8-2020

Nitrogen Fertilizer Needs of First-Year Small Grains Following Alfalfa

Collin Pound
Utah State University

NITROGEN FERTILIZER NEEDS OF FIRST-YEAR SMALL GRAINS FOLLOWING ALFALFA

by

Collin Pound

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

of

MASTER OF SCIENCE

in

Soil Science

Approved:

Matt Yost, Ph.D. Major Professor	Grant Cardon, Ph.D. Committee Member
J. Earl Creech, Ph.D. Committee Member	Richard S. Inouye, Ph.D. Vice Provost for Graduate Studies

UTAH STATE UNIVERSITY
Logan, Utah

2020

ABSTRACT

Nitrogen Fertilizer Needs of First-Year Small Grains Following Alfalfa

by

Collin Pound, Master of Science

Utah State University, 2020

Major Professor: Dr. Matt Yost
Department: Plant Soils and Climate

Small grains including wheat (*Triticum aestivum*), barley (*Hordeum vulgare*), triticale (*Triticolsecale*), and oats (*Avena sativa*), are commonly grown as forage and grain following alfalfa (*Medicago sativa*) in Utah and the Intermountain West, especially during drought years as small grains require less applied irrigation water than corn (*Zea mays*). Several studies in many parts of the world have shown that first-year corn following alfalfa rarely needs N fertilizer, yet relatively few have evaluated the N needs of small grains, especially small grains grown for forage. Objectives of this research were to i) determine whether N fertilizer is needed to economically optimize the yield and quality of first-year small grains following alfalfa, ii) develop N guidelines, and iii) determine whether spring soil nitrate or leaf chlorophyll concentrations at flag leaf can predict N response. Fertilizer trials were conducted on 30 small grain site-years in the first-year following alfalfa during 2018-2019 in Idaho, Utah, and Colorado. At each site, four replications of up to 13 different N treatments ranging from 0 to 168 kg N ha^{-1} were applied. Results indicate that for small grains grown to kernel maturity, N fertilizer was

needed to increase levels in most cases; yield (56%), test weight (33%), and protein (83%). Responsive site-years required between 108 and 148 kg N ha^{-1}. Spring soil nitrate and leaf chlorophyll concentration tests were able to accurately predict grain yield response to N in 53% and 17%, respectively, and for grain quality in 80% and 64%, respectively. For small grains grown for forage, results indicate that N fertilizer was not needed to economically increase small grain forage yield at most (91%) sites. The one site that had an economic benefit was small grains following an old alfalfa stand (> 9 yr) and required only 67 kg N ha^{-1} to economically optimize yield. In contrast, forage quality improved at nearly all sites with N fertilizer applications up to 112 kg N ha^{-1}. Soil nitrate tests were able to separate forage yield response to N in 45% of the cases, and were able to separate forage quality response to N in 67%. This suggests that leaf chlorophyll concentrations and soil nitrate may be viable prediction tests to determine yield and quality responses in this rotation. These results indicate that growers may be able to withhold additional N fertilizer depending on the following conditions: if the small grain crop is harvested for grain or for forage, if soil nitrate levels are lower than 21 mg kg^{-1}, if small grains follow an older (10+ yr) stand, also if compensation for small grain quality improvement outweighs fertilizer cost. This information will help grower’s better utilizer N credits from alfalfa, improve their small grain yield, quality, profits, and reduce negative implications of excessive N fertilizer applications.

(90 pages)

PUBLIC ABSTRACT

Nitrogen Fertilizer Needs of First-Year Small Grains

Following Alfalfa

Collin Pound

Wheat, barley, triticale, and oats, are small grains commonly grown as hay and grain following alfalfa in Utah and the Intermountain West, especially during drought years as they require less irrigation than corn. Several studies in many parts of the world have shown that first-year corn following alfalfa rarely needs nitrogen (N) fertilizer, yet relatively few have evaluated the N needs of small grains, especially small grains grown for hay. Objectives of this research were to determine whether N fertilizer is needed to economically optimize the yield and quality of first-year small grains following alfalfa, develop N guidelines, and whether spring soil nitrate or leaf chlorophyll concentrations at flag leaf can predict N response. Fertilizer trials were conducted at 30 different locations in the first-year following alfalfa during 2018-2019 in Idaho, Utah, and Colorado. At each location, up to 13 different N treatments ranging from 0 to 168 kg N ha^{-1} were applied as ammonium nitrate in the fall, spring, or mid-season. Results indicate that for small grains grown to kernel maturity the alfalfa N credit was not adequate to increase levels in most cases, yield (56%), test weight (33%), and protein (83%). Out of all responsive locations, 93% had a spring soil nitrate level lower than 21 g kg^{-1}, indicating that spring soil nitrate may play a role in responsive locations. Responsive locations required up to 115, 108, and 148 kg N ha^{-1}, in yield, test weight, and protein, respectively. Spring soil nitrate and leaf chlorophyll concentration tests were able to

accurately predict grain yield response to N in 53% and 17%, respectively, and for grain quality in 80% and 64%, respectively. These results suggest that growers who have a spring soil nitrate level less than 21 g kg^{-1} may still apply up to 115 kg N ha^{-1} in the spring. Doing so can increase yield up to 31%, test weight up to 1.37%, and protein up to 20%. For hay, results indicate that N fertilizer was not needed to economically increase yield at most (91%) locations. The one responsive location following an old alfalfa stand (> 9 yr) and required only 67 kg N ha^{-1} to economically optimize yield. In contrast, hay quality improved at nearly all locations with N fertilizer applications up to 112 kg N ha^{-1}. Soil nitrate prediction tests were able to separate yield response to N in 45% of the cases, and were able to separate hay quality response to N in 67% of the cases. This suggests that leaf chlorophyll concentrations and soil nitrate may be viable prediction tests to determine yield and quality responses in this rotation. These results indicate that growers may be able to withhold additional N fertilizer depending on the following conditions: if the small grain crop is harvested for grain or for hay forage, if soil nitrate levels are lower than 21 mg kg^{-1}, if small grains follow an older (10+ yr) stand, also if compensation for small grain quality improvement outweighs fertilizer cost. These are key factors in determining additional N fertilizer need when growing small grains in the first-year after alfalfa. This information will help grower's better utilizer N credits from alfalfa, improve their small grain yield, quality, profits, and reduce negative implications of excessive N fertilizer applications.

ACKNOWLEDGMENTS

I would like to thank my family, my wife Lauren, sons Noah and Thomas, and daughters Lucy, Ellie, and Scarlett, for their patience and support while I have worked on this project. I would also like to thank my excellent committee, Drs. Matt Yost, Grant Cardon, and J. Earl Creech for their constant support, advice, and direction. I would like to thank Kathleen Russell from Colorado State University, Michael Pace, Jody Gale, other Utah State University faculty members and cooperating growers for all their help. I thank Jonathan (Jonno) Holt and Cole Harding as co-graduate students, as well as Matt Harper, Jeff Austin, Justin Bean, Leann Johnston, Dan Isom, and Jared Butler as undergraduate students, for all their support with the trials and data collection. I would like to acknowledge the Utah Department of Agriculture and Food as well as the USU Extension Water Initiative for funding this project.

Collin Pound

CONTENTS

LIST OF TABLES

LIST OF FIGURES

CHAPTER 1

NITROGEN FERTILIZATION OF SMALL GRAINS AND SMALL GRAIN FORAGES IN THE FIRST-YEAR AFTER ALFAFLA: A REVIEW OF LITERATURE

1 INTRODUCTION

1.1 Corn vs. small grains

Drought conditions are common in Utah and much of the Intermountain West. Drought causes economic margins to tighten and increases the need for growers to optimize their inputs. Nitrogen fertilizer is one of the most expensive crop inputs in small grain production. It is an essential nutrient for most crops and often increases yield more than any other nutrient, and according to the United States Department of Agriculture (USDA) it accounts for an average of 25% of total operating costs. With N fertilizer prices and environmental concerns about N contamination rising, growers need to optimize their N use (Stopes, Millington, & Woodward, 1996).

In Utah, crop rotations are typically four to five years of alfalfa, followed by one to three years of corn and/or small grains. Alfalfa is the dominant crop in Utah in terms of area and gross sales, covering about 216,000 ha with an average value of $339 million USD each year (USDA-NASS, 2018). As an N-fixing legume, alfalfa typically does not require additional N fertilizer. When terminated, alfalfa residue decomposes and slowly supplies N back into the soil for subsequent crops. The amount of N that it supplies to following crops has been termed the ‘alfalfa N credit’. In many cases, this credit can be up to 336 kg N ha^{-1} for the two crops that follow alfalfa (Yost, Russelle, & Coulter, 2014;

Clark, 2014) and can benefit rotational crops for several years after alfalfa stand termination (Forster, D. A., 1998).

Recent water shortages in Utah and surrounding states have caused some growers to consider planting more small grains instead of corn to help stretch limited water supplies. These small grains will often consist of variations of one or more species including wheat, barley, triticale, and oats. Small grains typically require less applied irrigation water per year than corn, and depending on the soil type and weather conditions, the grower could see a reduction in water use per year by growing small grains instead of corn. In addition to water savings, many growers utilize the shorter growing season of small grains to more rapidly return back to alfalfa or other crops in the crop rotation.

1.2 Small Grain N Fertilization

Wheat accounts for approximately 71,000 ha of Utah farmland with an average value of $48 million USD each year (USDA-NASS, 2018). Current N recommendations for irrigated wheat production in Utah is to apply up to 212 kg N ha^{-1} (James & Topper, 2010) minus the available soil nitrate and 112 kg N ha^{-1} for following alfalfa. This recommendation does not consider the variation of localized characteristics and environments that are present throughout the Intermountain West, which may influence the alfalfa N credit. Grain corn accounts for an average of 31,000 ha with an average value of $22 million USD each year and has a higher recommendation of 246 kg N ha^{-1}, but also subtracting for available soil nitrate and 112 kg N ha^{-1} from the previous alfalfa.

