A Survey of Carbon to Nitrogen Ratio in Primary Cereal Crops in Idaho and Decomposition Rates of Those Residues in situ

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Authorization to Submit Thesis

This thesis of Garrett W. Thurgood, submitted for the degree of Master of Science with a major in Plant Science and titled "A Survey of Carbon to Nitrogen Ratio in Primary Cereal Crops in Idaho and Decomposition Rates of Those Residues in situ," has been reviewed in final form. Permission, as indicated by the signatures and dates below, is now granted to submit final copies to the College of Graduate Studies for approval.

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Abstract

Barley (*Hordeum vulgare* L.), corn (*Zea mays* L.), and wheat (*Triticum aestivum* L.) are commonly grown cereal crops throughout the state of Idaho. Residue management from these cereal crops should be considered to optimize residue-soil nutrient availability and improve factors which affect residue decomposition. High carbon to nitrogen (C:N) ratios and biomass accumulation for barley, corn, and wheat are commonly found post-harvest and effects from this are important for soil N availability in subsequent crops. The first study of this thesis sought to increase the understanding of the C:N ratios of barley and wheat. This was accomplished via a sample survey which was conducted throughout multiple locations with the objective to assess the C: N ratio of residue and biomass accumulation from various cultivars throughout Idaho. The results from this survey study showed high variability of C:N ratios between locations and no differences between cultivars. In contrast, biomass accumulation from the survey measured greater output from irrigated regions in general and differences were seen between locations and cultivars separately. The second study of this thesis focused on common practices for residue decomposition. Residue may be managed by placing the residue on the soil surface (no till) or by incorporation (tillage). Factors which may influence the rate of residue decomposition include residue source, C:N ratio, and cultural practices in the field (e.g., fertilizer nitrogen (N) additions). Therefore, a field study was set up with the objective to utilize residual cereal crop biomass and assess variation of in-field residue decomposition as affected by N fertilizer rates and residue placement (surface vs. incorporated) between fall and springtime. In general, the findings from the field study measured greater carbon and weight loss from incorporated treatments.

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Dedication

I dedicate this thesis to my wife Erin who has been supportive of me during my education, along with my family, and close friends who have encouraged me while completing my goals. When I complete my M.S. degree, I hope to become a valuable contributor in the agricultural community.

Table of Contents

List of Tables

List of Figures

Chapter 1

INTRODUCTION

Barley (*Hordeum vulgare* L.), corn (*Zea mays* L.), and wheat (*Triticum aestivum* L.) are some of the most widely grown cereal crops in the world. Of the 1.5 billion ha^{-1} of land cropped annually, over 30% of average is planted to these three cereals (FAO, 2011). In recent years, barley has been grown on 49 million ha^{-1}, corn on 191 million ha^{-1}, and wheat on 216 million ha^{-1} worldwide (USDA, 2018a). Production of barley in the United States for 2018 was 768,000 ha^{-1}, field corn 36 million ha^{-1}, and wheat 16 million ha^{-1}. For the state of Idaho in 2018, barley production was 214,000 ha^{-1}, corn 46,000 ha^{-1}, and wheat 445,000 ha^{-1} of harvested crop area (USDA, 2018a).

Background

Average global yields in 2018 were 2.9 metric tons ha^{-1} for barley, 5.9 metric tons ha^{-1} for all corn, and 3.4 metric tons ha^{-1} for wheat. In the United States average barley yield was 4.2 metric tons ha^{-1}, field corn harvested for grain was 11.8 metric tons ha^{-1}, and wheat was 3.2 metric tons ha^{-1} (USDA, 2019). Average yields throughout Idaho in 2018 were 6.8 metric tons ha^{-1} for barley, 14.3 metric tons ha^{-1} for corn, and 6.2 metric tons ha^{-1} for wheat (USDA, 2018a). These above average yields in Idaho are largely driven by high-input irrigated production throughout the southern part of the state as well as adequate rainfall and favorable climate during the growing season in the northern part of the state.

Fertilizer management is a primary factor in ensuring optimal yields for cereal crop production. When dealing with cereal grain crops, nitrogen (N) is the essential mineral nutrient needed in the greatest quantity, and proper nutrient management is critical to promote ideal growth. Nitrogen availability may be influenced by climate, soil type, timing of planting, and irrigation conditions (i.e. irrigated vs. dryland moisture regime). Other management practices which may affect N availability include crop rotation, tillage practices, and the N use efficiency of standard cultivars (Raun, 1999). Post-harvest residue from cereal crops have a high carbon to N (C:N) ratios (e.g. barley, corn, and wheat) which can inhibit plant uptake of N from the soil.

Carbon to N ratio represents the number of C:N units found within the residue. Nitrogen is a required nutrient for optimal growth of cereal crops. Nitrogen is accessible to crops when microbial decomposition converts organic matter/residues into inorganic ammonium (mineralization). Immobilization (conversion of inorganic into organic) of N is common when residues from cereal crops with high C:N ratios are left in the field (Johnson et al, 2005). Adjustment of the C:N ratio may help facilitate the rate of residue decomposition in the field. Cereal crops have C:N ratios which are reported to range from 80:1 for wheat, 56-60:1 for barley, and 60-70:1 for corn (USDA, 2011; Jensen, 1997). Since ideal mineralization of residue falls at a ratio of 24:1, fertilizer additions of N may help adjust residue of cereal crop C:N ratios to enable decomposition and increase N availability in the soil for subsequent crops (USDA, 2011).

The following research gaps have been identified:

(i) A lack of information is currently available describing cereal (barley and wheat) residue biomass, C, N, and C:N ratio for the range of barley and wheat cultivars currently produced across the state of Idaho.

(ii) Information is needed on the effect of N fertilizer additions and residue placement (surface v. sub-surface) for barley, corn, and wheat residues to improve best management practices.

Based on the research gaps the following research objectives have been identified:

(i) The first objective is to conduct a survey of cereal grain crops (i.e., barley & wheat) to assess the variation in C:N ratios and residue biomass at select locations throughout Idaho. The survey will increase understanding of the degree of variability in C:N ratios and biomass of both barley and wheat within each crop and across locations in the state of Idaho.

(ii) The second objective is to utilize residual crop biomass (i.e., barley/corn/wheat) to assess variation of in-field residue decomposition as affected by N fertilizer rates and subsurface vs. surface placement between fall and spring prior to the time planting would occur.

Chapter 2

LITERATURE REVIEW

History of Barley

Barley (*Hordeum vulgare* L.) has a cultivated history dating back to 8,000 B.C. and archeologists theorize it originated out of areas around Syria, Turkey, Iran, and Iraq (Harlan, 1979). Barley was transported to North America in 1494 by Christopher Columbus through a second voyage. Further development of barley cultivation started in New York in the year of 1602 along the east coast of the United States. Barley cultivation expanded into the Midwest during the mid-1850's and continued with the discovery of gold in California. In 1859, California was the top producer of barley in the United States. By 1879, barley production moved into the Pacific Northwest (PNW) in areas of eastern Oregon and Washington state (Wiebe, 1979). During the early years of barley production, the crop was most commonly malted for alcohol production and used as a dietary staple for animal feed rations.

Current End-Uses of Barley

In the United States, barley production is 65% for animal feed, 30% for malt and alcohol production, and the remainder is used for other consumption purposes such as distilling and food (Newman, 2006). Typically feed barley is distributed to dairy and beef cattle and studies have shown high amounts of energy, protein, and fiber from feed barley (Anderson, 1999). Compared to corn, feed barley provides higher protein levels which result in greater ruminal fermentation and improves microbial protein synthesis (Hunt, 1995). Idaho's unique climate and location in the PNW have resulted in it being a leader in malting barley production where the majority of hectares in the state are for malting purposes (Peterson, 2006). The process of malting is controlled germination followed by drying. The malting process occurs through steeping in water resulting in a large increase of hydrolytic enzymes, partial degradation of endosperm cell walls and protein, and structural changes within the grain tissues that render starch and protein substrates readily extractable (Schwarz and Li., 2011). Typical starch levels desired for malting range between 60 to 65% and protein percentage ranges from 10.5 to 13.5% (Schwarz and Li., 2011). Environmental conditions are favorable in Idaho for barley production due to the arid climate and accessible high-quality water through irrigation or rainfall (Wiebe, 1979). Idaho generally has a desired soil pH for barley, which is typically between 6.0 to 8.5 and favorable loamy soil types which allow for adequate drainage of the soil profile (USDA, 2016).

Barley Production

In the United States, barley is grown on over 800,000 ha on which 3.3 million metric tons of barley grain was produced in 2018 (USDA, 2018a). Harvested acreage of barley in the PNW (Idaho, Oregon, Washington, Colorado, and Montana) reached 485,622 ha in 2018 with the majority being produced in Idaho and Montana. In the state of Idaho, 214,483 ha of barley was harvested in 2018, resulting in 1.2 million metric tons of barley grain (USDA, 2018a).

History of Corn

Corn (*Zea mays* L.) cultivation dates to at least 7,000 years ago. The origin of corn is not completely known; however, archeological evidence indicates corn was developed out of southern Mexico (Beatle, 1980). Corn at one point crossed with a wild grass and became a new genus of plant, which would later be known as *Zea mays*. One of the theories behind corn evolution is that teosinte (a combination of pod corn (seeds enclosed in hard protective layer) and wild grass (*Tripsicum spp*)) developed multiple stalks per plant and then evolved into modern corn which only contains one stalk per plant. By the time Christopher Columbus came into the written pages of American history, there were hundreds of corn cultivars already established in areas of the Americas (Smith, 1994; 2004).

Current End-Uses of Corn

Corn provides a wide selection of food products with varying end uses that are important for feeding global populations. Some of the most common end uses of corn are for livestock feed, ethanol for internal combustion engines, corn oil, starches, and a variety of beverages with and without alcohol. Corn is found in a wide range of products including items like shampoo, crayons, paper, toothpaste, and other human goods (ICGA, 2019). Animal protein sources (e.g., dairy, beef etc.) in the United States are largely dependent on the amount of corn feed available on the market. The expansion of ethanol production has also increased over the years and 40 percent of corn is produced for the end use of ethanol in the United States (USDA, 2019a).

Corn Production

Corn planted and harvested for grain in the United States was grown on 36.4 million ha in 2018 and produced 2.4 billion metric tons, where 10 to 20% was exported to other countries throughout the globe (USDA, 2019b). Total area planted for grain in the PNW was 886,000 ha which produced 36.2 million metric tons of corn for grain. The state of Idaho planted 146,000 ha and produced 5.5 million metric tons of corn for grain (USDA, 2018a).

History of Wheat

Cultivation of wheat (*Tritcum aestivum*, L.). began around 10,000 years ago and originated from the south-eastern part of Turkey (Shewry, 2009). Wheat is a widely adaptable crop and can be grown in various regions around the globe. Favorable environments include temperate climates under irrigated and dryland conditions in cooler regions (Acevedo, 2002).

Wheat is grown in nearly all regions of the globe with major production areas located in the United States, Canada, China, India, Russia, Ukraine, France, Argentina and Pakistan (Shiferaw, 2013). Wheat has been widely grown globally because of its genetic diversity and range of end-uses (Shewry, 2009). In the early stages of wheat production, farmers selected the natural wild wheat varieties which produced greater yields. Wheat is considered a highly adaptable crop among cereals to climate change and environmental variability.

Current End-Uses of Wheat

Wheat has an extensive range of end uses for human consumption and is used for a variety of flours, breads and noodles (Shiferaw, 2013). Wheat is a staple food crop for large populations and provides 20% of total dietary calories worldwide (Shewry, 2009). In regions with a higher population density like Central Asia, wheat provides 47% of daily calories and proteins (Shewry, 2009). Production of wheat is critical for protein intake for both humans and animals.

Wheat Production

Wheat in the United States is produced on 16 million ha^{-1}, which produced 51.3 million metric tons of harvested wheat in 2018 (USDA, 2018a). Large amounts of wheat are grown in the PNW and Idaho specifically has a large number of hectares under irrigation. This contrasts with the Mid-west and other areas in the United States where rain fed production predominates. Total harvested area of wheat in 2018 in the PNW was 3.6 million ha (USDA, 2018a). In 2018, 275,000 ha of winter wheat were harvested in Idaho, resulting in 1.7 million metric tons of grain. Spring wheat was harvested on 180,000 ha, which produced 1.2 million metric tons of grain. Total wheat production in Idaho was nearly a half million hectares and 3 million metric tons of wheat grain (USDA, 2018a).

Nitrogen in Crop Production

Globally growers apply 100 million tons of nitrogen (N)-fertilizers annually for production in agriculture (Walsh and Belmont, 2015). Nitrogen is critical for plants and fertilizer applications are needed in many instances to provide optimal amount of N for growth, yield, and quality. Nitrogen availability in the soil is commonly deficient to optimize yields and additional inputs of N-fertilizers are often recommended. Application of N fertilizers has provided food for billions of people in the world and the demand for food is expected to increase by 70% for the year 2050 (Walsh and Belmont, 2015). In the Earth's atmosphere, 78% is N_2 whereas only 0.03% of N is easily plant available within the soil surface (Walsh and Belmont, 2015; Scharf, 2015). While large amounts of N are available in the atmosphere, few plants can directly fix N_2 gas (Scharf, 2015). Plants obtain N primarily through the soil system and microbial activity influences N mineralization for plant uptake (Bremer and Kessel, 1992). Nitrogen in the soil is accessible when microbes convert organic N into inorganic forms of N ((ammonium (NH_4) and nitrate (NO_3)) (Walsh and Belmont, 2015).

Nitrogen Fertilizer Management for Cereal Crops in Idaho

Nitrogen fertilizer management for cereal crops varies depending on farming practices (input costs, final yield goals, current end-uses, locations, type of crops, cultivars, irrigation management, residue management, etc.), local climate, and soil N-status. Nitrogen inputs in southern Idaho is largely in irrigated production systems; however, northern Idaho is primarily rain fed with no supplemental irrigation and can sustain high yields without irrigation. Plant conditions may influence nitrogen use efficiency (NUE) which may come from the capacity of plant N-uptake in the soil and efficiency of absorbed N (Benincasa et al, 2011). To evaluate NUE in crops, previous research by Benincasas et al., (2011) measured plant N uptake and absorbed N to determine factors influencing NUE in the field. Nitrogen use efficiency can be affected by tillage, where reduced tillage has been reported to improve soil structure and reduce N runoff (Walsh and Belmont, 2015). Nitrogen runoff may be influenced by the type of irrigation system used in the field. Irrigation management can be done through sprinkler or subsurface systems which can help avoid leaching of N, however excessive irrigation may lead to higher N runoff (Walsh and Belmont, 2015). In areas where crops are rainfed, cover crops and timing of planting may be considered to avoid N losses from the soil.

Nitrogen Management in Barley throughout Idaho

Nitrogen application for spring barley is a key component in providing a quality crop with higher yields. Previous crop rotation and soil test results are considered when making N recommendations in the field. Combined with soil results, north Idaho N fertilizer recommendations are based on potential yields produced from the field (Mahler and Guy, 2007). Along with field potential, precipitation influences the amount of N applied. Once precipitation is generally known for an area, calculation of N application is done by multiplying a range of fixed values from 0.044 to 0.051 kg per ha by the potential yield (Mahler and Guy, 2007). For example, if the field has an annual rainfall of 533 mm or less, then 0.040 kg ha would be multiplied by the potential yield of this area (Mahler and Guy, 2007).

Spring barley is commonly grown in southeast Idaho and N management plays a vital role in yield and quality. Yield estimates in the field are made after evaluation of soil type, environment, crop rotation, and available residual inorganic N (Stark and Brown, 2003).

