Zinc (Zn), Sulfate-Sulfur (S).

<table>
<thead>
<tr>
<th>Treatment</th>
<th>pH</th>
<th>EC (dS/m)</th>
<th>NO$_3^-$ N (mg/kg)</th>
<th>TN (%)</th>
<th>OM (%)</th>
<th>TC (mg/kg)</th>
<th>P (mg/kg)</th>
<th>K (mg/kg)</th>
<th>Fe (mg/kg)</th>
<th>Cu (mg/kg)</th>
<th>Mn (mg/kg)</th>
<th>Zn (mg/kg)</th>
<th>S (mg/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rep1</td>
<td>7.8</td>
<td>0.5</td>
<td>0.96</td>
<td>0.09</td>
<td>2</td>
<td>1.7</td>
<td>9</td>
<td>553.8</td>
<td>3.1</td>
<td>1.2</td>
<td>3.8</td>
<td>0.3</td>
<td>3.2</td>
</tr>
<tr>
<td>Rep2</td>
<td>7.7</td>
<td>0.5</td>
<td>0.89</td>
<td>0.1</td>
<td>2.1</td>
<td>2</td>
<td>13.9</td>
<td>622.6</td>
<td>3.3</td>
<td>1.2</td>
<td>4.4</td>
<td>0.3</td>
<td>3.3</td>
</tr>
<tr>
<td>Rep3</td>
<td>7.7</td>
<td>0.5</td>
<td>2.33</td>
<td>0.1</td>
<td>1.9</td>
<td>2.7</td>
<td>11.6</td>
<td>609.3</td>
<td>4.3</td>
<td>1</td>
<td>3.5</td>
<td>0.3</td>
<td>4.2</td>
</tr>
<tr>
<td>Std E</td>
<td>0.007</td>
<td>0.03</td>
<td>0.15</td>
<td>0.003</td>
<td>0.02</td>
<td>0.2</td>
<td>2.7</td>
<td>3.6</td>
<td>0.2</td>
<td>0.08</td>
<td>0.2</td>
<td>0.05</td>
<td>0.19</td>
</tr>
<tr>
<td>P value</td>
<td>&lt;0.05</td>
<td>0.04*</td>
<td>0.03*</td>
<td>0.06</td>
<td>0.1</td>
<td>0.08</td>
<td>0.5</td>
<td>0.009*</td>
<td>0.7</td>
<td>0.5</td>
<td>0.2</td>
<td>0.7</td>
<td>0.1</td>
</tr>
</tbody>
</table>

Rep1 (Replication 1), Rep2 (Replication 2), Rep3 (Replication 3)
* significantly different at $p < 0.05$, ** significantly different at $p<0.01$, *** significantly different at $p<0.001$, **** significantly different at $p<0.0001$

Table A-2. Replication effects on soil nutrients at soil depth 15-30 cm. pH, Soil Electrical Conductivity (EC), Nitrate Nitrogen (NO$_3^-$ - N), Total Nitrogen (TN), Organic Matter (OM), Total Carbon (TC), Phosphorus (P), Potassium (K), Iron (Fe), Copper (Cu), Manganese (Mn), Zinc (Zn), Sulfate-Sulfur (S).

<table>
<thead>
<tr>
<th>Treatment</th>
<th>pH</th>
<th>EC (dS/m)</th>
<th>NO$_3^-$ N (mg/kg)</th>
<th>TN (%)</th>
<th>OM (%)</th>
<th>TC (mg/kg)</th>
<th>P (mg/kg)</th>
<th>K (mg/kg)</th>
<th>Fe (mg/kg)</th>
<th>Cu (mg/kg)</th>
<th>Mn (mg/kg)</th>
<th>Zn (mg/kg)</th>
<th>S (mg/kg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rep1</td>
<td>7.8</td>
<td>0.5</td>
<td>3.3</td>
<td>0.07</td>
<td>1.6</td>
<td>2.2</td>
<td>5.3</td>
<td>450.9</td>
<td>2.7</td>
<td>1</td>
<td>3.4</td>
<td>0.2</td>
<td>4.3</td>
</tr>
<tr>
<td>Rep2</td>
<td>7.8</td>
<td>0.6</td>
<td>4.1</td>
<td>0.07</td>
<td>1.5</td>
<td>2.9</td>
<td>4.6</td>
<td>545.3</td>
<td>3</td>
<td>0.8</td>
<td>3.1</td>
<td>0.1</td>
<td>5.1</td>
</tr>
<tr>
<td>Rep3</td>
<td>8</td>
<td>0.7</td>
<td>7.5</td>
<td>0.07</td>
<td>1.3</td>
<td>3.8</td>
<td>3.5</td>
<td>614.1</td>
<td>3.4</td>
<td>0.7</td>
<td>2.4</td>
<td>0.1</td>
<td>5</td>
</tr>
<tr>
<td>Std E</td>
<td>0.05</td>
<td>0.08</td>
<td>1.2</td>
<td>0.008</td>
<td>0.07</td>
<td>0.4</td>
<td>0.9</td>
<td>35.4</td>
<td>0.3</td>
<td>0.02</td>
<td>0.1</td>
<td>0.03</td>
<td>0.3</td>
</tr>
<tr>
<td>P value</td>
<td>&lt;0.05</td>
<td>0.1</td>
<td>0.4</td>
<td>0.008</td>
<td>0.07</td>
<td>0.4</td>
<td>0.9</td>
<td>35.4</td>
<td>0.3</td>
<td>0.02*</td>
<td>0.1*</td>
<td>0.4</td>
<td></td>
</tr>
</tbody>
</table>

Rep1 (Replication 1), Rep2 (Replication 2), Rep3 (Replication 3)
* significantly different at $p < 0.05$, ** significantly different at $p<0.01$, *** significantly different at $p<0.001$, **** significantly different at $p<0.0001$
Table A-3. Replication effects on soil DHA at soil depth 0-15 cm and 15-30 cm.