Utah is ranked 11th for alfalfa production in the US, 9th for wheat, and 22nd for corn (USDA-NASS, 2018). However, with recent water shortages in Utah and surrounding states some growers have had to consider planting more small grains instead of corn to help stretch limited water supplies. Small grains typically require less applied irrigation water per year than corn, and depending on the soil type and weather conditions, growers may realize annual reductions in irrigation of up to 45% by growing small grains instead of corn (Hill, Miner, & Hinton, 2002). In addition to water savings, many growers utilize the shorter growing season of small grains to more rapidly return to alfalfa or other crops in the crop rotation.

A challenge growers face when relying on N released from decaying alfalfa is timing. This additional N may not be available until much later in the growing season (Ballesta & Lloveras, 2010; Orloff et al., 2012). Stute and Posner (1995) found that challenge in corn during a legume research project looking at the synchronization of N release and crop demand. That difference in N release time has shown to be between 45–168 kg N ha^{-1} depending on which part of the growing season it is, earlier in season or mis-season (Kelling et al., 2000). Timing may be different where small grains uptake more N earlier in the growing season than corn. Dogan and Bilgili (2010) found that the release of N from decaying alfalfa residue was slower to become available compared to applying additional N fertilizers. This slow rate of decay may increase the N fertilizer response because small grains have greater N uptake needs earlier in the season than corn, and may be greater than the alfalfa might be able to supply. For small grain N support for vegetative growth and kernel count establishment, N needs to be available

during the early growth stages, tillering up to boot stage. For protein content, N needs to be available in the heading to grain fill stages (Ballesta & Lloveras, 2010). The N release and uptake relationship may explain why corn may not need additional N fertilizer and small grains may need additional N fertilizer.

Research on N contribution of alfalfa to small grains is sparse compared to what is available for corn, especially in the United States. There are many studies that investigate the nitrogen requirements of small grains, but few that examine additional N fertilizer needs of small grains grown after alfalfa in the first year. A Canada study from 2004 to 2007 evaluated yield and protein response to increasing N rates following a 7-year-old alfalfa stand on a loam soil texture with a Gray Luvisol (Typic Cryoboralf) soil series. They tested additional fertilizer N rates of 0, 40, 80, and 120 kg N ha^{-1} and observed that yield and protein increased with increasing N rates in the first year following alfalfa after differing termination methods and times (Malhi, Lemke, & Schoenau, 2010). Meaning that the decomposing alfalfa was not able to supply adequate N to optimize yield and protein for the following wheat. In contrast to the results seen in Canada, a Wisconsin study in 2002, at three different experiment stations with different soil types, showed no benefits in winter wheat yield to additional fertilizer N, and that the previous alfalfa crop provided sufficient or excess N. They also reported that increased N rates above what was needed caused negative effects of decreased wheat yield and increase lodging (Kelling, Speth, Kilian, Wood, & Mlynarek, 2002). However, in agreeance with the Canada study, an additional study done in Turkey in 2010 had similar results, that the previous alfalfa crop provided all N needs for the wheat (Dogan &

Bilgili, 2010). This varied response shows the need for additional work, especially in the Intermountain West.

Along with a general look at N response, evaluating split N applications in the fall and spring is crucial to small grain management. Growers will follow this practice to help reduce N loss by making sure N is applied where it is needed and when it is needed (Kanwar, J. Baker, & D. Baker, 1988; Jones, 2017). A study in Wisconsin during 2001, found at three different sites that wheat following a three-year-old alfalfa stand did not show a benefit in yield with split N applications in the fall and spring when compared to singular spring N applications, totaling up to 90 kg N ha^{-1} (Kelling et al., 2002). In agreeance with the previous Wisconsin study, an additional Wisconsin study during 1997 to 1999, evaluated splitting N applications during the fall and spring after varying alfalfa termination methods. This study was at 3 different sites in the state on two different soil types, following three different alfalfa stand densities. They observed that there were no benefits to split applications following varying alfalfa termination methods when compared to applying only in the spring and in some cases a negative effect was observed due to increased lodging (Kelling, Speth, & Wook, 2000). Additional studies have also found similar results of decreased response (Huber, 1971; Alcoz, Hons, & Haby, 1993; Sowers, Pan, Miller, & Smith, 1994). Similar to the results observed from fall and spring split N applications in small grains, results were also observed for corn following alfalfa where split N applications at planting and as sidedress often decreased the economic optimum N rate (EONR) but rarely improved corn yield (Yost, Russelle, & Coulter, 2013). In contrast to the previous studies showing that no additional N fertilizer is

needed, research in Argentina in 1996 and 1997 showed that wheat had a positive yield response to additional N fertilizer while looking at the influence of varying nitrogen levels on wheat yield, yield components, and test weight (Simón, Perelló, Cordo, & Struik, 2002). This study had different environmental factors but shows discrepancies in the literature. Thus, additional work is needed to clarify and estimate how frequently small grains might need N fertilizer, especially in the varying environments of the Intermountain West.

Similar to a split fall and spring N applications a mid-season application from boot stage to as late as two weeks after flowering is a common practice for growers in Utah and Idaho, it is used to assist in achieving optimal small grain protein levels. This application varies depending on desired protein level, yield level, and the wheat cultivar, typically this application amount is up to 56 kg N ha^{-1} (Orloff et al. 2012). Previous studies on mid-season N applications have results. Bulman and Smith (1993) found in eastern Canada that additional N fertilizer (up to 200 kg N ha^{-1}) increased protein content in spring barley following alfalfa. Additionally, Gooding, Kettlewell, and Hocking (1991) observed similar benefits at four out of five experiments in wheat using only 15 kg N ha^{-1}, however, it was in a non-legume rotation. Doyle and Shapland (1991) noted the same increase even with applications up to 40 kg N ha^{-1} in a non-legume rotation. Small grains following alfalfa vs. other non-legume crops may respond differently to N timing. The addition of organic N from decaying alfalfa plants, enhanced mineralization, and increased soil N content which is common when following alfalfa and will likely influence optimal N timing and rates for small grains.

1.3 Small Grain Forage N Fertilization

There are many studies that investigate nitrogen requirements of small grains grown as a forage (Harmoney & Thompson, 2005; Khalil et al. 2011; Malhi, Berkenkamp, & McBeath, 2014), but few that examine small grain forages grown after alfalfa. A California study in 2013 and 2014 at three sites showed that nonfertilized wheat following alfalfa had increased aboveground biomass accumulation compared to wheat following sudangrass (*Sorghum drummondii*) fertilized with 56 to 168 kg N ha^{-1} (Lin et al., 2015). One site required no applied N to optimize wheat biomass following alfalfa in both years of the study, but the other two sites required N in both years. These results show significant but variable N credits of alfalfa to small grain forages. Thus, additional work is needed to estimate how frequently small grain forages might need N fertilizer when grown after alfalfa across environments in the Intermountain West, and whether these responses can be predicted reliably.

1.4 Predicting N Fertilizer Response

Reliable prediction of N fertilizer response in small grains is essential for aiding in the acceptance and use of alfalfa N credits. There may be a variety of ways to determine if whether small grains grown after alfalfa might need supplemental N fertilizer. Spring soil nitrate concentrations prior to planting or shortly after planting are sometimes used to guide N fertilizer applications to corn and wheat with high levels of accuracy (Fox, Roth, Iversen, & Piekielek, 1989; Blackmer, Pottker, Cerrato, & Webb, 2013; Kaiser et al., 2013). Soil nitrate in the spring has been termed the late spring soil nitrate test or the pre-sidedress soil nitrate test. These results have shown promise in

helping to separate N-responsive and non-N-responsive sites of corn following alfalfa (Lory, Russelle, & Peterson, 1995; Walker et al., 2017) and could likewise help identify N response in small grains following alfalfa in the Intermountain West area. An additional soil nitrate test is the interaction between spring soil nitrate levels and alfalfa stand age. Walker et al. (2017) observed 87% accuracy levels at separating N response from non-response in 1st year corn following alfalfa. There are no studies that we are aware of that use this prediction test in small grains grown in the Intermountain West, however, the same level of accuracy may also be observed.

An additional prediction tool that is available for growers is measuring the chlorophyll concentration in the top leaf of the small grains during the flag leaf to boot stages using an optical chlorophyll concentration meter. There are no studies that we are aware of that evaluate the predictability of N fertilizer response using leaf chlorophyll concentration in small grains grown after alfalfa. However, this method has been used in corn with great success (Wood, Reeves, Duffield, & Edmisten, 1992; Varinderpal-Singh et al. 2011). Furthermore, Piekielek and Fox (1992) found increased levels of accuracy in predicting N response using an optical chlorophyll concentration meter (Minolta SPAD-502 chlorophyll meter) and evaluating the data with a critical concentration line at 43.4 Minolta Special Products Analysis Division (SPAD) units. This same method may have the same accuracy in small grains grown after alfalfa

CHAPTER 2

NITROGEN FERTILIZER NEEDS OF FIRST-YEAR SMALL GRAINS FOLLOWING ALFALFA

1 MATERIALS AND METHODS

1.1 Site Characteristics

On-farm trials were established at 18 sites in Idaho, Utah, and Colorado. Eight trials were conducted in 2018 in the following Utah and Colorado counties; Cache, Box Elder, Beaver, Uintah, and Montezuma. Ten trials were conducted in 2019 in the following Idaho and Utah counties; Franklin, Cache, Box Elder, Weber, and Beaver (Table 2.1). Trials were established in the fall, usually in October, or the spring between March and May, depending on small grain planting date and weather conditions. Cooperating growers planted a single small grain cultivar of either wheat, barley, or triticale (Table 2.2). Pest management, irrigation, and all other agronomic operations besides N fertilization were managed by cooperating growers and consequently differed among but not within sites.