Crop rotation influences the amount of residual N leftover in the field. Residual N (within 0-60 cm soil depth) from the previous crop and yield goal impacts the amount of N needed for application. Yield is ultimately dependent on field potential and the amount of N applied depends upon previous crop and amount of inorganic N remaining in the soil. For example, if barley following row crops or grain crops with residue removed, with 45 kg ha^{-1} of N found in the soil (0-60 cm) and with a yield goal of 8,070 kg ha^{-1} then 157 kg ha^{-1} of N would be needed.

Nitrogen Management in Corn throughout Idaho

Increased dairy production has developed in recent years in southern Idaho. Therefore, areas of planted corn have increased to meet demands for livestock feed. Fertilizer management of corn is variable as per the final yield goal in Idaho as in barley and wheat. To achieve optimal yields with corn, N fertilizer is required in the largest proportion of the essential plant nutrients. Nitrogen application rates can range from 45 to 448 kg per ha^{-1} depending on pre-plant soil test results (Brown et al, 2010). A metric ton of corn requires 1,000 kg N (1.4-1.5 lbs. of N per bushel) if pre-plant soil tests are in favorable conditions. Side-dress applications of N may be done when inorganic-N soil test results in the first foot are less than 25 ppm during the V5/V6 stages of corn growth in the field and before the first irrigation to determine if side-dress application of N is needed (Brown et al, 2010).

Nitrogen Management in Wheat throughout Idaho

Nitrogen management for soft white spring wheat in northern Idaho is dependent upon yield potential of the field and annual precipitation. The University of Idaho fertilizer guide recommends between 85 to 92 kg N/metric ton^{-1} (2.3 - 2.5 lbs. of N per bushel) and this correlates with annual precipitation ranging from 533 mm or lower, 559 to 604 mm, or greater than 609 mm. Calculations can be made by taking fixed variables multiplied by yield potentials (kg ha^{-1}) (Mahler, 2004). Application of N for irrigated spring wheat is influenced by inorganic N available in the soil and previous crop. Yield potential is determined by conditions in each field, and under irrigated conditions, crop yields can range from 5380 to 10760 kg per ha^{-1}. If yields are expected to be greater than 8070 kg ha^{-1}, less than 74 kg N/metric ton^{-1} (2 lbs. of N per bushel) is needed (Brown et al, 2001).

Residue Management for Cereal Crops

A critical factor for N-fertilizer management for cereals in Idaho is post-harvest residue management for straw decomposition. For example, 17 to 56 kg N ha^{-1} is recommended for every ton of straw per the University of Idaho Extension recommendation (Robertson and Stark, 2003; Brown et al., 2010; Mahler, 2007). The C:N ratio of straw can result in immobilizaiton of N in microbial forms, and thus, additional N is recommended to speed up residue decomposition and supply accessible N for the subsequent crop.

High yields from cereal production systems in turn result in large amounts of residue/biomass that will either be recycled back into the soil or harvested and removed from the field. This is an important factor as large amounts of associated nutrients will be cycled through the environment. Carbon (C) being captured in the soil is affected by management practices and influences C sequestration (Al-Kaisi, 2003). Carbon sequestration occurs from cereal crop residue decomposition returning organic C to soil while avoiding carbon dioxide (CO_2) release into the atmosphere (Al-Kaisi, 2003). Amounts of C sequestration are variable for locations and depend on climate, soil type, residue management (tillage), and crop rotation. The improvement of soil C sequestration results in greater soil aggregates, water infiltration, and improvement of soil organic matter (SOM). Improvement of SOM allows for higher nutrient and water holding capacity (Al-Kaisi, 2003).

Management of cereal crop residue can impact soil health and future crop yield. Barley, corn, and wheat in Idaho are common in crop rotations and may contribute to soil health, diversify weed control and provide soil cover (Claassen et al, 2018). However, post-harvest residues from these cereal crops can limit available N in the soil due to high C:N ratios. To decompose residues with high C:N ratios, growers may attempt different types of tillage. Tillage can affect the amount of residue cover left on the field and is variable depending on management preferences. Each type of tillage management will affect the status of residue cover and the amount of residue-soil contact. For example, when using a moldboard plow for corn or small grain residue, only 0 to 10 percent of residue cover is left on the soil surface (USDA, 2018b). In contrast, using a disk (offset, primary >9" spacing) or a chisel plow will result in 40 to 80% of residue cover left on the soil surface (USDA, 2018b). The amount of residue cover is ultimately determined by grower management decisions as well as what type of production system is available.

A laboratory experiment conducted at the University of Idaho Aberdeen Research and Extension Center evaluated the decomposition of barley cereal residue between surface vs. incorporated, residue size (chopped vs. ground and sieved) and soil type (sand vs. sandy loam) treatments. Through a controlled environment in the lab (based on protocols as reported in Al-Kaisi et al., 2017), barley residue decay was observed over a 50-day period (Loomis et al., 2020). The experiment concluded no significant differences in decomposition of residues except for the incorporated-sieved treatment, which showed less CO_2 release compared to other the treatments. Chopped residue placed on the soil surface displayed greater C mineralization than ground incorporated treatments (Loomis et al., 2020). This study examines residue decomposition in situ with the soil on which it was produced. These additional studies will improve the understanding of the soil residue environments over that from the lab study of Loomis et al., (2020) as it was performed and reflective of in-field interactions.

Studies on cereal residue decomposition have shown similar and contrary results when comparing conclusions in terms of the impact of residue management practices (Al-Kaisi et al., 2017; Curtin et al., 2008). There are varying results from studies on whether tillage assists in decomposition of cereal residues (Al-Kaisi et al., 2017). Factors which can affect the rate of residue decomposition and applicability to on-farm practices are not all from mechanical management, but some occur from environmental impacts like soil temperature. From an agronomic perspective, if the soil temperatures remain low from cereal residue cover, seed germination may be slower resulting in reduced productivity of the subsequent crop (Morris, 2010). This may limit the ability of certain growers to implement this practice.

A study conducted at the Crop & Food Research farm near Lincoln, Canterbury, New Zealand evaluated rates of decomposition between wheat and barley (Curtin et al, 2008). The study analyzed both residues using a litter bag technique vs. mixing the residue within the soil. Both management practices were analyzed by evaluating weight loss and CO_2 losses over time. The CO_2 measurements were taken by pressing a plastic chamber over the plot and recording CO_2 emissions by using an infrared gas analyzer. Decomposition of the two methods in this study varied and residue samples mixed with soil tended to decompose quicker than the litter bag method which represented plow incorporation (Curtin et al, 2008). Residue decomposition from the mixed samples were believed to decay faster due to water absorption in the soil along with greater contact of residue and soil surfaces and thus, microbial populations were able to access substrate more easily. The CO_2 losses within the study were also greater with mixed soil residue trials (Curtin et al, 2008). Thus, Curtin et al. (2008) concluded that increase residue-to-soil contact increased decomposition rates in their study.

A similar study in the United States was conducted in Iowa observing corn residue decomposition (Al-Kaisi et al, 2017). This study had treatments evaluating N application to see if decomposition would be greater with treatments containing additional applied fertilizer-N from previous crop residues in the field. In some of the locations for this experiment, they found control treatments had greater decomposition than those treated with fertilizer-N (Al-Kaisi et al, 2017). The conclusion made from this study showed no significant effect of N application rates with residue decomposition rate in the field (Al Kaisi et al, 2017). Additional research evaluating decomposition of corn in Iowa used three different tillage system (deep tillage (DT), strip tillage (ST), and no-tillage (NT)). Two different types of corn residue were tested (Bt and non-Bt) where Bt decomposed slower under DT and ST methods. The differences between decomposition rates in all three of the tillage methods was not significant (Al-Kaisi, 2014). Thus, in contrast to Curtin et al. (2008), Al-Kaisi (2014) concluded that tillage operations did not affect decomposition rates of corn residue in Iowa.

Soil Microbial and Aggregate Influence on Residue Decomposition

Microbial communities exist in the soil and populations tend to increase as C increases within the environment (Hoorman and Islam, 2010). Various types of microbial species including bacteria, actinomycetes, fungi, algae, protozoa, and nematodes are commonly found in surface soil from the 0 to 15 cm depth. Tillage practices can influence the presence of certain microbial species (Hoorman and Islam, 2010) and significant differences in microbial populations have been observed based on tillage practices. In tilled soils, bacteria, actinomycetes, and protozoa dominate as compared to fungi and nematode populations under no-till systems (Hoorman and Islam, 2010).

A study conducted at McGill University in Quebec, Canada evaluated the impacts of tillage, residue management, and time in a corn production system to see how these factors influence soil microbial biomass C and N (Spedding et al., 2004). The study included three tillage methods (conventional, reduced, and no tillage) and two residue levels (with and without residue). Soil cores were taken periodically throughout the growing season which included pre-planting, 6 weeks after planting, mid-season, and pre-harvest. Soil microbial biomass of carbon and nitrogen were measured by chloroform fumigation-extraction (Spedding et al., 2004). Seasonal effects in this study tended to influence microbial communities more than factors regarding tillage and residue management. This study concluded that soil microorganisms may be influenced from crop growth stage, resource availability, and physical/chemical soil conditions. Further research is still needed to predict microbial community variability and the temporal environmental factors which may vary in differing regions (Spedding et al., 2004).

Soil aggregates are important for the field environment because they improve water movement, erosion control, and make plant growth feasible. A group of soil particles bound together stronger than adjacent particles are what make up a soil aggregate (USDA-NRCS, 1996). Soil aggregates are influenced by the texture and soil management of the field (Sarker et al., 2017). Aggregates from the field are grouped into different sizes which are as follows: mega-aggregates (>2 mm), macroaggregates (0.25–2 mm) and micro-aggregates (<0.25 mm)

(Sarker et al., 2017). Size of soil aggregates may influence microbial activity and impact decomposition of SOM in the field (Sarker et al., 2017).

A research lab study was conducted in Australia to evaluate the soil aggregate influence on soil organic C (SOC) and how this impacts nutrient mineralization dynamics (Sarker et al., 2017). The experiment had five locations under management of conventional tillage (one depth at 10 cm and the other at 2 cm incorporation) and no-till (stubble remained on surface after harvest) in the field. Residues observed in the study were from canola (*Brassica napus*) and wheat. Soil cores were collected from the five locations and 12 to 15 cores (7.6 cm diameter) were taken from 0 to 10 cm depth. Soil samples were dried down and aggregates were separated by sieving. After soil collection, harvested residues from canola and wheat were dried and ground to be processed. Treatments in the experiment included 45 aggregate samples, five tillage methods ((conventional (CT), no-till (NT), and reduced tillage (RT)), two soil types (Luvisol and Vertisol), and three aggregate sizes for each treatment (Sarker et al., 2017). The incubation lab experiment was over a controlled environment which lasted for a 126-d period. Conclusions from the experiment indicated greater SOC mineralization under macro- versus mega- and micro-aggregates under CT, RT, and NT methods in the Luvisol soils and no differences in Vertisol soils (Sarker et al., 2017). This experiment concluded that shallow tillage for stubble incorporation enhanced the release of plant available nutrients (N, P, and S) from the coarser sized aggregates (Sarker et al., 2017). Further research is needed to confirm results from this experiment and additional studies could support which tillage methods are optimal for residue decomposition in the field.

Cereal residue management is conducted by various methods depending on the crops in rotation, grower’s resources, and overall management strategy appropriate in the region.

Improved understanding of the effect of residue leftover from the previous crop are needed for Idaho growers as the management of residue may impact decomposition rate within the field, nutrient availability, and long-term C storage. Factors that influence rate of residue decomposition come from tillage methods, climate, soil characteristics, and types of irrigation (dryland vs. irrigated) (Al-Kaisi et al., 2017; Spedding et al., 2004; Curtin et al., 2008). Research continues to evaluate best methods for residue management by evaluating different methods in different production scenarios and regions. Additional research evaluating residue decomposition will help determine cultural management practices that influence breakdown and nutrient cycling.

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Chapter 3

COMPARISON OF C: N RATIOS IN BARLEY AND WHEAT RESIDUES

Abstract

Fertilizer management of commonly grown cereal crops (barley (*Hordeum vulgare* L.) and wheat (*Tritcum aestivum*, L.)) throughout Idaho are dependent on post-harvest residue management in the field. Generally, cereal crops have a higher carbon to nitrogen (C:N) ratio and lowering the C:N ratios facilitate soil-N mineralization (~residue decomposition). A commonly used practice by farmers in Idaho is to apply additional N-fertilizer to facilitate mineralization. Further, the C:N ratio of grain crops may be cultivar-dependent and site-specific. The objective of the study was to assess the C:N ratio and biomass accumulation of residues collected from various cultivars of common cereal crops (barley, wheat) throughout Idaho. The residue survey study was conducted throughout Idaho where ten spring cultivars between barley and wheat were collected from nine different locations. The tissue samples from each location were ground and analyzed for total C and total N by high-temperature combustion. Findings from this survey showed high variability between locations for the C:N ratio but little differences between cultivars. In contrast, biomass accumulations showed variability for both location and cultivars separately with greater biomass accumulation in general from irrigated regions. The results of the study will improve grower estimates of nutrient cycling and/or removal of C and N-across Idaho.

Introduction

Idaho growers produce a wide variety of broadleaf crops (e.g., sugar beets (*Beta vulgaris*), potatoes (*Solanum tuberosum*), dry beans (*Phaseolus vulgaris*), lentil (*Lens culinaris*), etc.) and grass/cereal crops (wheat, barley etc.) which are common in crop rotations. Management of these crops is done under irrigated and dryland systems throughout the state. When rotating crops with cereals, post-residue management needs to be considered by either leaving the residue on the surface (no-till) or by incorporating the residue through tillage (disc harrow, plow, etc.) (Rogers et al., 2019a). Intensive residue management is often needed for cereal crops because of the high C:N ratios and the amount of residue produced. The C:N ratios of barley and wheat vary between production areas but estimates from across the United States put barley at about 60:1 and wheat at 80:1 (USDA, 2011).

Ideal residue decomposition (mineralization) occurs when C:N ratios are at a 24:1 ratio or lower (USDA, 2011). Nitrogen mineralization occurs when organic material is converted into inorganic available N. Higher C:N ratios in the field will immobilize and limit inorganic-N release and uptake for subsequent crops (USDA, 2011). Soil microorganisms along with other environmental factors like (climate, precipitation, and organic matter content) may influence the C: N ratio of cereal crops. Studies evaluating the C: N ratio throughout Idaho have not been conducted with modern cultivars and production practices. A research evaluation was conducted to see if C: N ratios were similar for residues removed from (a) cereal crops (e.g. barley and wheat) and (b) cultivar of a specific crop in multiple locations throughout Idaho. Therefore, the objective of this study was to assess the C: N ratios and accumulated biomass of residues collected from various cultivars of common cereal crops throughout Idaho.

Materials and Methods

Soil Sampling

This survey study evaluated C:N ratios of spring wheat and barley from the years 2018 and 2019. Collection of soil samples were taken in spring around the months of March and April just prior to spring planting where agronomic dates are listed in (Table 3.2). Soil samples from southern Idaho locations (Aberdeen, Idaho Falls, Rupert, Ashton, Soda Springs, and Parma) were taken from 0 to 60 cm depths and in the northern Idaho locations (Bonner's Ferry, Genesee, and Ferdinand) took soil samples were taken from 0 to 60 cm and 60 to 122 cm depths. Samples were analyzed for inorganic N, Olsen phosphorus (P), Olsen potassium (K), sulfur (S), percent soil organic matter (OM), and soil pH by standard methods (Miller et al., 2013). Soil test values for the 2018 and 2019 growing season are listed on Table 3.3 and 3.4.