<table>
<thead>
<tr>
<th>Treatment</th>
<th>DHA (0-15cm) ugTPF/g soil/hr</th>
<th>DHA (15-30cm) ugTPF/g soil/hr</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rep1</td>
<td>3.4</td>
<td>2.2</td>
</tr>
<tr>
<td>Rep2</td>
<td>3.6</td>
<td>1.8</td>
</tr>
<tr>
<td>Rep3</td>
<td>2.8</td>
<td>1.3</td>
</tr>
<tr>
<td>St E</td>
<td>0.3</td>
<td>0.07</td>
</tr>
<tr>
<td>P value &lt;0.05</td>
<td>0.3</td>
<td>0.02</td>
</tr>
</tbody>
</table>

Rep1 (Replication 1), Rep2 (Replication 2), Rep3 (Replication 3)
* significantly different at $p < 0.05$
** significantly different at $p < 0.01$
*** significantly different at $p < 0.001$
**** significantly different at $p < 0.0001$
Curriculum Vitae

Phearen Kit Miller
423 E, Crescent Dr, Logan,
Utah 84341, USA.
Contact: 435 294 5915.
E-mail: kitphearen@gmail.com

EDUCATION
1. Master degree in Plant Science: Plants, Soils and Climate Department, Utah State University, USA. 2015-August, 2018.

Graduate Research Experiences

Graduate research assistant May, 2015- August 2018:
- Fieldwork (wheat and barley) such as seed packing NAM nursery planting, irrigating, monitoring and recording phenotypic data, and harvesting.
- Germplasm selection and development for disease resistance, water use efficiency, and population improvement.
- Laboratory processing such as post-harvest storage weighing, test weight, and wheat quality testing (NIR, Mixograph)

Conferences/Workshop/Training For Professional Development
- Our Farm, Our Future Conference at St. Louis, Missouri. (April 3-5, 2018)
- The Synergy of Science and Industry: Biochar's Connection to Ecology, Soil, Food, and Energy at Oregon State University. August 22-25, 2016

2. Bachelor degree in Science majoring in Agricultural Technology and Management, Royal University of Agriculture, Cambodia. 2009-2013
- Student project: Effect Of Drip Irrigation System And Different Rates Of Fertilizer On Growth And Yield Of Eggplant (*Solanum melongena*). March 7- August 31, 2013

Undergraduate Research

- Surveyor for post- harvest production of vegetable production in Cambodia, organized by USAID. June-December 2013.
- Doing experiment on Effect of drip irrigation system and different rates of fertilizer on growth and yield of eggplant (*Solanum melongena*). March 7- August 31, 2013
- Surveyor and questionnaire developer for Facilitator of AGRI Cambodia: Promoting Agri-Cambodian portal system for safe vegetables and online project. March 2014-March 2015
- Surveyor and facilitator for the students from Nagoya University, Japan to interview with farmers at Woman Leaders Program to Promote Well-being in Asia. 3-8 March-2014.

GRANTS


HONOR AND AWARD

4. Frank O. & Ina Seeley Morgan Scholarship 2016 and 2017
5. 33rd International Vegetable Training Course “Vegetables: From Seed to Table and Beyond”, sponsored by AVRDC. Thailand. September 15 to December 5, 2014.
8. World Congress of Global Partnership for Young Woman sponsored by UN woman and Duksung Woman’s University. Duksunk Woman’s University, Korea. August 10-13, 2012.
PUBLICATION

Undergraduate


PRESENTATION

Oral Presentation


8. Kit P. (Presenter & Author ) “Analyzing adoptions and problems in sow raising of Osaray farmers after establishing pig raising farmer groups in Cambodia at the

Poster Presentations.
2. Kit, P (Presenter & Author), Effect of drip irrigation system and different rates of fertilizer on growth and yield of eggplant (Solanum Melongena) at Research Workshop of Agricultural Development Research Interest Group, Development Research Forum Phase II, Cambodia. October 11, 2013
3. Kit, P (Presenter & Author) “Water quality project. BLT summer program”, at Utah State University. USA. August 5, 2011.

SERVICE ACTIVITIES
1. Volunteer at TEDx USU. October, 2016
   - Run workshop and training on raising awareness for local farmers to start sow farming.
   - Operate and monitor the situation of sow farmers
3. Volunteer for Fulbright and Undergraduate State Alumni Association of Cambodia (FUSAAC) which is an organization supported by US Embassy. 2011-2015.
   - Facilitate outreach program for ethnic students in Cambodia.
4. Vice president for Youth Volunteer for Environment group. 2011-2012
   - Workshop coordinator on water quality and waste management
5. Cambodian Red Cross Youth at Royal University of Agriculture. 2009-2015
   - Participate in fund raising, charity and cleaning environment activities.

MEDIA APPEARANCE: BROADCAST INTERVIEW
Ms. Phearen Kit, interview by Mr. Chanraksmey Kim at SEATV Khmer student forum. SEATV Cambodia Channel. 24 June 2013. Only outstanding and high academic performance students were interviewed by this TV show.
REFERENCE

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Phone: (435) 797-3455