Management characteristics were recorded where possible. Irrigation types varied among sites; 56% were irrigated by wheel line, 28% by flood irrigation, and 17% by pivot irrigation (Table 2.1). Irrigation rates and methods within each site were constant. Alfalfa stand age at time of termination ranged from 2-11 years, with an average of six years. Alfalfa stand establishment occurred in the fall at 39% of the sites and in the spring at 61% of the sites. Termination methods for the alfalfa stand varied between herbicide and/or tillage, but was constant within each site. Alfalfa stands were terminated in the fall

or spring at 83% and 17% of the sites, respectively (Table 2.4). Small grain planting occurred in the fall at 83% of the sites and in the spring at 17% of the sites according to weather and other grower-specific operational needs (Table 2.2).

Weeds and volunteer alfalfa were adequately controlled all small grain site-years. Cooperating growers terminated volunteer alfalfa at 13 site-years. At five of the site-years (Cache 4-7) where it was not possible for the grower to terminate volunteer alfalfa and weeds, 2, 4-dichlorophenoxyacetic acid (2, 4-D) and 3, 6-dichloro-*o*-anisic acid (Dicamba) were applied at 191 and 48 ml a.i. ha^{-1}, respectively, using a CO_2 pressurized backpack sprayer with a 3 m hand-held boom in May 2019.

Soil classification and textural group data were obtained from the University of California-Davis SoilWeb (casoilresource.lawr.ucdavis.edu/gmap/) (Table 2.1). Soil chemical data (pH, organic matter, P and K concentrations) were measured from composite soil samples taken from each replication from each site. An average of the four composite samples from each site were taken and reported for each soil data indicator (Table 2.1). Composite samples consisted of 10 cores each (15 cm deep × 1.9 cm i.d.). The samples were analyzed at the Environmental Analytical Lab at Brigham Young University in Provo, UT. Soil pH was determined on a saturated paste (Rhodes, J.D. 1982), organic matter by Walkley-Black dichromate oxidation (Walkley & Black, 1934), P concentrations by extraction with 0.5 M sodium bicarbonate (Olsen, Cole, Watanabe, & Dean, 1954), and K concentrations by extraction with 0.5 M sodium bicarbonate and analyzed by an AAnalyst 200 machine (PerkinElmer, Waltham, MA; Schoenau & Karamonos, 1993). If P or K deficiencies were detected [according to Utah State

University Extension fertilizer guidelines for small grains (Cardon, Kotuby-Amacher, Hole, & Koenig, 2008)], potash and/or triple superphosphate were surface-broadcasted by hand at recommended rates. Daily cumulative precipitation and average air temperatures (Figures 2.11-2.12; 2.21-2.22) were obtained from the nearest National Weather Station through the Utah Climate Center Database (https://climate.usu.edu).

1.2 Nitrogen Treatments

Nitrogen fertilizer treatments were arranged in a randomized complete block design at each site. Four replications of all N rates were applied in plots measuring 3 × 9 m each. Nitrogen fertilizer was surface-broadcast as granular NH_4NO_3. This source was chosen due to its decreased risk of volatilization due to it not being incorporated. Fertilizer was either applied by hand spreading a pre-measured amount or by a calibrated 1.5 m Gandy Drop Spreader (Gandy, Owatonna, MN) towed behind an ATV. Spring N rates of 0, 34, 67, 101, 134, and 168 kg N ha^{-1} were applied on all sites between March to June depending on planting timing and weather conditions. At 10 sites (Cache 2-7, Box Elder 4-5, Weber, and Beaver 2) fall rates of 0 and 34 kg N ha^{-1} were applied in October within 1 to 3 weeks after small grain planting to test split applications. At 12 sites (Cache 2-7, Box Elder 3-5, Beaver 1-2, and Weber) a mid-season (May) N application of 67 kg N ha^{-1} was applied on non-fertilized plots to examine the benefits of a late rescue application during the flag leaf to boot stages.

1.3 Prediction Tools

Prior to spring N fertilization and in the non-fertilized treatment, an additional set of soil samples (30 cm deep × 1.9 cm i.d.) were collected to measure NO_3^- concentration

(Table 2.1) (Holford & Doyle, 1992) at 17 site-years. A single composite sample consisting of 10 cores was collected and analyzed for each replicate at each site, then the four replicates were averaged to obtain a single value per site. Soil nitrate concentration was measured by chromotropic acid analysis (Sims & Jackson, 1971) at the Environmental Analytical Lab at Brigham Young University to determine if it could be used as a reliable indicator of N fertilizer need using the same critical nitrate concentration of 21 mg kg^{-1} that is commonly used for corn (Andraski & Bundy, 2002; Blackmer et al., 2013; Rehm et al., 2013).

Leaf chlorophyll concentration was measured at 10 site-years to help determine if it could be used as a reliable indicator of additional mid-season N fertilizer need. Measurements were taken using an optical Apogee MC-100 chlorophyll concentration meter (Apogee Instruments Inc., Logan, UT) from non-N-fertilized plots. Measurements were taken during the flag leaf to boot stages using the average of 20 readings per plot collected from the flag leaf or highest leaf. Data were analyzed using a critical concentration level of 43.4 SPAD units (Piekielek & Fox, 1992) to evaluate the separation of N-responsive (below 43.4 SPAD units) and non-N-responsive sites (above 43.4 SPAD units).

1.4 Harvest and Sample Analysis

Small grains were harvested within a week before or after when cooperating growers harvested their fields. This occurred normally in July and August for at each site-year except for Montezuma which was harvested in late October. Difficult field conditions and grower needs delayed harvest at that site (Table 2.4). Sites in 2018 were

harvested using an Almaco PMC-10 plot harvester (Specialized Agricultural Equipment, Nevada, IA) to harvest a 1.5 m × 7.6 m strip centered in each plot. Sites in 2019 were harvested using a Massey Ferguson Model 8 plot combine harvester (Massey Ferguson, Duluth, GA) to cut a 2 m × 7.6 m strip in the center of each plot. Harvest equipment varied year to year based on availability, but equipment did not vary within a site. Harvested areas were centered within each plot to eliminate border effects. Harvested grain from each plot was weighed in the field using an Inficon Wey-TEK Refrigerant Charging scale (Inficon, Santa Clara, CA). Representative subsamples (approximately 1-2 kg) were collected and weighed in the field, dried at 60℃ until mass was constant, then weighed again to determine dry matter yield.

Dried samples were analyzed for test weight (2019 sites) and protein content (18 site-years). Test weight was determined by using a Cox Funnel that overflowed into a 1 US quart cup, then the excess grain was cleaned off the top using a Strike Off Stick (Seedburo Equipment Company, Des Plaines, IL). The remaining grain in the cup was weighed and converted to test weight values (kg hl^{-1}). Protein content was determined by grinding the dried samples through a 1 mm sieve using a Thomas-Wiley Laboratory Mill Model 4 (Thomas Scientific, Swedesboro, NJ) and analyzed for protein content (g kg^{-1}) with a Foss NIRS DS2500 F feed analyzer (FOSS North America Inc., Eden Prairie, MN) at the Utah State University Analytical Lab.

1.5 Statistical Analysis

The data were analyzed at $P \leq 0.05$ using the MIXED procedure of SAS (SAS Institute, 2016) (Table 2.5). The three dependent variables were grain yield, test weight,

and protein. Site, N rate, and their interaction were considered fixed effects, whereas replicate (nested within site), and interactions involving replicate were considered random effects. The UNIVARIATE procedure of SAS was used to inspect the residuals for normality, and scatterplots of the residuals vs. predicted values were used to assess common variance. In all three analyses, the site × N rate interaction was significant (Table 2.5). Therefore, the influence of N rate was evaluated at each site. When N rate significantly influenced yield and quality indicators, regression analysis was used to describe the response of the dependent variables to fertilizer N. Several regression models were evaluated and the model that was significant at $P \leq 0.05$ and produced the smallest residuals that were normally and randomly distributed was selected (Kutner, Nachtsheim, & Neter, 2004). Linear and quadratic regression equations were developed using the MIXED procedure of SAS, and nonlinear regression equations were developed using the NLIN procedure of SAS (Tables 2.6 and 2.7). When regression models did not fit the data, Fisher's protected LSD test ($P \leq 0.05$) was used for mean comparisons utilizing the PDIFF procedure of SAS.

2 RESULTS AND DISCUSSION

2.1 Weather

Cumulative precipitation during the small grain growing season (1 Oct to 31 Aug) ranged from 94 to 534 mm across sites (Figure 2.11). Weber had the most cumulative precipitation and Uintah 1 had the least, with an average across all sites of 323 mm. When each site-year was compared to its respective 30-year normal values, there were differences in the deviations from the normal between years. Sites in 2019 (Franklin,

Cache 3-7, Box Elder 4-5, Weber, and Beaver 2) had cumulative precipitation values above their 30-year normal values, while sites in 2018 (Cache 1-2, Box Elder 1-3, Beaver 1, Uintah 1, and Montezuma) had cumulative precipitation values below their 30-year normal (Figure 2.12). The Box Elder 4 and 5 sites had the greatest deviation above their 30-year normal and Montezuma had the greatest deviation below their 30-year normal.

In contrast to precipitation differences among site-years, average daily air temperatures were relatively consistent among site-years (Figure 2.21). Temperatures ranged from -16 to 30 ℃ among all sites throughout the growing season. Air temperature deviations from the 30-year normal were common among sites and ranged from -14 to 14 ℃ (Figure 2.22).