Cultivar Description

The survey study included four spring barley and six spring wheat cultivars. Barley cultivars included were Gemcraft (malt), LCS Odyssey (malt), Champion (feed), and Claymore (feed) (Table 3.5). Marshall and others (2018) have cultivar release information for the tested cultivars in the study, which is summarized below. Gemcraft is a 2-row malt barley which was released by the USDA- Agricultural Research Service (ARS) in 2018. Limagrain Cereal Seeds (LCS) Odyssey is a European 2-row malt barley which was released by LCS and is favored for malt quality. Development of both Champion and Claymore cultivars was for 2-row feed barley and these cultivars were released by WestBred and Highland Specialty Grains. Wheat cultivars included within the survey study were Alum (hard red), WB9668 (hard red), Dayn (hard white), UI Platinum (hard white), Seahawk (soft white), and UI Stone (soft white). The cultivar Alum was released by Washington State University and was developed because of its exceptional tolerance of aluminum toxicity in low pH soils. The other hard red cultivar used within the study was WB9668, which was released by WestBred and has above average protein content. Dayn was developed and released by Washington State University and the USDA-ARS in 2012. This cultivar has acceptable end use quality and good resistance to some common diseases. UI Platinum is a hard white wheat developed by the University of Idaho with good test weight and resistance to lodging. The soft white cultivar Seahawk was developed by Washington State University and released in 2014 and shows some resistance to common insect pests and diseases around the area. UI Stone was released by Idaho AES and has high yield potential along with some resistance and tolerance to common diseases in the region (Marshall, 2018).

Site Description and Field Experiment Design

All the plots in each location were arranged in a randomized complete block design (RCB) for the years 2018 and 2019. Fertility of each field was conducted per farmers practices based on previous crop (Table 3.1) and inorganic-N as measured via soil testing (Table 3.3 and 3.4). Application of N for each field location were made according to yield goal. Taxonomic soil description for each location was classified accordingly as shown in Table 3.1. All the northern Idaho locations (Bonner’s Ferry, Genesee, and Ferdinand) were under dryland/rainfed conditions along with the Soda Springs location in southern Idaho. Irrigated locations in this study were Aberdeen, Rupert, Idaho Falls, Ashton, and Parma (Figure 3.1). Wheat and barley were planted in north Idaho using a no-till seed drill with flexi-coil stealth openers which allows banding fertilizer below the seed. Openers on this drill are hoe-type with paired rows 8 cm (3 in.) apart and the openers spaced 25 cm (10 in.) apart for north Idaho locations (Bonner's Ferry, Ferdinand, and Genesee). Seeding rate for spring wheat is approximately 3,000,000 seeds per ha^{-1} and 2,500,000 seeds per ha^{-1} for spring barley in north Idaho locations (Schroeder et al., 2018). Southern Idaho locations were planted using a cone seeder drill and application rates were applied as follows: irrigated wheat: 2,500,000 seeds per ha^{-1}, irrigated barley: 2,000,000 seeds per ha^{-1}, dryland wheat: 1,700,000 seeds per ha^{-1}, and dryland barley: 1,500,000 seeds per ha^{-1}. All the southern Idaho locations were set at 18 cm (7 in.) for row spacing by using double disk openers (Marshall, 2018; Brown and Walsh, 2016).

Residue Collection

Tissue for wheat and barley cultivars were collected across the state of Idaho from Aberdeen, Rupert, Ashton, Idaho Falls, Soda Springs, Parma, Genesee, Ferdinand, and Bonner's Ferry (totaling 9 different locations). Harvest occurred between the months of July to September (Table 3.3). At crop maturity and prior to harvest, samples were taken from each location of all cultivars of all 4 replications of each (Table 3.4). Each sample was hand-cut using a hang sickle knife from one row of the plot. Length of cutting from the one row was 0.5 m and samples were then put into large paper bags to be dried and processed. Samples were dried at 54℃ until a constant weight was obtained.

Processing and Analysis of Residue Samples

Following drying, samples had grain removed by hand and tissue was weighed and ground with a Wiley mill (Thomas Scientific, Swedesboro, NJ, USA) to pass a 2 mm screen. Ground tissue samples were analyzed for total C and N through high temperature combustion using a VarioMax CN analyzer (Elementar Americas, Inc. Mt Laurel, NJ).

Statistical Analyses

This survey study compared C: N ratios and biomass output differences for spring barley and wheat residues throughout Idaho. The experiments were conducted as a RCB with four replications at each location with independent factors location, variety, and class as independent factors. Statistical analyses were performed in JMP 13.0 (SAS Institute, Cary, NC, USA). Each class of barley or wheat (malt, feed, hard red, hard white, and soft white) were analyzed separately to compare location by variety and their interactions. Data were analyzed by an analysis of variance (ANOVA) where location and cultivar were fixed effects and year and block were considered random effects in the model. All mean separations were performed using Fisher's protected least square differences (LSD) as a post-hoc multiple comparisons analyses at the $P < 0.05$ level.

Results

Variability of C: N within locations

Malt Barley

The C:N ratio of malt barley only differed based on location where cultivar and the interaction of cultivar and location were not significant (Table 3.6). The C:N ratios were highly variable ranging from 54:1 to 126:1 (Fig. 3.2). Lower C:N ratios were measured at Aberdeen, Ashton, and Rupert in southern Idaho where the C:N ratio ranged 54:1 to 66:1, respectively. No difference was measured between Aberdeen, Rupert, Ashton, and Bonner's Ferry locations. In contrast, the C:N ratio of 126:1 as Parma was greater than any other location in the study. Ferdinand location had the second highest C:N ratio of 109:1 which was greater than all other locations excluding Parma. Idaho Falls, Soda Springs, and Genesee did not differ and had C:N ratios ranging from 80:1 to 88:1.

Feed Barley

The interaction between cultivar and location were not significant and only the main effect of location was significant; however, the C:N ratio differed based on location (Table 3.5). Variability of feed barley ranged from 48:1 to 125:1 between locations (Fig. 3.3). The largest C:N ratios were measured from Ferdinand and Parma where the C:N ratio was 116:1 and 125:1, respectively. The lowest C:N ratio was measured from Aberdeen at 48:1 but showed comparable results to Rupert and Bonner's Ferry (Fig. 3.3). Further similar C:N ratios were found between Soda Springs, Idaho Falls, and Genesee which measured 88:1, 90:1, and 94:1, respectively. The C:N ratio of Ashton measured 63:1 and was comparable to both Bonner's Ferry and Rupert.

Hard Red Wheat

Differences in C:N ratios were measured between locations where interaction of location by cultivar was not significant and only the main effect of location was significant (Table 3.6). The highest C:N ratio measurement came from Parma at 115:1 and showed comparable results to Idaho Falls and Bonner's Ferry with C:N ratios at 102:1 and 109:1, respectively (Fig. 3.4). Additionally, Genesee, Soda Springs, and Ferdinand had similar C:N ratios ranging from 80:1 to 89:1. The lowest C:N ratio recorded came from Aberdeen at 56:1 but was comparable to Rupert which measured a C:N ratio of 64:1. Further similar C:N ratios were measured between Ashton, Genesee, and Soda Springs which had C:N ratios at 70:1, 80:1, and 82:1, respectively.

Hard White Wheat

The interaction of cultivar by location was not significant and only the location effect was significant. (Table 3.6). Hard white wheat had the highest measured C:N ratio from

Parma at 126:1 (Fig. 3.5). Bonner's Ferry had the second highest C:N ratio at 106:l and was significantly different from Parma. Comparable results were then measured between Genesee, Ashton, Ferdinand, Idaho Falls, and Soda Springs with C:N ratios ranging from 77:1 to 91:1 (Fig. 3.5). No differences were observed between Rupert and Genesee with C:N ratios of 63:1 and 77:1, respectively. For hard white wheat, Aberdeen had the lowest C:N ratio at 57:1 but had similar measurements to Rupert.

Soft White Wheat

For soft white wheat, differences between locations were less than other wheat and barley types. All locations showed similar measurements of C:N ratio except for Aberdeen and Rupert (Fig. 3.6). Measurements of C:N ratios from Aberdeen and Rupert were 67:1 and 77:1, respectively. Both Aberdeen and Rupert were comparable with C:N and all other locations showed no differences and ranged from 97:1 to 115:1 (Fig. 3.6).

Variability of aboveground biomass within locations

Malt Barley (Aboveground Biomass)

Interaction between cultivar and location was not significant and only the main effect of location was significant on biomass output (Table 3.7). The highest biomass came from Aberdeen, Parma, and Rupert which ranged from 8,202 to 9,187 kg ha^{-1} (Fig. 3.7). Comparable measurements were seen between Aberdeen, Parma, and Rupert, yet Idaho Falls (7,158 kg ha^{-1}) measured similar biomass production with Aberdeen (8,202 kg ha^{-1}) and Parma (8,350 kg ha^{-1}). Further comparable biomass measurements were shown between Nez Perce, Ashton, Soda Springs, and Genesee (Fig. 3.7). The lowest biomass production came from Bonner's Ferry at 1,907 kg ha^{-1} and differed from all other locations.

Feed Barley (Aboveground Biomass)

Biomass production only differed between locations, where the combination of cultivar by location and the main effect of cultivar were not significant (Table 3.7). Highest biomass production came from Aberdeen at 8,936 kg ha which showed comparable measurements to both Parma (8,412 kg ha^{-1}) and Rupert (8,140 kg ha^{-1}). Measurements from Idaho Falls biomass production showed similarities to the measurements made from Rupert (Fig. 3.8). Additional similarities were shown between Ashton (5,003 kg ha^{-1}) and Soda Springs (4,108 kg ha^{-1}), while Genesee (5,591 kg ha^{-1}) biomass production was comparable to Ashton (Fig. 3.8). In contrast, Ferdinand had the second lowest biomass production at 3,619 kg ha^{-1} but compared closely with Soda Springs. The lowest biomass production came from Bonner's Ferry at 2,139 kg ha^{-1} and differed from all locations.

Hard Red Wheat (Aboveground Biomass)

Biomass production differed for location and cultivar separately while the combination of location by cultivar was not significant (Table 3.7). Rupert had the highest biomass production at 8414 kg ha^{-1} and was comparable to Aberdeen, Parma, and Idaho Falls (Fig. 3.9). In general, southern Idaho locations produced greater biomass than north Idaho, however Ashton and Soda Springs were comparable to Genesee. The second lowest biomass production came from Ferdinand at 4,003 kg ha^{-1} and Bonner's Ferry then followed with the lowest at 2134 kg ha^{-1}. Under the two cultivars (Alum and WB 9668) used within the trial, Alum showed greater biomass production of 6,574 kg ha^{-1} averaged across locations than WB 9,668 at 5611 kg ha^{-1} (Fig. 3.10).

Hard White Wheat (Aboveground Biomass)

Biomass production differed between location and cultivar separately and the combination of location by cultivar was not significant (Table 3.7). The highest biomass production came from Rupert at 8781 kg ha^{-1} which compared to both Aberdeen and Idaho Falls (Fig. 3.11). Yet, Idaho Falls (7,813 kg ha^{-1}) was comparable to Parma which measured 7,350 kg ha^{-1} of biomass production. Similar measured biomass weights were recognized between Ferdinand, Soda Springs, Ashton, and Genesee which ranged from 4,242 to 5,209 kg ha^{-1}. Throughout all locations, Bonner's Ferry continued to differ and measure the lowest biomass production at 2,081 kg ha^{-1}. Cultivar differences measured greater biomass production from Dayn (6,468 kg ha^{-1}) than UI Platinum (5,506 kg ha^{-1}) (Fig. 3.12).

Soft White Wheat (Aboveground Biomass)

The biomass production differed for location and cultivar with the combination of location by cultivar not being significant (Table 3.7). The highest biomass production was measured from Parma at 9,463 kg ha^{-1} and showed comparable biomass production to Rupert, Aberdeen, and Idaho Falls (Fig. 3.13). Both Soda Springs (5,115 kg ha^{-1}) and Genesee (4,369 kg ha^{-1}) showed similar measurements for biomass production, however the biomass from Ashton (5,615 kg ha^{-1}) differed from Genesee. The second lowest biomass production came from Ferdinand at 3,617 kg ha^{-1} but was comparable to output measured from Genesee. The lowest biomass production was measured from Bonner's Ferry at 2,313 kg ha^{-1} and differed from all locations. Biomass between the two cultivars ranged between 6,016 and 6,692 kg ha^{-1} with Seahawk having greater biomass production than UI Stone (Fig. 3.14).

Discussion

Climate and soil characteristics

Locations in this survey study have variable climate and soil conditions relating to precipitation, pH, soil organic matter (SOM), and soil type. Between the growing season from planting to harvest, temperatures ranged from an average of 13 to 32℃ from March to August throughout all locations (U.S. Climate, 2020). Rain fall in each area is variable and north Idaho locations may receive 530 to 560 mm (in general) on average for annual precipitation (U.S. Climate, 2020). While southern Idaho locations (Parma, Rupert, Aberdeen, Idaho Falls) will receive 250 to 305 mm on average for annual precipitation. Yet, southern Idaho higher elevation locations in Ashton and Soda Springs may receive up to 406 mm on average for precipitation (U.S. Climate, 2020). Soil OM percentages ranged from 0.9 to 4.1 % with locations in north Idaho (Bonner's Ferry, Genesee, and Ferdinand) having higher OM content (3.5 to 4.1%) compared to (0.9 to 3.1%) OM from southern Idaho (Aberdeen, Idaho Falls, Rupert, Ashton, Parma, and Soda Springs) (Table 3.3 and 3.4). Soil pH throughout Idaho is highly variable with north Idaho locations ranging from 5.6 to 8.0 and southern Idaho locations having pH levels from 5.9 to 8.0. Variation of pH levels can affect N, phosphorus (P), and potassium (K) availability in the soil and root systems of crops (Jensen, 2017).

Variability of C:N ratios

Malt Barley & Feed Barley

Differences in C: N ratios among locations for malt and feed barley may have been influenced by soil type, tillage, previous crops, and N rate. Research by Kumar and Goh, (2003) reasoned that differences of C: N may come from temperature changes, residue particle size, and variability of incorporation (tillage). In this survey study, Aberdeen, Rupert, Ashton, and Bonner's Ferry showed lower C:N ratios compared to all other locations for malt and feed barley. Effects of N application could have influenced lower C: N ratios and previous work by Zebarth et al. (2009) showed a decrease in C: N ratio as N rate increased, but a consecutive year from Zebarth et al. (2009) research also found increased C: N as N rate increased. Yet, the research done by Zebarth et al. (2009) is contradicting to Jantalia and

Halvorson, (2011) who found decreased C: N in corn stocks as N rate increased. In this study, yield goal and in turn applied N for Aberdeen, Rupert, and Ashton were higher than most other locations.

Comparable C: N ratios were seen between Idaho Falls, Ashton, and Genesee for malt and feed barley. Similarities between these locations may have been from similar yield goals and thus, N rates, similar tillage practices, and/or similar growing conditions. Other research by Bremer and Kuikman, (1997) has shown higher N in residual straw from mixed incorporated treatments rather than layered treatments within the soil. Research from Bremer and Kuikman, (1997) concluded in results wheat straw decomposing at a quicker rate under incorporated (mixed) than incorporated (layered (meaning plow layer). Ferdinand along with other dryland/rainfed locations may be variable with C:N ratios due to the fluctuation of precipitation each year. Conditions for Parma measured a higher C:N ratio potentially due to the lower elevation of the region which could have caused other environmental stresses.