2.2 Grain Yield

Grain yield was influenced by the two-way interaction of site-year × N. Thus, the response to N was examined for each site-year. Fall and spring split N fertilizer applications, and the mid-season application did not increase yield. At the nine site-years where split N applications were tested, all but one split treatment lacked statistical difference when compared to their equal applications in the spring, a singular fall application of 34 kg N ha^{-1}, where there were negative impacts on yield levels.

Spring N applications were applied to all 18 site-years. Maximum grain yield ranged widely from 1.98 Mg ha^{-1} to 11.34 Mg ha^{-1} across site-years (Table 2.4) with an average of 8.14 Mg ha^{-1}. This was mainly due to differences in cultivar selection, environment, and management practices of cooperating growers. The interaction between site and N rate was significant, signifying that the response to fertilizer N differed among

sites. Grain yield was influenced by spring N rates at 10 site-years (56%) (Figure 2.31). Responsive site-years had agronomically optimum N rates that ranged from 94 to 168 kg N ha^{-1}, which resulted in maximum yield levels that ranged from 7.43 to 11.34 Mg ha^{-1}, with an average of 9.71 Mg ha^{-1}. The ENOR for each responsive site was also calculated using \$0.25 USD kg^{-1} N and an estimated market value of \$40 USD Mg^{-1} for small grains. EONR values for responsive sites ranged from 83 to 168 kg N ha^{-1}, with an average of 115 kg N ha^{-1} (Figure 2.31). Grain yield increases from the non-fertilized control to the EONR ranged from 12% (Beaver 1) to 54% (Franklin), with an average increase of 31%. The eight non-responsive site-years had maximum yield levels that ranged from 1.98 to 9.54 Mg ha^{-1} with an average of 6.18 Mg ha^{-1}. The need for additional N fertilizer to optimize yield suggests that the release of N from the soil and decaying alfalfa was not adequate or rapid enough (Dogan & Bilgili, 2010) for first-year small grains. Although N response in first-year small grains was much more common than first-year corn in Utah (Clark, 2014; Creech, Yost, Cardon, Ransom, & Clark, 2020), no N response was observed in nearly one-half of the site-years. The lack of N response occurred across site-years with a range of irrigation, crop, and soil managements (Tables 2.1, 2.2, and 2.3), which indicates that alfalfa can often provide all the N needed to optimize yield of first-year small grains.

At all 12 site-years where a late N application was made near the flag leaf stage, 67 kg ha^{-1} did not increase yields. In nine site-years there were no statistical differences for delaying N application compared to applying the same amount in the spring and in three site-years yields were negatively impacted after delayed application. Thus, when

additional N is required for optimal small grain yield levels, it is recommended to apply all additional N fertilizer in the spring.

Site-year characteristics (Tables 2.1, 2.2, and 2.3) were not able to separate response from non-response. Responsive site-years were established across varying environments, including a wide range of alfalfa stand ages, suggesting that alfalfa stand age did not influence N fertilizer need. Furthermore, maximum yield levels overlapped between responsive (average of 11.1 Mg ha^{-1}, range of 8.8 to 12.5 Mg ha^{-1}) and non-responsive sites (average of 7.2 Mg ha^{-1}, range of 3.2 to 11.1 Mg ha^{-1}), which also suggested that yield did not influence N fertilizer need. Cumulative precipitation may have had an influence on response and non-response as water stress can reduce yield levels, increase N loss, and increase N fertilizer need (Saint Pierre et al., 2008). The 2019 growing season had more precipitation before the first irrigation (1 Oct to 15 Apr) at 310 mm, compared to 2018, which had 147 mm. Most responsive site-years (9 of 10) occurred in 2019 while most non-responsive site-years (7 of 8) occurred in 2018. This suggests that cumulative precipitation before the first irrigation may influence N fertilizer need, and that growers may only need to apply N in years with normal or above-normal precipitation. Even though alfalfa age at termination did not influence response to additional N fertilizer, it is suspected that overall timing of release of N from the soil and decaying alfalfa was a factor that may have influenced response to added N fertilizer. All other recorded site-specific factors could not separate response from non-response.

Soil nitrate levels ranged from 5 to 42 mg kg^{-1} among the 17 site-years where it was measured (excluding the Cache 5 site), with an average of 15 mg kg^{-1}. Based on the

same critical concentration of 21 mg kg^{-1} that is often used in corn (Andraski & Bundy, 2002; Blackmer et al., 2013; Rehm et al., 2013), soil nitrate levels were able to separate grain yield agronomic response from non-response in 53% of cases (Figure 2.32). There was considerable overlap between soil nitrate levels at responsive site-years (range of 5 to 30 mg kg^{-1}, average of 12 mg kg^{-1}) and non-responsive site-years (range of 9 to 41 mg kg^{-1}, average of 18 mg kg^{-1}). Responsive site-years had a lower average soil nitrate level, most were under 12 mg kg^{-1}, and were often correctly classified as responsive (78% of 10 site-years) suggesting that soil nitrate levels may be a reliable prediction tool for grain yield. The accuracy of soil nitrate for first-year small grains after alfalfa was lower than previous reports for wheat in other rotations (Blackmer et al. 2013) or first- or second-year corn following alfalfa (Walker et al., 2017). It is unclear why spring soil nitrate levels did not hold the same high level of accuracy in small grain forages grown after alfalfa, but may have been influenced by slow release of N from the decaying alfalfa, and the earlier uptake and use of N (prior to July) in small grains compared to corn. Thus, spring soil nitrate levels may not be a reliable method to predict small grain yield response to additional N fertilizer. However, when taking stand age into account, along with soil nitrate levels, by multiplying soil nitrate levels by stand age, the accuracy increases significantly. The new indicator was able to separate yield response from non-response in 88% of cases. Meaning, that the two indicators together may be a highly effective predicting tool for knowing when additional N fertilizer is needed.

Leaf chlorophyll concentrations measured in meter units [Minolta Special Products Analysis Division (SPAD) units] ranged from 29 to 50 SPAD units across 12

site-years where measured, with an average of 39 SPAD units. Based on the critical concentration level of 43.4 SPAD units (Piekielek & Fox, 1992), leaf chlorophyll concentrations were able to separate grain yield mid-season application response from non-response in only 17% of cases. All site-years that were evaluated did not respond to a mid-season N application, showing that yield is not influenced by additional N fertilizer mid-season. Indicating that a predictive tool for mid-season yield response is not necessary.

First-year small grains did require additional N fertilizer to economically optimize yield levels in about half (56%) of the cases. Responsive site-years often had higher than average precipitation before the first irrigation and soil nitrate levels less than 21 mg kg^{-1}. If these conditions are met, growers may consider applying up to 115 kg N ha^{-1} in the spring, which could result in yield increases of up to 31%. Otherwise, growers should be able to withhold additional N fertilizer without sacrificing grain yield and save up to $130 USD ha^{-1}.

2.3 Grain Quality: Test Weight

Maximum test weight across all sites in 2019 ranged from 77.4 to 86.9 kg hl^{-1}, with an average of 80.6 kg hl^{-1}. According to the United States Department of Agriculture (USDA), ideal test weight for Grade #1 wheat is 79.7 kg hl^{-1}. Fall and spring split applications benefited test weight at 60% of the 10 sites where it was measured (Figure 2.41). Response occurred when the total N application was at or above 134 kg N ha^{-1} (34 kg N ha^{-1} in the fall and 101 or 134 kg N ha^{-1} in the spring), which resulted in an average 1.12% increase in test weight compared to 134 and 168 kg N ha^{-1}, respectively. Other

small grain studies where wheat was grown after non-legume crops had opposite test weight results. For example, a winter wheat study in Ontario during 2010 to 2013 found that split N applications (34 kg N ha^{-1} in the fall, then 0, 67, 101, 134 or 168 kg N ha^{-1} in the spring) had no significant impact on test weight (Johnson & McClure, 2015), and another study in Kentucky also showed that split application had no positive implications on wheat test weight (Knott, Ritchey, & Murdock, 2015).

Six of the 10 sites that were evaluated for test weight responded to spring N application rates. Sites with a test weight response had agronomically optimum nitrogen rates that ranged from 59 to 168 kg N ha^{-1}, with an average of 108 kg N ha^{-1}. When compared to non-fertilized controls these sites had an average increase in test weight of 1.3% increase (0.4% to 2.2%). At the four sites (Cache 5, Cache 6, and Box Elder 5) where N rate had no influence on test weight, maximum test weights averaged 79.3 kg ha^{-1} (77.4-80.4 kg ha^{-1}). The frequency of test weight response to N in the present study was greater than other studies in literature. Simón et al. (2002) observed much less test weight response. Three of 20 site-years with additional N fertilizer of 100 kg N ha^{-1} saw positive effects, 4 site-years saw negative effects, and thirteen site-years saw no statistical difference. Additionally, Jackson and Engel (2006) observed in Montana that wheat test weight also decreased with increasing N application rates across all site-years. However, in Turkey, a study observed in triticale that grain test weight increased with N fertilizer applications up to 180 kg N ha^{-1} (Mut, Sezer, & Gulumser, 2005). Thus, the mixed influence of N fertilizer on test weight in the present study does not exactly coincide with

previous reports. Results also indicate that alfalfa can sometimes provide all the N required to maximize first-year small grain test weight.

Applying 67 kg N ha^{-1} mid-season increased test weight at 67% of the sites by 1.57%, when compared to applying the same amount in the spring, lacked effect at three sites and had a negative effect at one site. However, the maximum test weight from the mid-season application (80.45 kg ha^{1}) did not exceed the levels achieved by singular spring applications (81.45 kg ha^{-1}), meaning that spring N treatments were the most beneficial for test weight levels.