Hard Red Wheat & Hard White Wheat

Variability along with similar results of the C:N ratio may be due to management by previous tillage. Previous research conducted by Bremer and Kuikman, (1997) showed C:N ratios lower with mixed residue (straw) than layered. Yet, contradicting research has found no significant effects of C removed from tillage-treatments (Malhi et al., 2006). Similar C:N ratios of hard red and hard white wheat may be related to common soil conditions (loamy soils) between these areas, relatively similar management, and potentially comparable microbial communities present due to environmental and production similarities. Other studies have shown microbial communities will fluctuate as soil management changes throughout the growing season indicating changes in production practices can influence this factor (Spedding et al., 2003).

Soft White Wheat

Effects from the locations may have shown similar results because of cultivar characteristics within the areas, and the potential that the cultivar was near a genetic limit in terms of C and N uptake. Both cultivars (Seahawk and UI Stone) used for this survey study were bred to be adapted to both dryland and irrigated regions (Chen et al. 2012) and this may explain the comparable results (Fig. 3.5.). Other research has found spring wheat cultivars with significant variability between root biomass, length, and surface area (Liang et al., 2017). Root measurements were not taken for this survey study but may be a reason behind C:N ratio similarities for soft white spring (SWS).

Variability of biomass (straw) within locations

Malt & Feed Barley (Aboveground Biomass)

Effects of greater residue biomass (straw) in general came from regions under irrigated management for both malt and feed barley. Biomass results were similar to Rogers et al., (2019b) where five barley cultivars were grown under irrigated conditions. Previous research by Sharma et al. (1990) found that growth rate increased as irrigation increased which resulted in more abundant biomass production. Data from U.S. climate (2020) shows that rainfall for the dryland production regions (Soda Springs, Bonner's Ferry, Ferdinand, and Genesee) can be variable during the growing season. In addition to water management, N application may be part of the reason for the differing amount of biomass growth between locations. Other research has shown that early N application in the season may result in greater vegetative growth (Tran and Tremblay, 2000). Nitrogen management along with tillage may be a factor for N availability in the soil and no-till and tilled systems would be the most extreme variation (Table 3.2). Previous research by (Bingham et al., 2010) observed soil compaction-N interactions in barley and found no significant interactions between N supply and soil compaction. Each grower has different strategies for N management tillage practices, and this may affect early plant growth (Munkholm et al., 2008).

Hard Red Wheat (Aboveground Biomass)

The variability between biomass production in each location may be influenced by the cultivar, available water, and N availability. Previous research has shown that straw yield of hard red wheat increased as both water and N application increased (Engel et al., 2003). This would agree with why biomass production was highest from irrigated southern Idaho locations (Aberdeen, Idaho Falls, Rupert, and Parma). However, research conducted by (Engel et al., 2003) found no significant interactions between the combination of cultivar, N rate, and water. Effects from cultivar differences for biomass production may have been due to plant physiology. The cultivar Alum is typically 10 to 13 cm taller than other cultivars (Marshall et al., 2019). On the contrary, WB 9668 measured 5 cm shorter than average (Marshall et al., 2019) and this may explain the reasoning behind less biomass production compared to Alum.

Hard White Wheat (Aboveground Biomass)

In addition to irrigation and N applications, the increased biomass production came from Rupert, Aberdeen, Parma, and Idaho Falls. Yield potential from these areas are typically higher and require additional N compared to the other locations within the study. This would agree with research conducted by Malhi et al., (2006) who concluded that improve fertilizer N would yield greater biomass from barley and wheat. Conclusions made by Malhi et al.,

(2006) would also agree with Engel et al., (2003) who measured greater straw yield from hard red wheat as both water and N application increased. The effect of Dayn showing greater residue biomass than UI Platinum may be result from plant physiology where Dayn is 5 to 7 cm taller than the average found in cereal variety trials (Marshall et al., 2019).

Soft White Wheat (Aboveground Biomass)

High biomass production from southern Idaho locations (Aberdeen, Rupert, Idaho Falls, and Parma) may have shown greater residue output due to accessible water (irrigation) and nutrient availability for crop demand. This would agree with research by (Engel et al., 2003) who concluded straw yield increase as both water and N rate increased. Effects of Seahawk showing greater residue output than UI Stone may be from plant growth characteristics. In general, it’s been common for Seahawk to have slightly above average plant height in cereal extension trials and a longer growing season as noted by it heading out 1 to 3 d later compared to other cultivars (Marshall et al. 2019).

Conclusion

The findings from this study showed differences in C:N ratios and biomass production observed from 9 different locations. Implications from this survey study showed that depending on the climate of a region, production management, soil characteristics, and class of barley or wheat, locations will differ in C:N ratios and biomass production. The combination of cultivar by location was not significant when comparing C:N ratios, but the fixed variable of location was significant for each class of wheat and barley. However, soft white wheat in general showed a similar trend in the C:N ratio and reasoning may be from similar plant characteristics and the plant reaching its genetic limit. Other factors which may have affected soft white wheat may have been due to similar root lengths of cultivars used within the study along with cultivars being adapted to both dryland and irrigated areas. Additionally, biomass production measured in this survey study in general showed greater residue output from irrigated southern Idaho locations. Only the fixed variable of location was significant for each class of barley but independently location and cultivar were significant for each class of spring wheat. These findings from this survey study can help narrow the adjustments of residue management and increase understanding of N availability within spring barley and wheat residues throughout Idaho. Further research may investigate what specific environmental factors influence the C:N ratio. Other correlations of research could measure the precipitation/irrigation effects on biomass accumulation.

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Table 3.1. Soil description and previous crop at research locations located in Idaho for the 2018 and 2019 growing seasons.

Location	Series	Taxonomic classes of soil	Previous Crop (2018)	Previous Crop (2019)
Aberdeen	Declo Loam	Coarse-loamy, superactive, mesic Xeric Haplocalcid	Green Manure Oats	Green Manure Oats
Idaho Falls	Pancheri silt loam	Coarse-silty, mixed, superactive, frigid Xeric Haplocalcids	Alfalfa	Alfalfa
Rupert	Portneuf silt loam	Coarse-silty, mixed, superactive, mesic Durinodic Haplocalcids	Sugar Beets	Sugar Beets
Ashton	Robinlee silt loam	Coarse-silty, mixed, superactive, mesic Durinodic Haplocalcids	Potatoes	Potatoes
Soda Springs	Foundem-Rexburg Complex	Foundem: Coarse-silty, mixed, superactive, frigid pachic haploxerolls: Rexburg: Coarse-silty, mixed, superactive, frigid Calcic Haploxerolls	Spring Barley	Spring Barley
Parma	Silt Loam	Coarse-silty, mixed, superactive, mesic Durinodic Haplocalcids	Wheat	Wheat
Bonners Ferry	Ritz-Schoorson complex	Coarse-silty, mixed, active, calcareous, frigid Aeric Fluvaquents	Winter Wheat	Winter Wheat
Ferdinand	Nez Perce Silt Loam	Fine, smectitic, mesic Xeric Argialbolls	Winter Wheat	Winter Wheat
Genesee (barley)	Palouse-Athena Complex	Fine-silty, mixed, superactive, mesic Pachic Ultic Haploxerolls	Winter Wheat	Winter Wheat
Genesee (wheat)	Naff-Palouse complex	Naff:Fine-silty, mixed, superactive, mesic Typic Argixerolls: Palouse: Fine-silty, mixed, superactive, mesic Pachic Ultic Haploxerolls	Winter Wheat	
Genesee (wheat)	Thatuna-Naff complex	Fine-silty, mixed, superactive, mesic Oxyaquic Argixerolls: Naff: Fine-silty, mixed, superactive, mesic Typic Argixerolls		Winter Wheat

Table 3.2. Planting and harvest dates along with tillage practices related to research locations located in Idaho for the 2018 and 2019 growing seasons

		2018		2019	
Location	Tillage Practice	Planting Date	Harvest Date	Planting Date	Harvest Date
Aberdeen	CT	4/9/18	8/14/18	4/19/19	8/26/19
Idaho Falls	CT	4/17/18	8/16/18	4/29/19	8/27/19
Rupert	CT	4/10/18	8/20/18	3/26/19	8/15/19
Ashton	CT	4/27/18	9/5/18	4/30/19	9/4/19
Soda Springs	CT	5/3/18	8/29/18	5/10/19	9/16/19
Parma	CT	3/20/18	7/31/18	4/2/19	8/9/19
Bonners Ferry	RT/NT	5/14/18	9/4/18	4/29/19	9/2/19
Ferdinand	RT/NT	4/25/18	9/6/18	5/7/19	9/4/19
Genesee (barley)	RT/NT	4/23/18	8/20/18	4/30/19	8/29/19
Genesee (wheat)	RT/NT	4/23/18	8/22/18		
Genesee (wheat)	RT/NT			4/30/19	8/29/19

† Genesee (wheat) trials were planted in separate fields and the table shows the different soil types. Locations with tillage practices with “CT” represent conventional tillage and “RT/NT” were under reduced tillage or No-till.

Table 3.3. Initial soil fertility status of locations surveyed across Idaho for the year 2018

Location	Soil pH	SOM %	NO_3-N	NH_4-N	S	P	K
			ppm				
Aberdeen	8.1	0.9	38	4	60	18	354
Idaho Falls	8.0	1.6	24	4	61	25	195
Rupert	7.5	1.2	13	12	40	30	282
Ashton	6.5	1.9	9	15	35	14	146
Soda Springs	6.5	2.6	27	12	19	34	409
Parma	7.8	3.1	14	2	16	17	189
Bonner’s Ferry	7.9	3.5	30	5	6	8	50
			9†				
Ferdinand	5.6	4	3	3	6	24	230
			2†				
Genesee	5.6	3.9	11	4	4	10	328
			10†				

† All values were taken from a 0-60 cm depth. Values with (†) were taken from 60-122 cm depth.

††SOM; soil organic matter, NO_3-N; nitrate-nitrogen, NH_4-N; ammonium-nitrogen, S; sulfur, P; phosphorus, K; potassium

Table 3.4. Initial soil fertility status of locations surveyed across Idaho for the year 2019

Location	Soil pH	SOM %	NO_3-N	NH_4-N	S	P	K
			ppm				
Aberdeen	8.0	0.9	38	5	65	24	326
Idaho Falls	7.4	1.4	8	5	18	18	172
Rupert	7.9	1.3	13	4	35	19	197
Ashton	5.9	1.8	9	13	23	23	230
Soda Springs	--	--	--	--	--	--	--
Parma	8.2	1.9	4	5	9	21	232
Bonner's	8.0	4.1	28	11	51	11	45
Ferry			9†				
Ferdinand	5.6	3.9	10	4	6	41	583
			16†				
Genesee	5.5	3.9	6	3	4	16	458
			8†				

† All values were taken from a 0-60 cm depth. Values with (†) were taken from 60-122 cm depth. Soda springs samples were unavailable for this time.

††SOM; soil organic matter, NO3-N; nitrate-nitrogen, NH4-N; ammonium-nitrogen, S; sulfur, P; phosphorus, K; potassium

Table 3.5. List of cultivars and breeding group for used in the survey study for years 2018 and 2019 in all 9 locations.

Spring Barley		Released by	Spring Wheat		Released by
Cultivar	Class		Cultivar	Class	
Gemcraft	Malt	USDA-ARS and University of Idaho	Alum	Hard Red	Washington State University
LCS Odyssey	Malt	Limagrain Cereal Seed	WB9668	Hard Red	WestBred
Champion	Feed	WestBred and Highland Specialty Grains	Dayn	Hard White	Washington State University and USDA-ARS
Claymore	Feed	WestBred and Highland Specialty Grains	UI Platinum	Hard White	University of Idaho
			Seahawk	Soft White	Washington State University
			UI Stone	Soft White	University of Idaho

†Detailed descriptions of each cultivar can be found in the annual Idaho cereals grain report (Marshall et al., 2019).

Table 3.6. Analysis of variance (ANOVA) where location and cultivar were fixed effects observing the variability of C:N between locations of barley and wheat at nine locations in Idaho over the 2018 and 2019 growing seasons.

Crop/Class	Source of variation	P-value
Malt Barley	Location	**<0.0001**
	Cultivar	0.3281
	Location*Cultivar	0.3354
Feed Barley	Location	**<0.0001**
	Cultivar	0.7577
	Location*Cultivar	0.5453
Hard Red Wheat	Location	**<0.0001**
	Cultivar	0.4716
	Location*Cultivar	0.0822
Hard White Wheat	Location	**<0.0001**
	Cultivar	0.1320
	Location*Cultivar	0.2153
Soft White Wheat	Location	**<0.0001**
	Cultivar	0.0982
	Location*Cultivar	0.6164

Table 3.7. Analysis of variance (ANOVA) where location and cultivar were fixed effects observing the variability of biomass between locations of barley and wheat at nine locations in Idaho over the 2018 and 2019 growing seasons.

Crop	Source of variation	P-value
Malt Barley	Location	**<0.001**
	Cultivar	0.1772
	Location*Cultivar	0.9106
Feed Barley	Location	**<0.0001**
	Cultivar	0.0667
	Location*Cultivar	0.8069
Hard Red Wheat	Location	**<0.0001**
	Cultivar	**<0.0001**
	Location*Cultivar	0.6144
Hard White Wheat	Location	**<0.0001**
	Cultivar	**<0.0001**
	Location*Cultivar	0.2654
Soft White Wheat	Location	**<0.0001**
	Cultivar	**0.0179**
	Location*Cultivar	0.9649

Figure 3.1. The map below shows the general locations from which field samples were collected. Ferdinand is located 20 miles to the east of Nezperce.