The synchrony between N fertilizer application and small grain N uptake may have influenced test weight responses. For vegetative growth and kernel count establishment, early N uptake is more critical, while for grain fill (test weight establishment), mid-season (starting at flag leaf stage and after) is more critical (Ballesta & Lloveras, 2010). Thus, split and spring only applications would be most beneficial for yield levels while the mid-season application may be most beneficial for quality. This may explain why the mid-season application had the greater benefit to test weight than yield.

Most site characteristics varied between sites with and without test weight responses and were generally not able to distinguish responsive from non-responsive sites, although there were a few that may help explain the differences in response. Small grain species had a notable variation between responsive and non-responsive sites. All sites with a test weight response were soft white wheat (SWW) seeded in the fall. There were non-responsive sites that had SWW, but none of the sites that had barley or triticale

showed test weight responses. This may hint that some small grain species have a greater likelihood of responding to additional N than others, but would need to be directly tested within site-years.

Soil nitrate levels were able to separate test weight response from non-response in 78% of the 9 site-years it was measured at, correctly predicting all responsive sites (Figure 2.42). Responsive sites had soil nitrate levels that ranged from 5 to 13 mg kg^{-1}, with an average of 9 mg kg^{-1}. There was slight overlap in soil nitrate levels with non-responsive sites, which ranged from 6 to 41 mg kg^{-1}, with an average of 18 mg kg^{-1}. Thus, soil nitrate levels in the spring may assist in predicting small grain test weight response to additional N fertilizer, but needs further research to understand how precipitation before the first irrigation other factors might influence critical soil nitrate levels.

Similar to the soil nitrate test, leaf chlorophyll concentration levels in the non-fertilized control plots were able to separate test weight response from non-response in 60% of the sites, using the critical concentration of 43.4 SPAD units (Piekielek & Fox, 1992). Unlike the grain yield results, leaf chlorophyll concentration levels were not able to closely predict all sites with a test weight response to N. This method may still be a reliable prediction tool with further research. There are no studies that we are aware of that evaluate the accuracy of using leaf chlorophyll concentration or soil nitrate to guide N fertilizer needs for small grain test weight.

Nitrogen fertilizer application often increased the test weight of first-year small grains, and this response could be predicted in about 60% of the cases with soil nitrate or

leaf chlorophyll concentration. Despite these advantages of N fertilization, application of additional N fertilizer should only be applied when an economic benefit is present. Non-fertilized controls had average test weights of 78.7 kg ha^{1}, which is only 0.2 kg ha^{-1} below ideal test weights according to the USDA. Most current markets in the Intermountain West and many other places do not incentivize test weight. If incentives exist, growers may benefit from applying additional N fertilizer, further work would need to be done to understand how much would economically optimize small grain test weight.

2.4 Grain Quality: Protein

Maximum protein levels for all 18 site-years ranged from 119 to 220 g kg^{-1}, with an average of 146 g kg^{-1}. Small grain protein was not influenced by the two-way interaction of site-year × N, thus, protein response to N was averaged across all site-years. Split N applications (fall and spring) at the same total rates as single spring applications did not enhance protein levels at all site-years where it was tested. In all treatments there was a negative effect for splitting N applications compared to singular spring applications. The rate of decrease ranged from 3.6 to 6.7%, with an average decrease in protein of 5.6%. This response agrees with what Brown and Petrie (2006) observed in non-legume rotation of wheat. They observed a decrease in protein of up to 13 g kg^{-1} in all cases when N treatments were split between fall and spring, compared to the same amount only in the spring. Johnson and McClure (2015) also observed similar results, that split N applications did not significantly benefit small grain protein.

In contrast, a mid-season application of 67 kg N ha^{-1} influenced small grain protein by the two-way interaction of site-year × N. Thus, the interaction was examined

for each site-year. Five of 12 site-years where mid applications were tested showed an average of 14% (10-18%) increase in g kg^{-1} protein when compared to the applying 67 kg N ha^{-1} in the spring, however, only two of those sites had protein levels higher than their respective maximum protein level from singular spring N applications, and seven of 12 site-years showed no significant response. Brown and Petrie (2006) studied the effects of a late season N application and its effects on protein levels in wheat in a non-legume rotation. They observed that a late season N application was essential to optimal protein levels when also applied after a spring N application. However, they did not evaluate the influence of the late season N application alone. Shapiro and Bavougian (2017) observed that N applied mid-season to wheat following alfalfa did not influence protein levels. The previous alfalfa crop supplied all the N required to optimize wheat protein levels. Thus, results from the current study follow what has also been observed in these two studies.

The interaction between site-year and spring N rates was highly significant, signifying that the response to fertilizer N differed among sites. Spring N rates influenced small grain protein levels at nearly all site-years (15 of 18) (Figure 2.51). Agronomically optimum N rates for protein at these 15 site-years ranged from 100 to 168 kg N ha^{-1}, with an average of 148 kg N ha^{-1}. These N rates increased protein by an average of 21% (11-31%) compared to the non-fertilized control. Site characteristics (field, small grain, and alfalfa) varied among the 15 responsive and 3 non-responsive site-years (Tables 2.1, 2.2, and 2.3), with no clear variable that distinguished responsiveness. This high level of small grain protein response to spring N fertilization coincides with several previous studies of small grains in other crop rotations. A study in Nebraska observed protein

response in all site-years for two different varieties of wheat with spring N fertilizer applications of up to 135 kg N ha^{-1}, however, this was a non-legume rotation (Johnson, Dreier, & Grabouski, 1973). Additionally, Brown and Petrie (2006) observed this same high level of wheat protein response to spring N applications up to 168 kg N ha^{-1}. Thus, results from this study correlate well with what has been shown in literature.

Ideal protein levels and economic benefits vary depending on small grain species and varieties, average protein levels between 100 to 140 g kg^{-1} are acceptable. Likewise, not all small grain species and varieties have economic benefits for elevated protein. Most site-years in this study were soft white wheat, which has a common protein range of 95 to 110 g kg^{-1} and has no economic benefit for increased protein. Furthermore, protein levels in soft white wheat above 110 g kg^{-1} are generally accepted at most grain elevators without a discount. Protein levels in hard red spring wheats (one of 18 site-years in present study) are more critical than soft white wheats, and have an economic benefit. If incentives do exist for increased protein, EONR's that incorporate yield and protein could be calculated, the one site-year of hard red wheat in this study did not respond to additional N fertilizer.

Soil nitrate levels, using the critical concentration of 21 mg kg^{-1} (Andraski & Bundy, 2002; Blackmer et al., 2013; Rehm et al., 2013), were able to separate protein response from non-response in 82% of the 17 site-years where nitrate was measured (Figure 2.52). Responsive site-years had soil nitrate levels that ranged from 5 to 23 mg kg^{-1}, with an average of 12 mg kg^{-1}. The three site-years with no protein response (Uintah 1, Montezuma, and Beaver 1) had soil nitrate levels of 41, 16, and 30 mg kg^{-1},

respectively. Thus, only one of these three (Montezuma) had low soil nitrate and a false negative result indicating that soil nitrate levels were a highly effective tool for predicting if additional N fertilizer was needed to agronomically optimize small grain protein levels. These results correlate well with current literature for small grains, Jackson (1998) observed high correlation between soil nitrate levels and protein response to increased levels of N fertilizer. This observation was made across all 34 site-years in a non-legume rotation. Abad, Michelena, and Lloveras (2005) agree with what was observed in this study and in the previously sited study, that soil nitrate levels can be a good indicator of N fertilizer need for optimal small grain protein levels, they observed that across 4 site-years in a Mediterranean climate in a non-legume rotation. Thus, the same results were observed in a legume rotation shown in this study.

Leaf chlorophyll concentrations, using a critical concentration of 43.4 SPAD units, were able to separate protein response from non-response from a mid-season application of 67 kg N ha^{-1} in 58% of 12 site-years where measurements were taken. Unlike the soil nitrate test, leaf chlorophyll concentrations weren’t as effective in predicting N response for agronomically optimum protein in small grains. Responsive site-years had leaf chlorophyll concentrations that ranged from 29 to 43 SPAD units, with an average of 39 SPAD units. Non-responsive site-years (Uintah 1, Montezuma, and Beaver 1) had leaf chlorophyll concentrations of 29 to 50 SPAD units, with an average of 39 SPAD units. There was considerable overlap for SPAD units measured in responsive site-years and non-responsive site-years. Thus, leaf chlorophyll concentrations were not an effective prediction tool for knowing if mid-season N fertilizer was needed to

agronomically optimize small grain protein levels. There are no studies that we are aware of that evaluate using leaf chlorophyll concentrations to predict small grain protein response to mid-season N applications. These results will help fill in the gap in literature.

Applying N fertilizer in first-year small grains after alfalfa to optimize protein should only occur when there is an economic benefit to enhanced protein. If incentives exist, growers may consider applying up to 148 kg N ha^{-1} in the spring if spring soil nitrate is below 21 mg kg^{-1}, the singular mid-season application that was tested in this study did not show higher protein levels in most site-years.