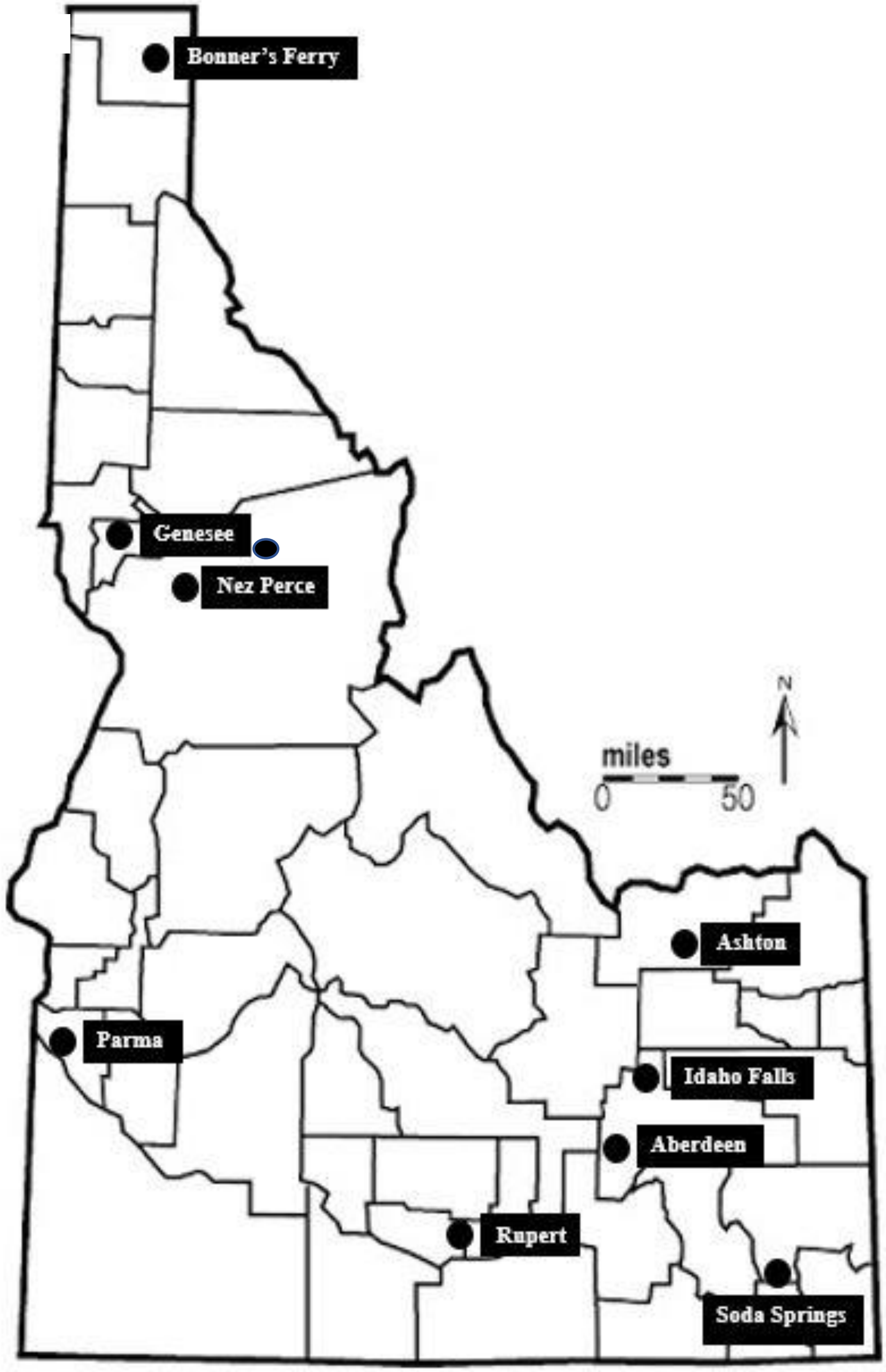


Figure 3.2. C:N ratio of malt barley averaged across two cultivars for nine locations across Idaho during the 2018 and 2019 growing seasons. Columns with different letters indicate significant differences in C:N ratio as compared using Fisher's protected least significant difference (LSD) test at the P < 0.05 level.

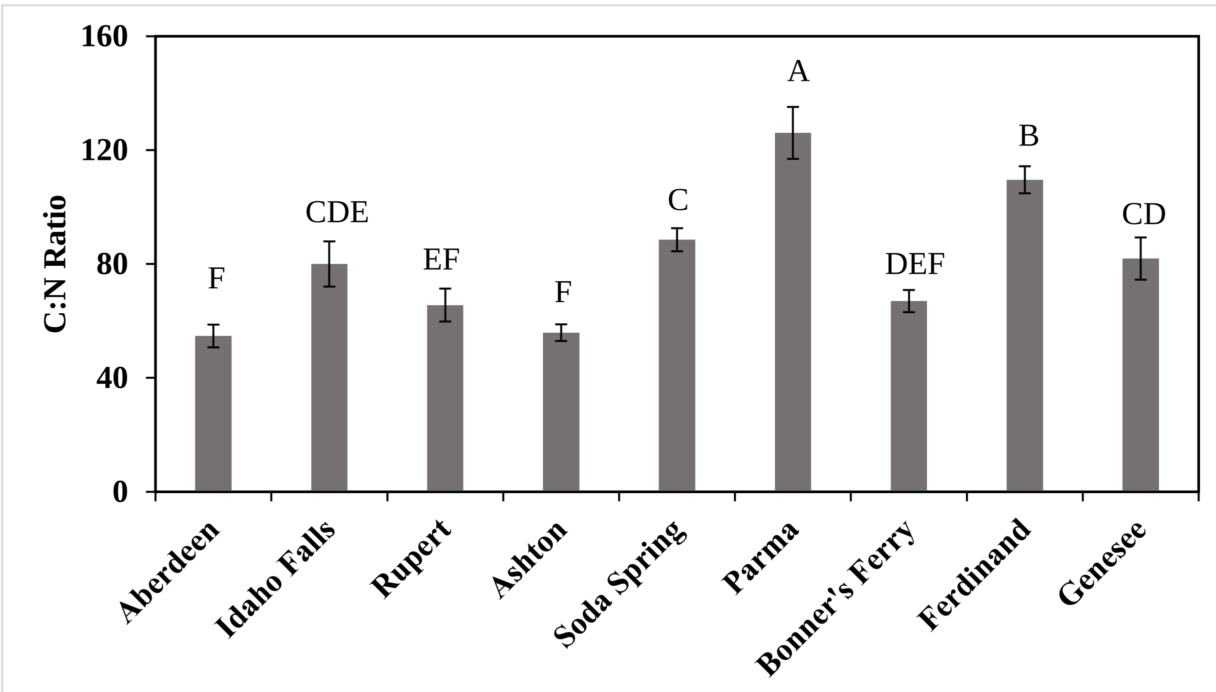


Figure 3.3. C:N ratio of feed barley averaged across two cultivars for nine locations across Idaho during the 2018 and 2019 growing seasons. Columns with different letters indicate significant differences in C:N ratio as compared using Fisher's protected least significant difference (LSD) test at the P < 0.05 level.

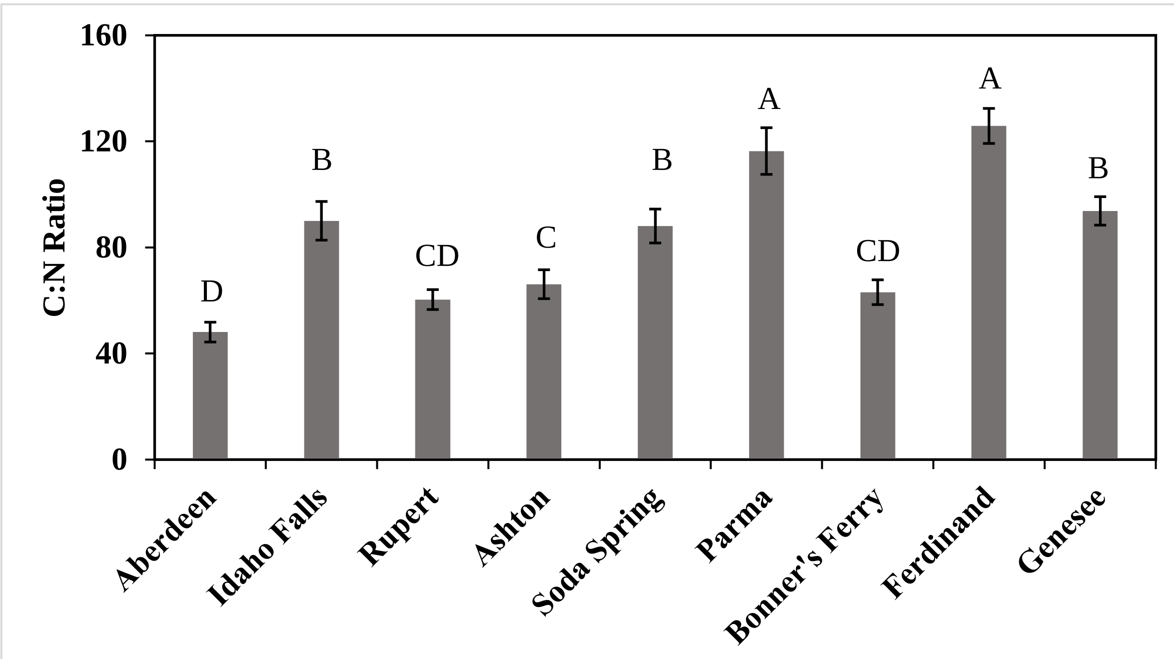


Figure 3.4. C:N ratio of hard red wheat averaged across two cultivars for nine locations across Idaho during the 2018 and 2019 growing seasons. Columns with different letters indicate significant differences in C:N ratio as compared using Fisher's protected least significant difference (LSD) test at the P < 0.05 level.

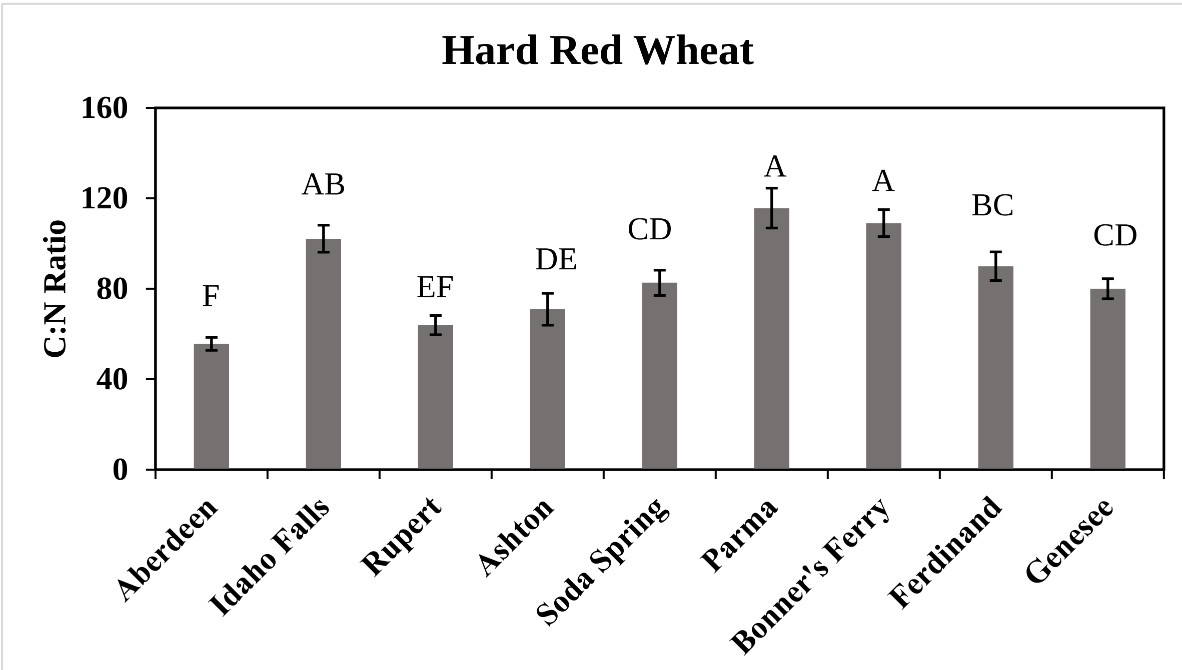


Figure 3.5. C:N ratio of hard white wheat averaged across two cultivars for nine locations across Idaho during the 2018 and 2019 growing seasons. Columns with different letters indicate significant differences in C:N ratio as compared using Fisher's protected least significant difference (LSD) test at the P < 0.05 level.

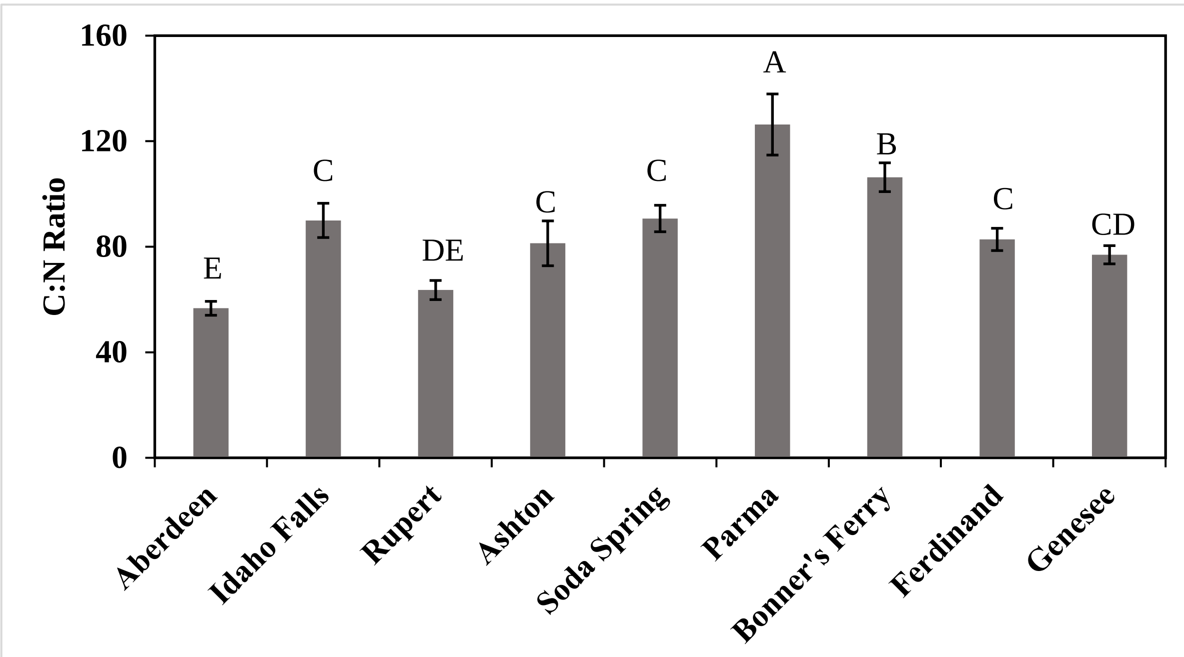


Figure 3.6. C:N ratio of soft white wheat averaged across two cultivars for nine locations across Idaho during the 2018 and 2019 growing seasons. Columns with different letters indicate significant differences in C:N ratio as compared using Fisher's protected least significant difference (LSD) test at the P < 0.05 level.

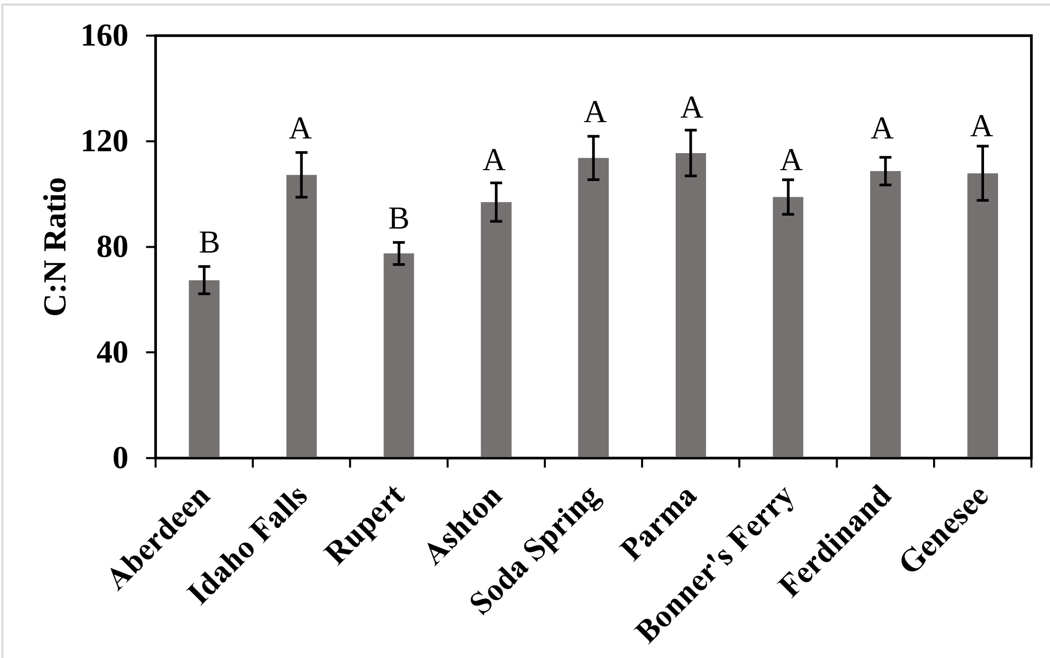


Figure 3.7. Biomass accumulation of malt barley averaged across two cultivars for nine locations across Idaho during the 2018 and 2019 growing seasons. Columns with different letters indicate significant differences in C:N ratio as compared using Fisher's protected least significant difference (LSD) test at the P < 0.05 level.

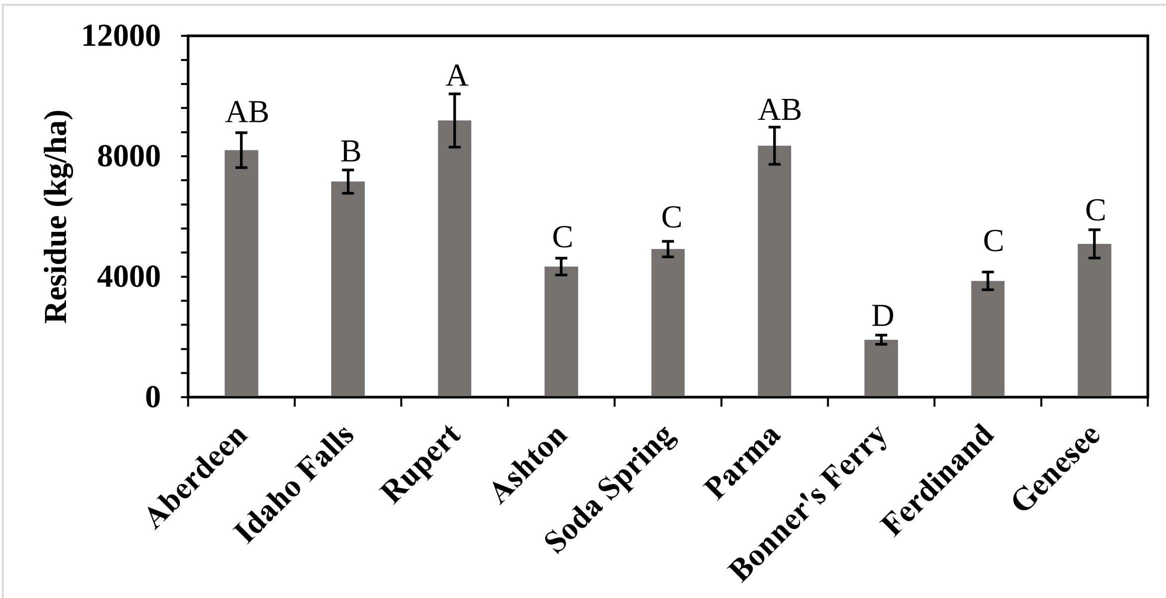


Figure 3.8. Biomass accumulation of feed barley averaged across two cultivars for nine locations across Idaho during the 2018 and 2019 growing seasons. Columns with different letters indicate significant differences in C:N ratio as compared using Fisher's protected least significant difference (LSD) test at the P < 0.05 level.

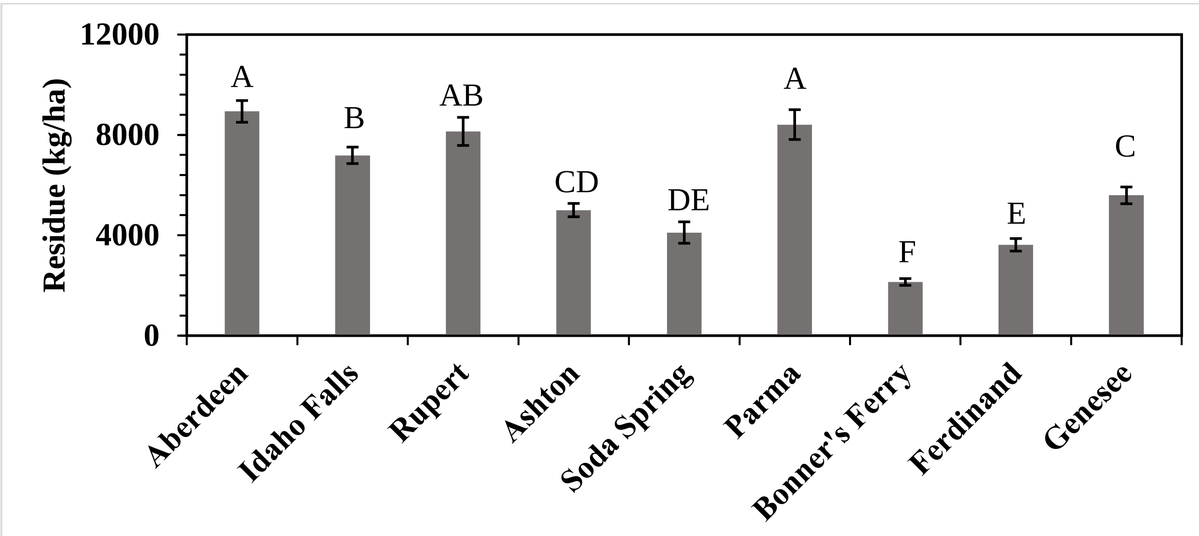


Figure 3.9. Biomass accumulation of hard red wheat averaged across two cultivars for nine locations across Idaho during the 2018 and 2019 growing seasons. Columns with different letters indicate significant differences in C:N ratio as compared using Fisher's protected least significant difference (LSD) test at the P < 0.05 level.

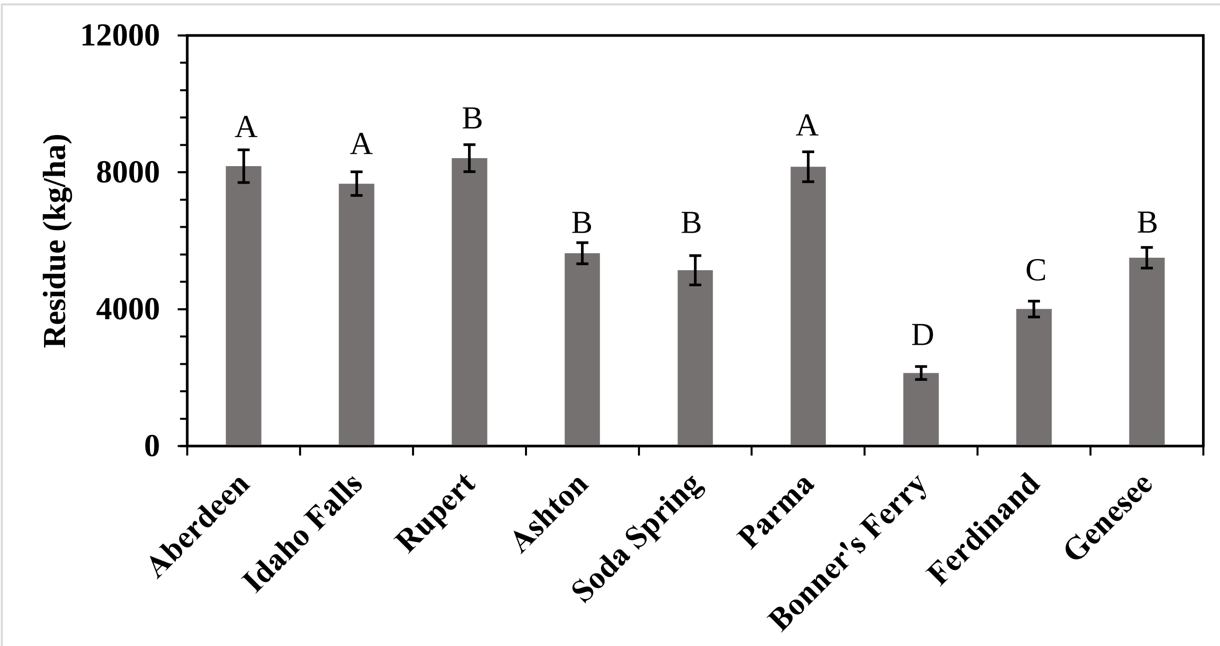


Figure 3.10. Aboveground biomass of two cultivars of hard red wheat averaged across two cultivars for nine locations across Idaho during the 2018 and 2019 growing seasons. Columns with different letters indicate significant differences in C:N ratio as compared using Fisher's protected least significant difference (LSD) test at the P < 0.05 level.

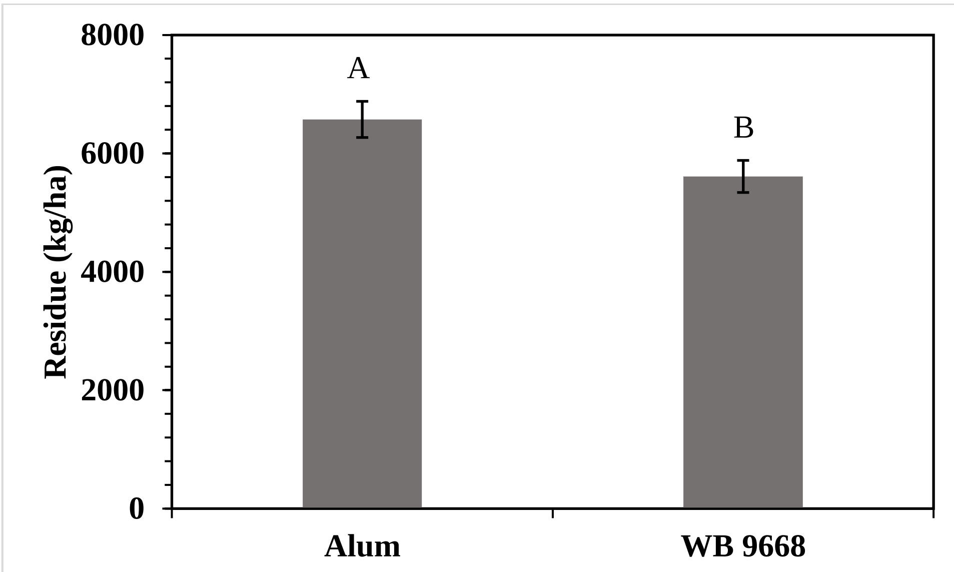


Figure 3.11. Biomass accumulation of hard white wheat averaged across two cultivars for nine locations across Idaho during the 2018 and 2019 growing seasons. Columns with different letters indicate significant differences in C:N ratio as compared using Fisher's protected least significant difference (LSD) test at the P < 0.05 level.

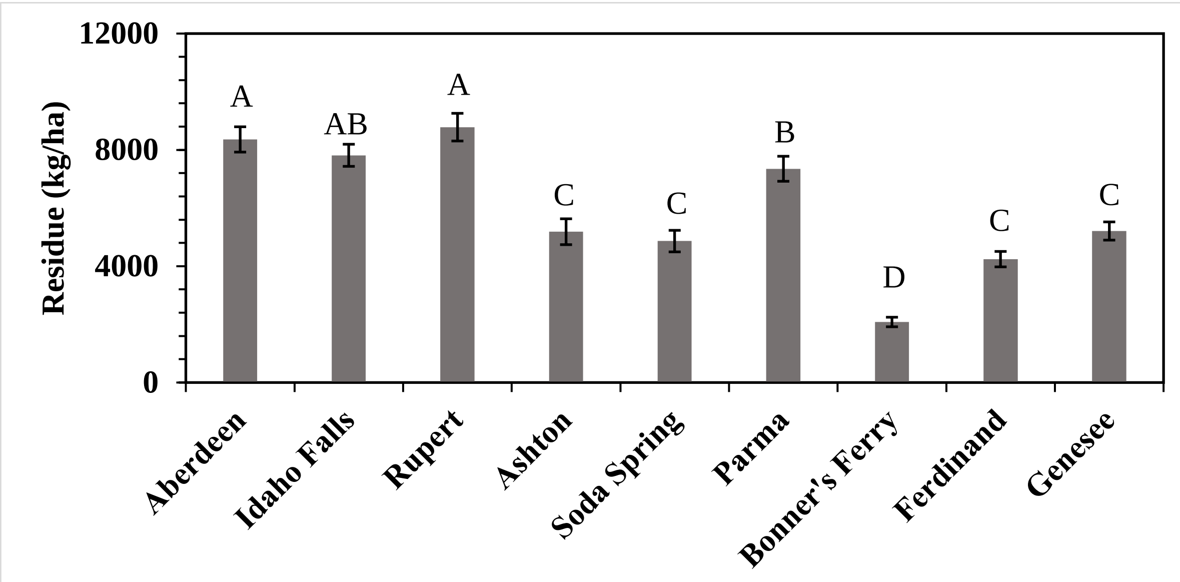


Figure 3.12. Aboveground biomass of two cultivars of hard white wheat averaged across two cultivars for nine locations across Idaho during the 2018 and 2019 growing seasons. Columns with different letters indicate significant differences in C:N ratio as compared using Fisher's protected least significant difference (LSD) test at the P < 0.05 level.

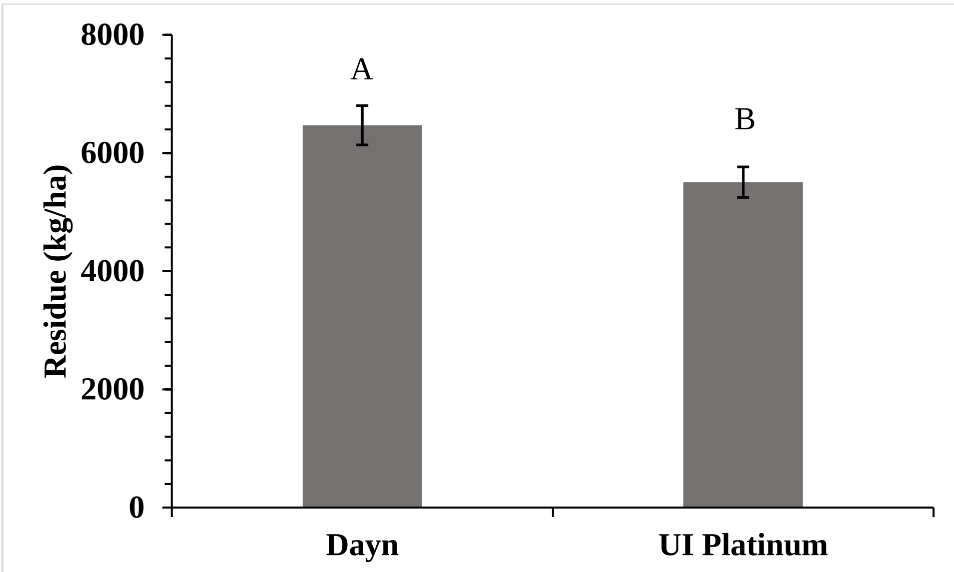


Figure 3.13. Biomass accumulation of soft white wheat averaged across two cultivars for nine locations across Idaho during the 2018 and 2019 growing seasons. Columns with different letters indicate significant differences in C:N ratio as compared using Fisher's protected least significant difference (LSD) test at the P < 0.05 level.