3 CONCLUSION

Small grains grown in the first-year after alfalfa required additional N fertilizer at ten site-years (56%). Thus, growers can often withhold additional N fertilizer for first-year small grains grown for grain and save up to $130 USD ha^{-1}. Yield responsive site-years required an average of 115 kg N ha^{-1} (83-168 kg N ha^{-1}) to economically optimize yield and had alfalfa of various ages, irrigated by various methods (pivot, wheel line, and flood), terminated in various ways (herbicide and/or tillage) in the fall or spring. Soil nitrate and leaf chlorophyll concentrations predicted yield responsiveness to spring N and mid-season N in 53% and 17% of 17 and 12 site-years where measured, respectively, indicating that spring soil nitrate levels aid in prediction and leaf chlorophyll concentrations do not. However, greater accuracy is needed. In contrast to yield, N fertilizer (average of 148 kg N ha^{-1}) was almost always (94% of 18 site-years) needed to optimize small grain protein content and N fertilizer (67 kg N ha^{-1} mid-season) was needed to achieve optimal small grain test weight. However, small grains used in this

study had few economic benefits for enhanced protein or test weight. If economic incentives do exist, soil nitrate and leaf chlorophyll concentration tests were able to predict test weight response in 82% and 67% of the site-years, and for protein, 82% and 58%, respectively. Soil nitrate levels were highly accurate in prediction small grain test weight and protein response for spring N applications. This suggests that both tests may have merit in this rotation, but that spring soil nitrate levels may take precedence because the value of small grain is more heavily influenced by yield and protein levels in most markets. Based on these results, growers may often withhold N to first-year small grains following alfalfa, but should utilize soil nitrate levels to guide N applications. Nitrogen should frequently be applied to first-year small grains if incentives for grain quality outweigh the cost of fertilizer.

TABLE 2.1 Site and soil characteristics for 18 on-farm sites in Idaho, Utah, and Colorado during 2018 to 2019 including year, site (coordinates), dominant soil series, soil pH, soil OM, soil P, soil K, soil nitrate, and irrigation type.

Site (Coordinates)	Soil Texture (Classification)	Soil pH	Soil OM	Soil P	Soil K	Soil Nitrate	Irrigation Type[a]
			g kg^{-1}	mg kg^{-1}	mg kg^{-1}	mg kg^{-1}	
Cache 1 (41.975782, -111.959664)	Fine sandy loam (Coarse-loamy, mixed, superactive, mesic Aquic Calcixerolls)	7.83	16.5	13.38	115.5	22.8	WL
Cache 2 (41.667158, -111.879846)	Silty clay loam (Fine, mixed, active, mesic Aquic Argixerolls)	7.35	28.5	60.9	497.25	12.7	P
Box Elder 1 (41.836516, -112.162482)	Loam (Fine-silty, mixed, superactive, mesic Calcic Argixerolls)	7.28	33.5	26.15	638.25	8.5	WL
Box Elder 2 (41.535951, -112.160242)	Fine sandy loam (Coarse-loamy, mixed, superactive, mesic Aquic Calcixerolls)	7.43	14.3	51.05	239	16.75	F
Box Elder 3 (41.533759, -112.068273)	Silt loam (Fine, mixed, active, mesic Typic Natrixeralfs)	7.63	17.5	12.3	269.5	14.03	F
Beaver 1 (38.363812, -112.999886)	Loam (Fine-loamy, mixed, superactive, mesic Xeric Haplocalcids)	7.58	33.3	22.13	149.75	30.15	P
Uintah 1 (40.460008, -109.564287)	Clay loam (Fine-loam, mixed, superactive, calcareous, mesic Oxyaquic Torriorthents)	7.58	22.8	12.85	50	41.43	WL
Montezuma (37.574332, -108.790233)	Loam (Fine-silty, mixed, superactive, mesic Calcidic Haplustalfs)	6.8	22.8	8.1	62	15.8	WL
Franklin (42.035589, -111.877442)	Silty clay loam (Fine, mixed, active, mesic Vertic Argixerolls)	7.94	44.7	111.27	758.32	23	WL
Cache 3 (41.990865, -111.956010)	Loamy fine sand (Mixed, mesic Psammentic Haploxerolls)	7.33	8.4	16.62	47.04	5.09	WL
Cache 4 (41.990899, -111.956921)	Loamy fine sand (Mixed, mesic Psammentic Haploxerolls)	7.37	9.4	15.1	53.52	6.3	WL
Cache 5 (41.990425, -111.958711)	Loamy fine sand (Mixed, mesic Psammentic Haploxerolls)	7.32	11.2	17.6	84.32	.	WL

Cache 6 (41.993380, -111.968582)	Silt loam (Fine-silty, mixed, superactive, mesic Calcic Pachic Argixerolls)	7.69	26.5	14.45	627.12	8.54	WL
Cache 7 (41.990526, -111.969036)	Silt loam (Fine-silty, mixed, superactive, mesic Calcic Pachic Argixerolls)	7.79	27.6	19.93	834.48	11.72	WL
Box Elder 4 (41.574117, -112.082475)	Fine sandy loam (Coarse-loamy, missed, superactive, mesic Aquic Calcixerolls)	7.78	11.7	6.41	28.32	8.24	F
Box Elder 5 (41.571613, -112.085249)	Silty clay loam (Fine, mixed, active, mesic Typic Calcixerolls)	7.52	23.5	9.21	134.48	7.22	F
Weber (41.203926, -112.066591)	Fine sandy loam (Fine-loamy, mixed, active, mesic Oxyaquic Calcixerolls)	7.73	18	18.56	53.2	5.66	F
Beaver 2 (38.342790, -113. 004612)	Silty clay loam (Fine-silty, mixed, superactive, mesic Cumulic Haploxerolls)	7.8	37.1	25.53	350.96	12.53	P

[a] WL, wheel line; P, pivot; F, flood.

TABLE 2.2 Small grain characteristics and N fertilizer application for 18 on-farm sites in Idaho, Utah, and Colorado during 2018 to 2019 including year, site, small grain species (varieties), seeding date, seeding rate, fall N fertilization date, and spring N fertilization date.

Year	**Site**	**Small grain species (varieties)[a]**	**Seeding date[b]**	**Seeding rate**	**Fall N fertilization date**	**Spring N fertilization date**
				kg ha^{-1}		
2018	Cache 1	Soft White Wheat (Ovation)	30 Sep 2017	149	n/a	4 Apr
	Cache 2	Barley (USU10201)	29 Sep 2017	111	18 Oct 2017	25 Apr
	Box Elder 1	Barley	Fall 2017	112	n/a	29 Mar
	Box Elder 2	Soft White Wheat	Fall 2017	146	n/a	13 Mar
	Box Elder 3	Triticale (Seed 141)	Fall 2017	112	n/a	13 Mar
	Beaver 1	Soft White Wheat (Westbred 470)	26 Sep 2017	112	n/a	20 Mar
	Uintah 1	Barley (Goldeneye)	20 Apr 2018	112	n/a	24 Apr
	Montezuma	Hard Red Spring Wheat (Jefferson)	Spring 2018	101	n/a	5 Jun
2019	Franklin	Hard White Wheat (Westbred 7589)	6 May 2019	149	n/a	3 Jun
	Cache 3	Soft White Wheat (Ovation)	28 Sep 2018	134	16 Oct 2018	30 Apr
	Cache 4	Soft White Wheat (Ovation)	28 Sep 2018	134	16 Oct 2018	30 Apr
	Cache 5	Soft White Wheat (Ovation)	28 Sep 2018	134	16 Oct 2018	30 Apr
	Cache 6	Soft White Wheat (Ovation)	29 Sep 2018	134	16 Oct 2018	1 May
	Cache 7	Soft White Wheat (Ovation)	29 Sep 2018	134	26 Oct 2018	1 May
	Box Elder 4	Soft White Wheat (Rosalyn)	20 Oct 2018	140	22 Oct 2018	2 May
	Box Elder 5	Soft White Wheat (Rosalyn)	20 Oct 2019	140	22 Oct 2018	2 May
	Weber	Soft White Wheat (Westbred 529)	27 Sep 2018	146	26 Oct 2018	9 May
	Beaver 2	Soft White Wheat (Westbred 470)	16 Oct 2018	134	Oct 18 2018	April 4

[a] Varieties and their respective varieties are listed where possible.
[b] If exact date was not known, a season and/or a year was provided.

TABLE 2.3 Alfalfa characteristics at 18 on-farm sites in Idaho, Utah, and Colorado during 2018-2019 including year, sites, seeding date, termination date, stand age, terminating type, and stand condition.

Year	Site	Seeding date[a]	Termination date[a]	Stand age[b]	Termination type[c]	Stand condition[d]
				years		
2018	Cache 1	Spring 2013	Fall 2017	5	H	Poor
	Cache 2	Spring 2012	Fall 2017	6	H	Poor
	Box Elder 1	Spring 2010	Fall 2017	8	H	Fair
	Box Elder 2	Spring 2014	Fall 2017	4	TH	Good
	Box Elder 3	2008	Fall 2017	10	TH	Poor
	Beaver 1	3 Jun 2009	1 Sep 2017	8	TH	Good
	Uintah 1	Spring 2016	Mar 2018	2	T	Good
	Montezuma	2009	Fall 2017	9	TH	Poor
2019	Franklin	Spring 2012	29 Sep 2018	7	H	Poor
	Cache 3	Sep 2012	Sep 2018	6	TH	Fair
	Cache 4	Sep 2013	Sep 2018	5	TH	Good
	Cache 5	Sep 2007	Sep 2018	11	TH	Poor
	Cache 6	Sep 2015	Sep 2018	3	TH	Good
	Cache 7	Sep 2016	Sep 2018	2	TH	Fair
	Box Elder 4	Spring 2014	8 Oct 2018	5	H	Poor
	Box Elder 5	Spring 2013	8 Oct 2018	6	H	Poor
	Weber	Fall 2012	Apr 2018	5	TH	Poor
	Beaver 2	20 Aug 2011	1 Oct 2018	7	H	Good

[a] If exact date was not known, a season and/or year was provided.
[b] Establishment year included if planted in the spring.
[c] T, tillage; H, herbicide. Tillage included various combinations of disk and turbo chisel. Herbicide included either glyphosate or 2, 4-D.
[d] Stand condition was based on visual ratings by cooperating growers.