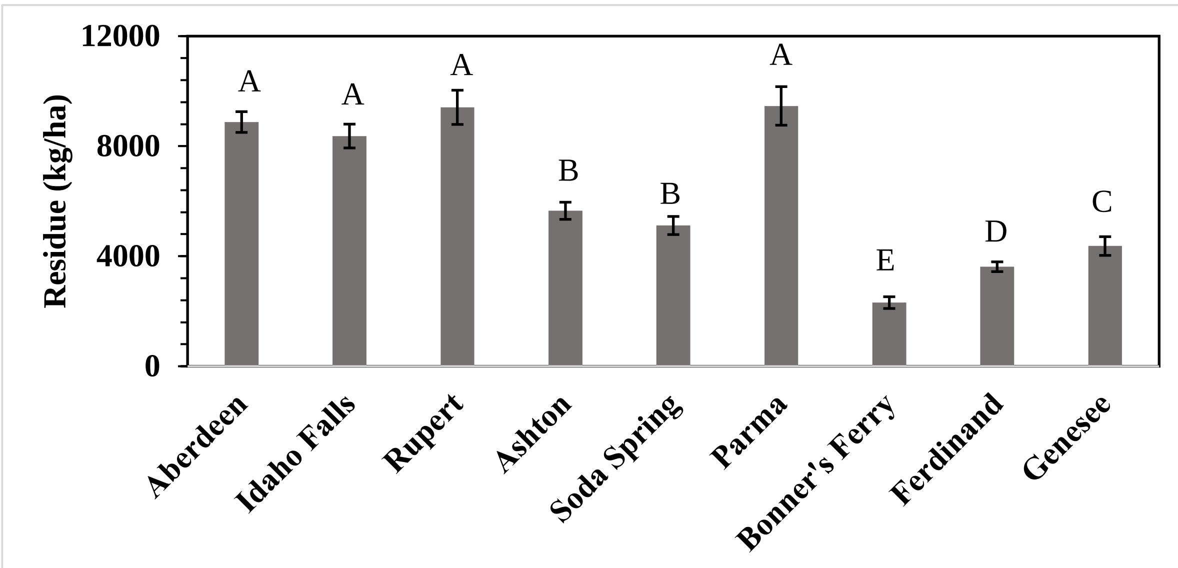
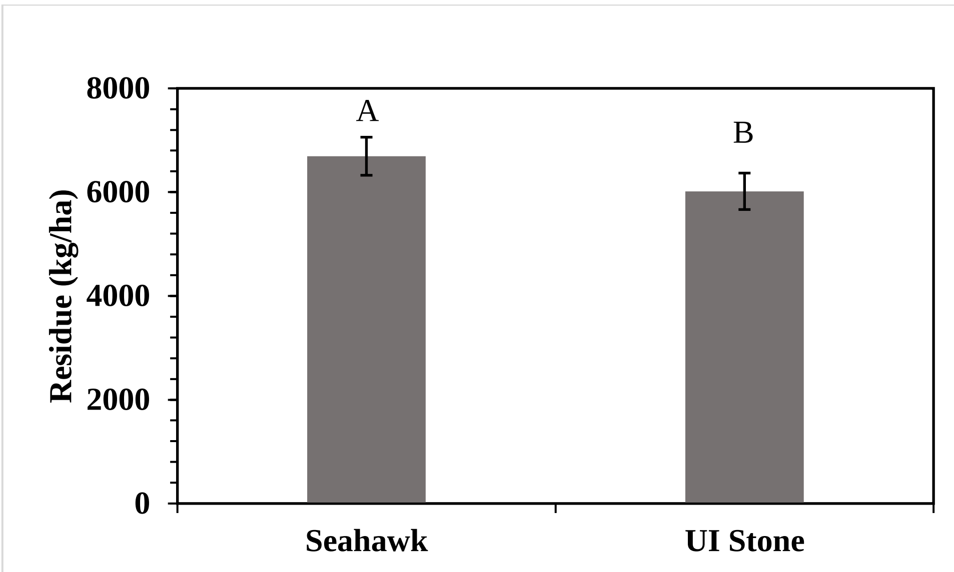


Figure 3.14. Aboveground biomass of two cultivars of soft white wheat averaged across two cultivars for nine locations across Idaho during the 2018 and 2019 growing seasons. Columns with different letters indicate significant differences in C:N ratio as compared using Fisher's protected least significant difference (LSD) test at the $P < 0.05$ level.



Chapter 4

COMPARISON OF RESIDUE DECOMPOSITION BETWEEN SURFACE VS. INCORPORATED BARLEY, CORN, AND WHEAT AT VARYING N-FERTILIZER RATES

Abstract

Residue management has been a concern since the beginning of production of barley (*Hordeum vulgare* L.), corn (*Zea mays* L.), and wheat (*Tritcum aestivum* L.). The source of residues has an impact on the post-harvest decomposition of residue left over in the field due to differences in carbon to nitrogen ratios (C:N). Further, the effects of management practices such as conventional tillage vs. conservation tillage (no-till) on residue breakdown vary throughout the state of Idaho. Application of supplementary nitrogen (N)-fertilizers are recommended to aid residue break down. The objective of this study was to evaluate barley, corn, and wheat residue, tillage practices, and nitrogen (N) application effects on in-field decomposition. A field study was conducted in Aberdeen, ID to evaluate the residue breakdown of surface applied (no tillage) and incorporated (conventional tillage) residues collected from various cultivars of barley, wheat, and corn with three different rates of N (0, 56 and112 kg ha^{-1}). The field experiment was laid out in a randomized complete block design. In general, greater carbon and weight loss measured greater for incorporated treatments. However, corn surface treatments measured comparable weight loss to both soft white and hard red wheat incorporated treatments. Additionally, N application at recommended rates did not increase residue decomposition. The findings from this study indicate that under these circumstances, incorporation of cereal residue will generally result in more rapid decomposition than surface applied residue between fall and spring. Additionally, N

applications at current or higher rates were not supported to increase residue decomposition. The results of this study indicate N application practices should be reconsidered.

Introduction

Cereal crops (barley, corn, and wheat) after harvest leave behind residue in the field which can tie up nitrogen (N) for the subsequent crop. Nitrogen tie up occurs from the high C:N ratio which is carried over from barley, corn, and wheat residues. The ideal C:N ratio for mineralization in the soil is a 24:1 (USDA, 2011). Management of cereal crop residues can be handled by different practices in attempts to reduce the tie up of N in the soil as organic material. Tillage is assumed to speed up decomposition of cereal residue by aerating the soil and increasing residue to soil contact. In Idaho, N is typically applied to facilitate residue decomposition and improve N availability for the subsequent crop. For management of residue for cereal crops in Idaho, it is currently recommended that for every ton of straw 17 kg N ha^{-1} should be applied and up to 56 kg N ha^{-1} as per the University of Idaho Extension recommendation despite known variations in the C:N ratio among crop residues (Robertson and Stark, 2003; Brown et al., 2010; Mahler, 2007). The objective of the study was to utilize residual cereal crop biomass to assess variation of in-field residue decomposition as affected by N fertilizer rates and residue placement (surface vs. incorporated) between fall and spring prior to planting.

Materials and Methods

Plot Management and Experimental Design

The field residue decomposition study was conducted during 2018 to 2019 and 2019 to 2020 from October to March. The field study was located at the University of Idaho Research Extension Center, Aberdeen, ID (42°58'27"N 112°48'51"W) where soil from the study is classified as a Declo fine sandy loam (Coarse-loamy, mixed, superactive mesic Xeric Haploacaldics). Soil samples were taken from the field at the initiation of the study in 2018 and 2019 to record initial nutrients as shown in (Table 4.1). The depths of the soil samples were 0 to 15, 15 to 30, and 30 to 60 cm. Soil samples were analyzed for soil pH, soil organic matter (SOM), Olsen P and K, and inorganic N (NH_4 and NO_3) based on standard procedure for the western United States (Miller et al., 2013). Residue samples involved in the study were from 5 cultivars of cereal crops grown at the Aberdeen Research and Extension Center: Voyager (malt barley (MB)), Transit (food barley (FB)), Mycogen 2v489a (field corn (FC)), Alturas (soft white spring (SWS)), and WB 9668 (hard red spring (HRS)) (Table 4.2). Standard management practices for each specific crop were collected from which barley and wheat samples were from Aberdeen, ID and corn samples from Kimberly, ID. Four replications of each bulk residue sample were collected by hand, put into paper bags, and dried at 60^{o}C to a constant temperature prior to laboratory analysis. Bulk samples were then tested for initial C and N by high temperature combustion using a VarioMax CN analyzer (Elementar Americas, Inc. Mt Laurel, NJ) (Table 4.3). Residues were then put into 120 separate non-reactive nylon mesh bags and weighed at 43 grams which represents 9,000 kg ha^{-1} of residue being left on the field. Each plot in the field was 1.5 m^{2} and surface area for the non-reactive nylon mesh bags was 480 cm^{2}. The study design included residue placement (incorporated vs. surface), three different rates of ammonium sulfate $(NH_4)_2SO_4$ fertilizer (0, 56, and 112 kg N ha^{-1}), and 1 extraction period (spring) for a total of 120 plots. Rates of fertilizer represented the control, recommended rate, and double the recommend rate for applying N in management for cereal residues in Idaho. The study was a factorial of cultivar/crop, fertilizer rate, four replications, and residue placement arranged in a randomized compete block design (RCB).

Application and Extraction of Residue Samples in the Field

The previous crop in the field was oats (*Avena sativa* L.) where all above ground oat material was bailed off to minimize alternate residue sources. Prior to application of treatments, field work entailed plowing followed by a disc harrow tillage method. All the samples from the study were applied to the field and fertilized at the initiation of the study in the fall of both 2018 and 2019. Incorporated trials were buried at approximately 15 cm deep within the soil representing placement following a disc harrow tillage in the field. Surface trials were held in place by using metal landscape pins to avoid being blown away or moved. Collection of samples were taken in the first week of spring between March 18th and March 21st for both years. Sample collection followed protocols described by (Al Kaisi et al., 2017), where samples extracted from the field were washed and hang dried for 24 hours and oven dried at 60^{o}C to a constant weight. Dried samples were then weighed, and the weight from the initiation of the study was subtracted from the final collected weight to record any loss of residue. Following sample weight determination, samples were ground using a Wiley mill grinder (Thomas Scientific, Swedesboro, NJ, USA) to pass a 2 mm screen. Tissue was then analyzed using high temperature via a VarioMax CN analyzer (Elementar Americas, Inc. Mt Laurel, NJ) to determine the amount of C and N in the samples.

Carbon remaining was calculated from measured C values from the initial and final samples based on the following formula.

Initial weight*(%Carbon/100) = amount of initial C

Amount initial C – ((weight loss* (%C/100)) = amount of C remaining

Statistical Analyses

Statistical analyses were performed using the Proc MIXED procedure of SAS (SAS Institute, 2011) where cultivar, residue placement, and fertilizer N rate were fixed effects and year and block were treated as random effects. All mean separations were performed using Fisher's protected least square differences (LSD) as a post-hoc multiple comparisons analysis at the $P < 0.05$ level.

Results

Weather and soil conditions

The field experiment had all weather data reported through (Agri-Met, 2016) as shown in Fig. 4.1 and 4.2. Precipitation for the years 2018 to 2019 was substantially greater than years 2019 to 2020 in the initial months. In 2018, temperature went from 7℃ starting in October while in 2019 the field study started from 2℃ and then dropped to -3℃ through most of winter. Precipitation and air temperature averaged over the six-month period for the years 2018 and 2019 were 15mm and 10mm and both at -1℃, respectively. Soil temperatures at the 10 cm depth averaged 6℃ for both years and the 20 cm depth averaged 6℃ and 7℃. Application of the field study was made at the beginning of October for both years and soil temperature at the 10 cm depth ranged from 7 to 15℃. By December and January, soil temperature at the 10 cm depth dropped to 3 to 5℃. At retrieval of the samples in spring

(March), soil temperatures ranged from 4 to 6°C for incorporated (buried) and 0 to 3°C (air temperature) for surface treatments.

Residue Composition and Weight Loss

Initial C:N ratios used within the study were 70:1 for barley, 67:1 for corn, and 96:1 for wheat on average (Table 4.3). Weight loss showed significant differences from the combination of cultivar by residue placement (Table 4.4). Nitrogen rate (0, 56, and 112 kg N ha^{-1}) showed no significant effects between all treatments. Measurements of percent weight loss in general were greater from incorporated treatments, however Mycogen (surface) was comparable to both Alturas and WB9668 (incorporated) (Fig. 4.3). Mycogen (incorporated) measured the greatest weight loss at 37% which was followed by Voyager (incorporated) at 30%. Mycogen (incorporated) measured greater weight loss than Voyager (incorporated) and both were greater in residue weight loss compared to all other incorporated treatments (Fig. 4.3). Comparable measurements of incorporated treatments were seen between incorporated Alturas, Transit, and WB9668. In contrast, Mycogen surface measured greater weight loss from all other surface residue treatments but comparable weight loss of surface residue treatments was measured between surface applied Alturas, Transit, Voyager, and WB9668.

Carbon Loss

Carbon loss only differed based on cultivar by residue placement and interactions between N rates (0, 56, and 112 kg N ha^{-1}) were not significant (Table 4.4). All incorporated residue treatments showed greater carbon loss than all surface applied treatments within the field study (Fig. 4.4). Effects from incorporated Voyager and Mycogen measured the highest carbon loss compared to all others where incorporated treatments of Mycogen showed the greatest carbon loss at 38 %. Comparable measurements of carbon loss were seen between incorporated residue of Alturas, Transit, and WB9668. In contrast, the greatest carbon loss measured for surface applied treatments was Mycogen at 24% followed by Voyager at 22% carbon loss. All surface treatments of the field study measured comparable carbon losses, but in this case Mycogen surface differed from all other surface applied residue.

Discussion

Post-harvest C:N ratios from residue may determine decomposition rate in the soil (Vigil, 1999). Residues with high C:N ratios tend to take a longer period for complete decomposition and particle size from residues may influence rate of decay in the soil (Vigil, 1999). The pattern seen in this study was generally corn > barley ≈ wheat in terms of the amount of residue decomposition. Particle size along with tillage can change the amount of soil-residue contact with microbial communities (Vigil, 1999). Research conducted by (Vigil, 1999) would explain why in general, all incorporated treatments measured greater carbon and weight loss because of greater soil contact with microbial communities. Microbial populations within the soil play a major part in residue decomposition (Curtin et al., 2008). As microbial communities decompose plant tissue, CO_2 -C is emitted out of the soil. This field study did not record CO_2 -C levels emitted from the field, however previous research has shown that straw type had minimal effects on CO_2 -C emissions (Curtin et al., 2008).

Along with soil properties, precipitation and temperature may have influenced the rate of residue decomposition (Al-Kaisi et al. 2017). Other research has observed how timing for incorporation of straw residue can provide greater amounts of mineral N as compared to leaving residue on the surface (Beare, 2002). In general, weight loss and carbon loss percentages from incorporated treatments were greater than surface except for Mycogen surface (Fig. 4.3) and this would contradict previous research by Al-Kaisi et al. (2013) who measured no significant differences of decomposition rate between deep tillage, strip tillage, and no-till treatments with corn residue. Conventional tillage management for straw residue is done by incorporating straw or by removing straw followed by tillage. According to Silgram et al. (2002), removing residue followed by plowing or tillage, increased soil mineral N at multiple depths.

Nitrogen rate (0, 56, and 112 kg N ha^{-1}) applications showed no significant effects on treatments. No significant effects from N rate were comparable to previous work by Al-Kaisi et al. (2017) who measured no significant effects of N rate on corn decomposition in Iowa. Effects of N rate may have been different if applied at an earlier time before air temperatures dropped (Al-Kaisi et al. 2017). Other research by Rezig et al. (2014) found significantly greater effects of wheat residue decomposition through application of N. Although, research conducted by Rezig et al. (2014) was conducted during the summer and high temperatures are likely to increase microbial activity (Biederbeck and Campbell, 1973) as compared to the current study where temperatures were low between fall and spring.

Voyager showed quicker decomposition vs all other barley and wheat cultivars used, and this contradicts research done by Curtin et al. (2008) who found no differences in mass loss between wheat and barley cultivars. Yet other research by Mulvaney et al. (2010) measured significant differences between residue types and found buried residues were variable on decomposition. In general, both weight loss and C loss outputs measured similar differences with incorporated treatments losing greater percentages of weight and C. All incorporated treatments showed greater weight and C loss except for Mycogen surface being comparable to Alturas and WB9668 incorporated treatments (mass). Weight loss similarities between Mycogen surface, Alturas, and WB9668 incorporated treatments are supported with research by Hadas et al. (2004) who found that rapeseed (*Brassica napus*) and tobacco (*Nicotiana*) residues were decomposing at similar rate to corn residue which has a C:N ratio 2.5 to 3 times larger.

Residues were all consistently dried and placed in the study but incorporated (buried) treatments were placed in moist soil while surface treatments remained above on a dry surface. Since incorporated treatments had greater residue-soil contact, this may have promoted microorganisms to initiate decomposition more quickly than surface applied treatments (Curtin et al. 2008). In this field experiment, soil samples were not taken to test for differences in microbial communities, though, other research has shown that microbial communities may fluctuate throughout the growing season (Spedding, 2003). Similar research has found that irrigation of fall incorporated treatments showed greater decomposition than spring irrigated and incorporated treatments (Beare, 2002). Since this field study was not conducted under irrigation, future research could evaluate the effects of irrigation vs environment around this area between autumn and spring.

Conclusion

In general, the findings from this study showed greater carbon and weight loss in all incorporated treatments compared to surface applied residue and the general pattern of corn > barley ≈ wheat in terms of residue decomposition. While this field study was conducted at only one location, similar results may be found from other areas in southeast Idaho. Effects from N rate were not significant in this case but differences between cultivar and residue placement was highly significant. To increase carbon decomposition between fall and spring, it would be recommended to incorporate residue into the soil in this case. Additional N to decrease carbon or weight loss in this scenario would not be recommended due to the nonsignificant effects shown within the study. Cereal residue decomposition from this study may change if applied in other regions or states with different conditions relating to climate, soil type, crop rotation, and other cultural practices. The findings from this study increase our understanding of which residue placement increases carbon and weight loss over time and helps with a step to refining soil fertility adjustments which might be made towards refining residue management.

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Table 4.1. Initial soil fertility status of field study conducted during the 2018-2019 fall-spring season at the Aberdeen Research and Extension Center, Aberdeen, ID.

Depth (cm)	**Soil pH**	**OM (%)**	**--------Olsen-------**		**----------2N KCL---------**	
			Phosphorus	**Potassium**	**Ammonium-Nitrogen**	**Nitrate-Nitrogen**
2018			**----------------mg/kg----------**		**---------------mg/kg-----------**	
0-15	8.29 (0.11†)	1.1 (0.05)	10.5 (0.36)	248 (11.10)	BDL	3.6 (0.37)
15-30	8.34 (0.05)	0.9 (0.10)	9.4 (0.37)	220 (14.90)	BDL	3.2 (0.34)
30-60	8.61 (0.13)	1.1 (0.25)	5.0 (0.61)	153 (15.09)	BDL	3.2 (0.52)
2019						
0-15	7.86 (0.15)	1.1 (0.03)	10.5 (2.17)	248 (8.99)	BDL	3.6 (0.12)
15-30	8.47 (0.10)	0.9 (0.06)	9.4 (1.12)	220 (14.61)	BDL	3.2 (0.80)
30-60	8.36 (0.02)	1.1 (0.25)	5.0 (1.45)	153 (12.18)	BDL	3.2 (0.38)

† Values represent standard error within the table. The “BDL” values were <1.25 for both years.

Table 4.2. List of cultivars conducted in this field study for years 2018 to 2019 and 2019 to 2020 (Marshall, 2018).

Cultivar	Crop	Released by
Voyager	Malt Barley	Bush Agricultural Resources
Transit	Food Barley	USDA-ARS and the University of Idaho AES
Mycogen-2v489a	Field Corn	Corteva
Alturas	Soft White Wheat	Idaho AES and USDA-ARS
WB9668	Hard Red Wheat	WestBred

Table 4.3. Initial mean chemical composition of barley, corn and wheat used in 2018 and 2019.

Crop	Cultivar	%N	%C	C/N
Barley	Transit	0.64 (0.02†)	41.3 (0.18)	69 (2.86)
Barley	Voyager	0.60 (0.03)	41.1 (0.13)	71 (4.15)
Corn	Mycogen	0.71 (0.06)	41.9 (0.22)	67 (6.50)
Wheat	WB9668	0.45 (0.01)	39.8 (0.38)	90 (1.10)
Wheat	Alturas	0.53 (0.03)	40.8 (0.13)	103 (15.87)

† Values represent standard error.

Table 4.4. Analysis of variance (ANOVA) where cultivar, N-rate, and residue placement were fixed effects observing the weight and carbon loss differences between five cultivars and three different crops.

	% C Loss	%Weight Loss
	P-value	P-value
cultivar	**<.0001**	**<.0001**
nrate	0.0526	0.0800
cultivar*nrate	0.2851	0.4303
residue placement	**<.0001**	**<.0001**
cultivar*residue placement	**<.0001**	**<.0001**
nrate*residue placement	0.4248	0.4604
cultivar*nrate*residue placement	0.0815	0.1660

Figure 4.1.

Pattern of precipitation (mm) and temperature (℃) during the field experiment in Aberdeen, ID for the year (a. 2018 to 2019) and (b. 2019 to 2020).

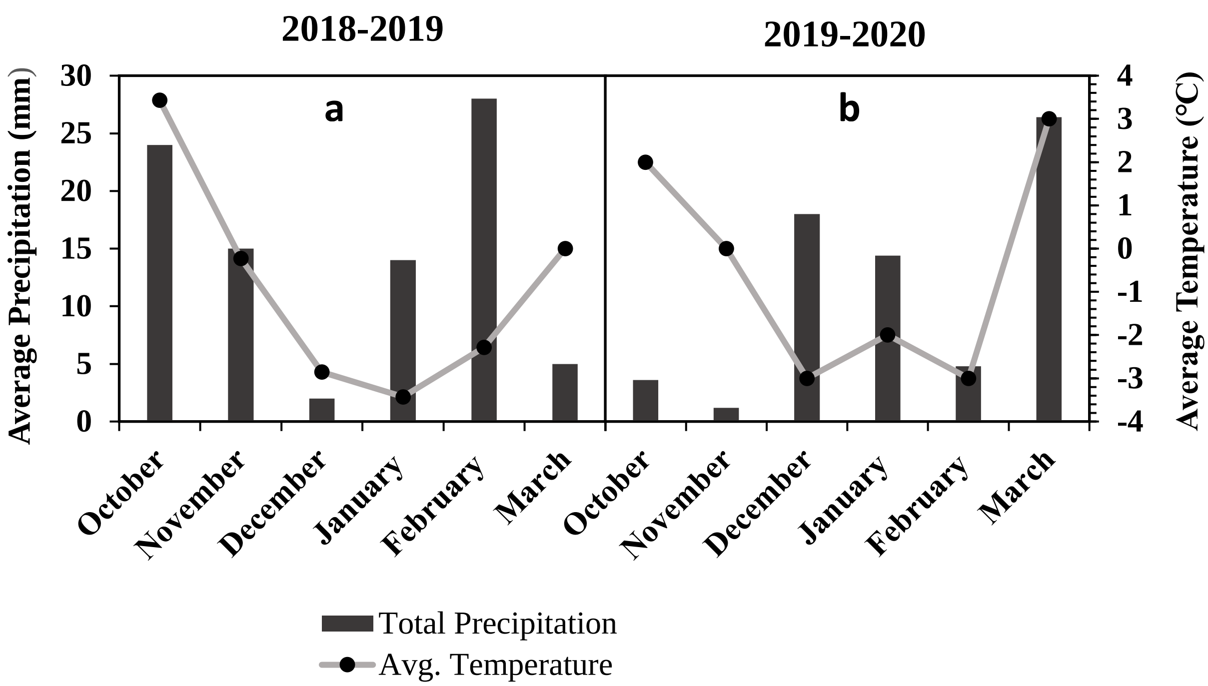


Figure 4.2.

Pattern of snow cover (mm) and soil temperature (°C) during the field experiment in Aberdeen, ID for the year (a. 2018 to 2019) and (b. 2019 to 2020).

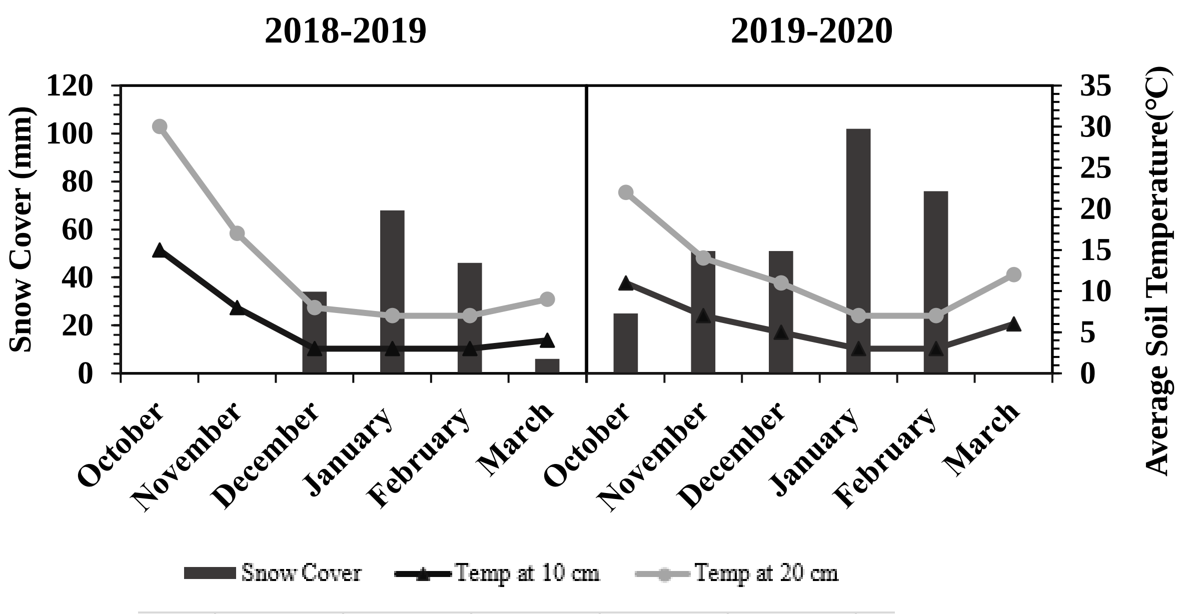
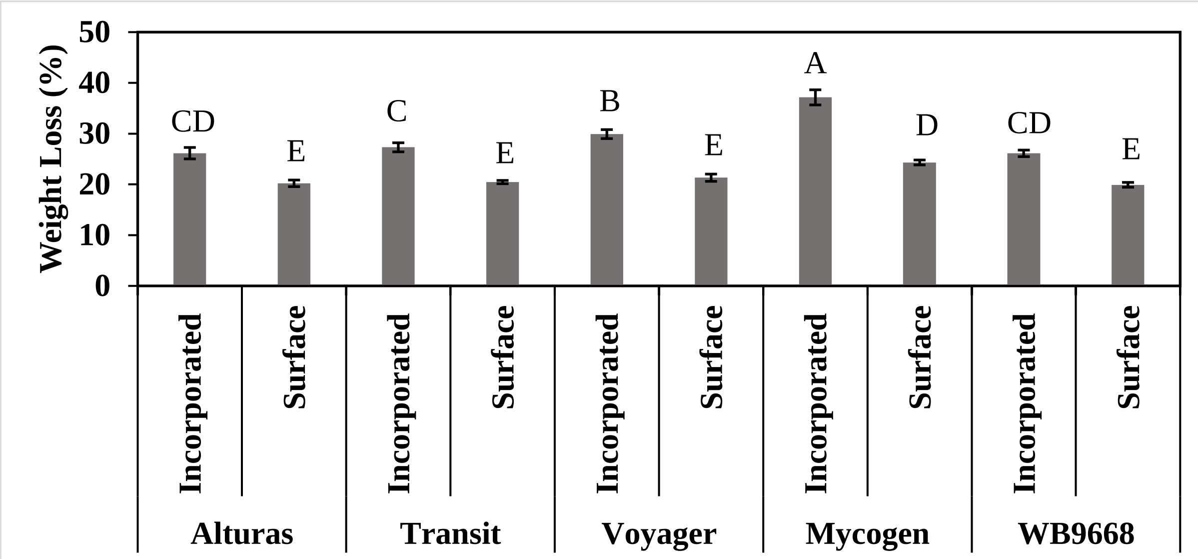
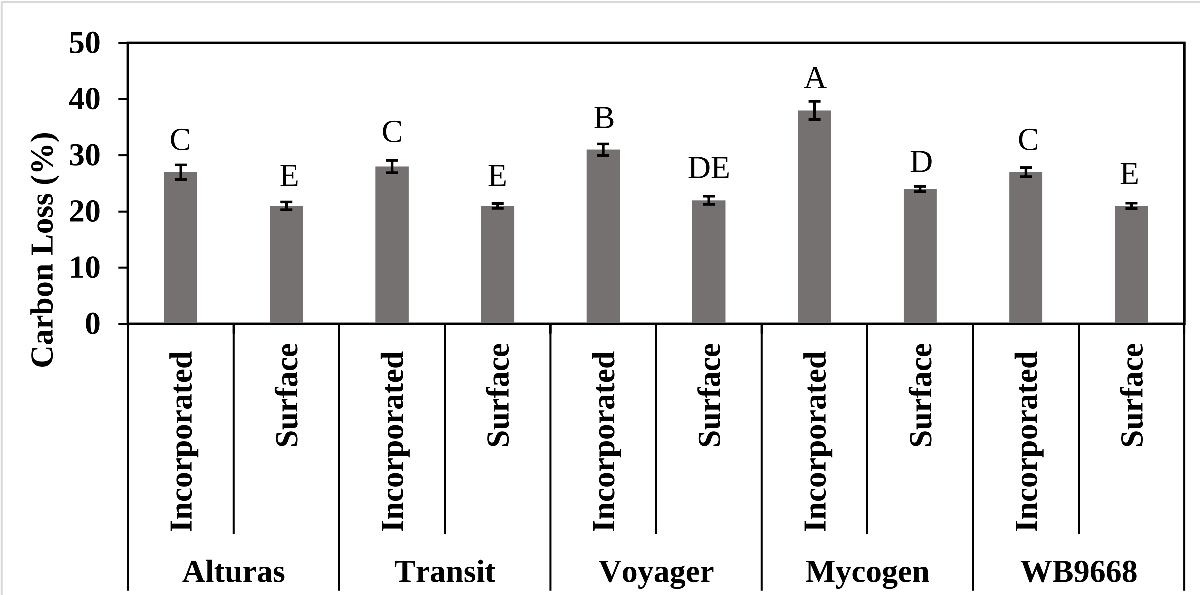


Figure 4.3. Residue weight loss of barley, corn, and wheat that was incorporated or left on the surface averaged across three N application rates for research conducted at the Aberdeen Research and Extension Center, Aberdeen, ID from 2018 to 2020.



†Different letters for each parameter indicate significant differences between cultivars and residue placement.

Figure 4.4. Residue carbon loss of barley, corn, and wheat that was incorporated or left on the surface averaged across three N application rates for research conducted at the Aberdeen Research and Extension Center, Aberdeen, ID from 2018 to 2020.



†Different letters for each parameter indicate significant differences between cultivars and residue placement.