TABLE 2.4 Harvest date and maximum yield amounts for 18 on-farm site-years in Idaho, Utah, and Colorado during 2018 to 2019.

Year	Site	Harvest date	Maximum yield[a]
			Mg ha^{-1}
2018	Cache 1	24 Jul	8.95
	Cache 2	23 Jul	8.09
	Box Elder 1	30 Jul	4.52
	Box Elder 2	26 Jul	6.25
	Box Elder 3	30 Jul	4.05
	Beaver 1	25 Jul	8.07
	Uintah 1	15 Aug	6.08
	Montezuma	29 Oct	1.98
2019	Franklin	22 Aug	7.97
	Cache 3	9 Aug	10.33
	Cache 4	9 Aug	9.88
	Cache 5	12 Aug	10.79
	Cache 6	12 Aug	11.34
	Cache 7	12 Aug	11.24
	Box Elder 4	1 Aug	10.92
	Box Elder 5	1 Aug	9.14
	Weber	18 Jul	7.43
	Beaver 2	5 Aug	9.54

[a] Maximum yield for responsive sites is the maximum value of the dependent variable predicted by the regression equation, for non-responsive sites, it is the average yield level attained.

TABLE 2.5 Significance of *F* tests for the fixed effects of site, spring N, and their interaction on grain yield and quality parameters (Test weight and Protein) across all site-years, along with the effect of spring N at each site-year.

Parameter	Yield	Test weight	Protein
	----------	$P > F$	----------
Site	<0.001	<0.001	<0.001
N	<0.001	<0.001	<0.001
Site*N	<0.001	<0.001	<0.001
		(Analysis of fixed effect of N by site)	
Site	**Yield**	**Test weight**	**Protein**
	----------	$P > F$	----------
Cache 1	0.177	n/a	<0.001
Cache 2	0.160	n/a	<0.001
Box Elder 1	0.061	n/a	<0.001
Box Elder 2	0.120	n/a	<0.001
Box Elder 3	0.118	n/a	0.001
Beaver 1	0.008	n/a	0.114
Uintah 1	0.071	n/a	0.768
Montezuma	0.405	n/a	0.980
Franklin	<0.001	<0.001	0.001
Cache 3	<0.001	0.288	<0.001
Cache 4	<0.001	0.300	<0.001
Cache 5	<0.001	0.941	<0.001
Cache 6	<0.001	0.002	<0.001
Cache 7	<0.001	<0.001	<0.001
Box Elder 4	<0.001	0.039	<0.001
Box Elder 5	<0.001	0.642	0.001
Weber	0.025	<0.001	<0.001
Beaver 2	0.058	0.010	<0.001

TABLE 2.6 Parameter estimates and significance for regression models used to describe the response of grain yield to fertilizer N, along with the corresponding economic optimum N rate (EONR) for grain yield at a fertilizer N cost: small grain price ratio of 0.25 US$ kg^{-1} N per $40 US$ Mg ha^{-1} (0.55 US$ lb^{-1} N per 4.86 US$ bu^{-1}). Regression models were not shown for sites where there was no response to N or where regression models did not fit the data.

		Parameter estimates[a]							
Dependent variable	**Site**	**Model**	$\hat{\beta}_0$	$\hat{\beta}_1$	$\hat{\beta}_2$	X_0	***Model significance***	Y_{max}[b]	**EONR**
						kg N ha^{-1}	$P > F$	Mg DM ha^{-1}	kg N ha^{-1}
Grain yield, Mg ha^{-1}	Beaver 1	L	7.21	0.005	n/a	168	0.008	8.07	168
	Franklin	QP	5.13	0.049	-0.00021	111	<0.001	7.97	100
	Cache 3	LP	8.27	0.022	n/a	95	0.006	10.33	95
	Cache 4	QP	6.61	0.045	-0.00015	140	<0.001	9.88	124
	Cache 5	QP	8.43	0.029	-0.00009	158	<0.001	10.79	124
	Cache 6	QP	8.75	0.055	-0.00029	90	<0.001	11.34	83
	Cache 7	QP	9.07	0.033	-0.00013	125	<0.001	11.24	104
	Box Elder 4	QP	8.18	0.039	-0.00014	134	<0.001	10.92	116
	Box Elder 5	LP	6.97	0.018	n/a	122	0.001	9.14	122
	Weber	LP	5.80	0.015	n/a	109	0.010	7.43	109

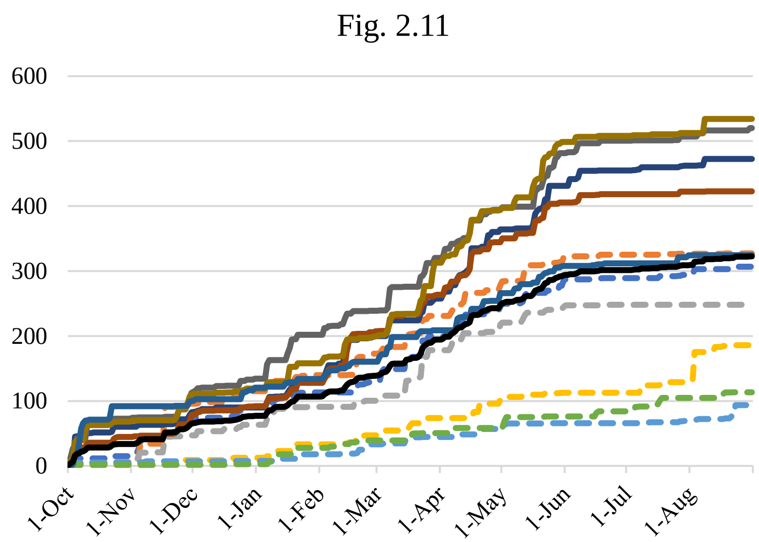
[a] L, linear; LP, linear plateau; QP, quadratic plateau; $\hat{\beta}_0$, intercept; $\hat{\beta}_1$, linear coefficient; $\hat{\beta}_2$, quadratic coefficient, X_0, fertilizer N rate at the junction of the linear/quadratic segment and plateau segment of the nonlinear regression models.
[b] Y_{max}, is the maximum value of the dependent variable predicted by the regression equation.

TABLE 2.7 Parameter estimates and significance for regression models used to describe the response of grain test weight and protein to fertilizer N. Regression models were not shown for sites where there was no response to N or where regression models did not fit the data.

Dependent variable	Site	Model	Parameter estimates[a] $\hat{\beta}_0$	$\hat{\beta}_1$	$\hat{\beta}_2$	X_0	*Model significance*	Y_{max}[b]
						kg N ha^{-1}	$P > F$	
Test weight	Franklin	LP	84.90	0.014	n/a	143	<0.001	86.90
kg hl^{-1}	Cache 6	QP	80.87	0.023	-0.00019	59	<0.001	81.54
	Cache 7	QP	81.16	0.012	-0.00004	166	<0.001	82.12
	Box Elder 4	Q	77.05	0.012	-0.00007	91	0.04	77.61
	Weber	L	80.91	0.009	n/a	168	<0.001	82.48
	Beaver 2	QP	77.12	0.019	-0.00011	88	0.002	77.97
Protein	Cache 1	LP	113.15	0.288	n/a	114	<0.001	145.95
g kg^{-1}	Cache 2	LP	113.61	0.176	n/a	99	<0.001	131.06
	Box Elder 1	L	132.19	0.123	n/a	168	<0.001	152.86
	Box Elder 2	L	133.94	0.137	n/a	168	<0.001	157.00
	Box Elder 3	QP	95.88	0.405	0.00145	140	0.005	124.12
	Franklin	L	160.96	0.118	n/a	168	<0.001	180.75
	Cache 3	L	116.53	0.175	n/a	168	<0.001	145.91
	Cache 4	L	123.16	0.150	n/a	168	<0.001	148.33
	Cache 5	LP	117.95	0.135	n/a	159	<0.001	139.36
	Cache 6	LP	108.34	0.206	n/a	154	<0.001	140.12
	Cache 7	LP	105.94	0.231	n/a	151	<0.001	140.83
	Box Elder 4	LP	102.11	0.205	n/a	114	<0.001	125.51
	Box Elder 5	L	99.37	0.163	n/a	168	<0.001	126.75
	Weber	LP	94.73	0.205	n/a	154	<0.001	126.30
	Beaver 2	LP	103.45	0.113	n/a	134	<0.001	118.65

[a] L, linear; LP, linear plateau; QP, quadratic plateau; $\hat{\beta}_0$, intercept; $\hat{\beta}_1$, linear coefficient; $\hat{\beta}_2$, quadratic coefficient, X_0, fertilizer N rate at the junction of the linear/quadratic segment and plateau segment of the nonlinear regression models.

[b] Y_{max}, is the maximum value of the dependent variable predicted by the regression equation.



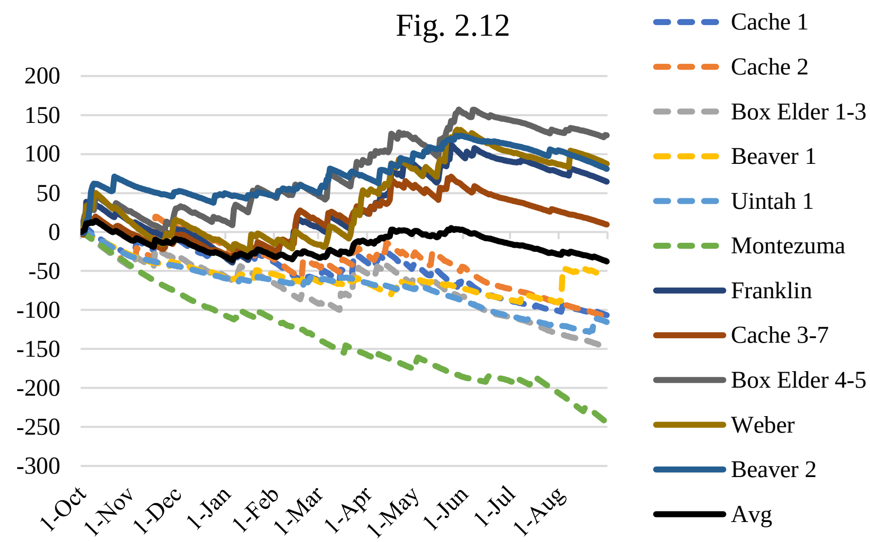


Figure 2.11: Cumulative precipitation measured daily per site-year (mm), October 1 through August 31 the following year, to cover the growing season of fall and spring planted small grains.

Figure 2.12: Cumulative daily precipitation per site-year shown as a percent difference of the 30-year normal (1981-2010), to cover the growing season of fall and spring planted small grains.

Fig. 2.21

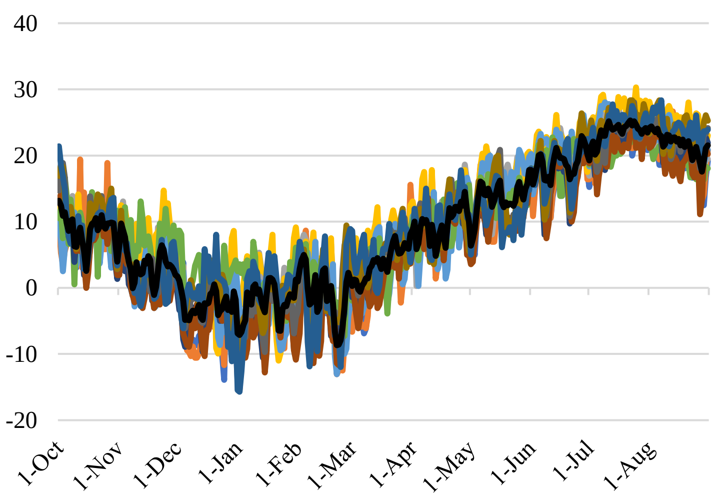


Fig. 2.22

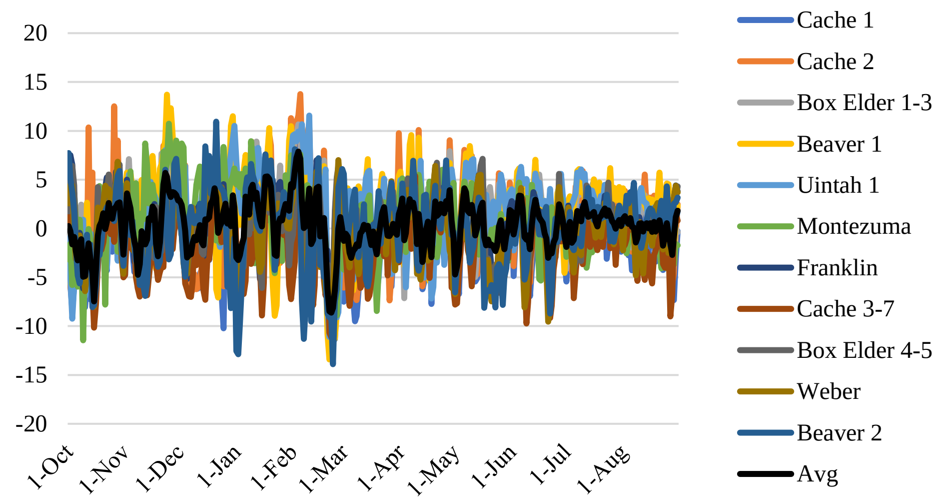


Figure 2.21: Average daily air temperature measurements recorded daily (℃) per site-year, October 1 through August 31 the following year, to cover the growing season of fall and spring planted small grains.

Figure 2.22: Daily average air temperature shown as a percent difference of the 30-year normal (1981-2010) (℃) per site-year, October 1 through August 31 the following year, to cover the growing season of fall and spring planted small grains.

Fig. 2.31

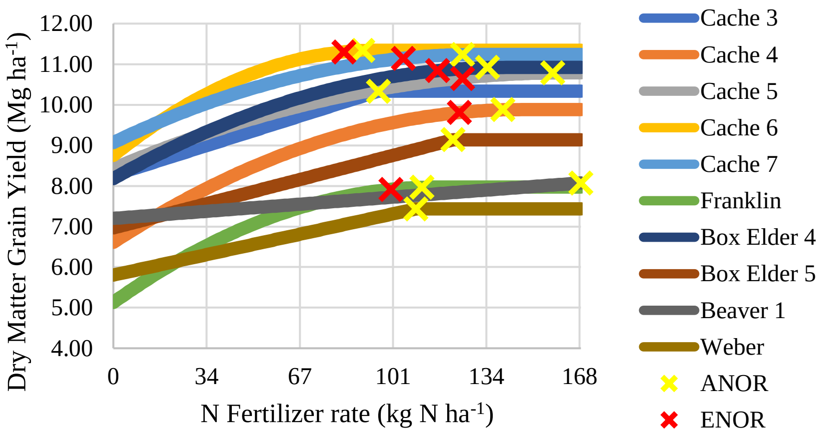


Figure 2.31: Regression models for each responsive site. AONR (Agronomic optimum N rate) for yield values shown (Yellow “X”) and ENOR (economic optimum N rate) (Red “X”).

Fig. 2.32

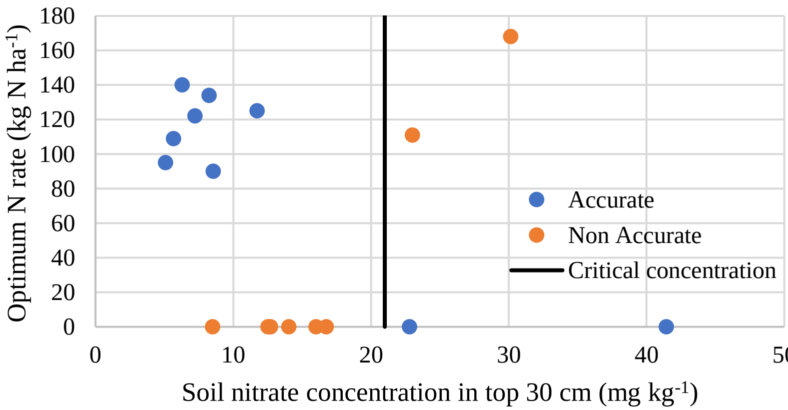


Figure 2.32: Relationship between spring soil nitrate in the top 30 cm and fertilizer N rates that agronomically optimized yield for each of the 17 small grain site-years in Idaho, Utah, and Colorado. A critical concentration of 21 mg kg^{-1} was used to gauge if additional N was required to achieve optimum levels. This prediction test was accurate in 53% of the sites.

Fig. 2.41

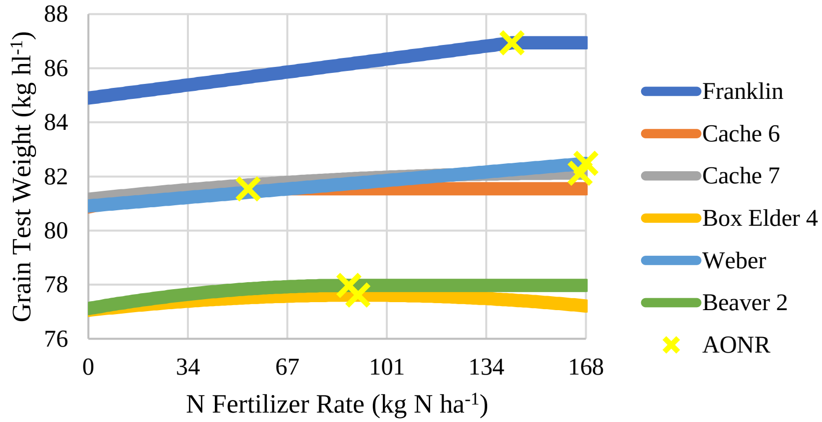


Figure 2.41: Regression models for each responsive site. AONR (Agronomic optimum N rate) for test weight values shown (Yellow "X").

Fig. 2.42

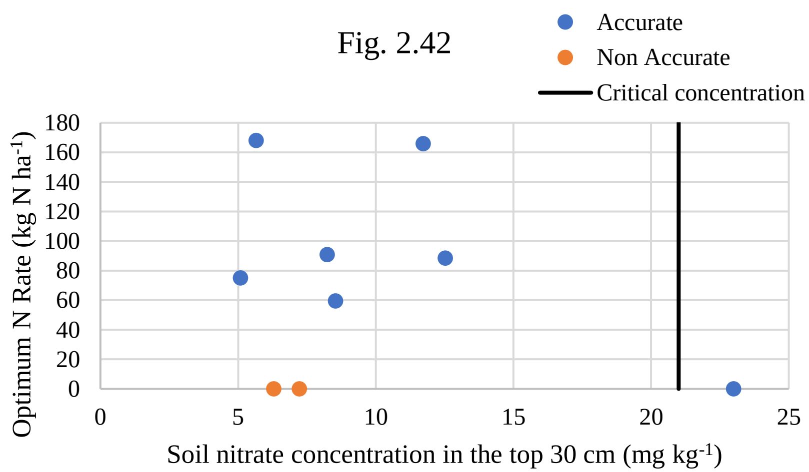


Figure 2.42: Relationship between spring soil nitrate in the top 30 cm and fertilizer N rates that agronomically optimized test weight for each of the nine 2019 small grain sites in Idaho and Utah. A critical concentration of 21 mg kg^{-1} was used to gauge if additional N was required to achieve optimum levels. This prediction test was accurate in 78% of the sites.

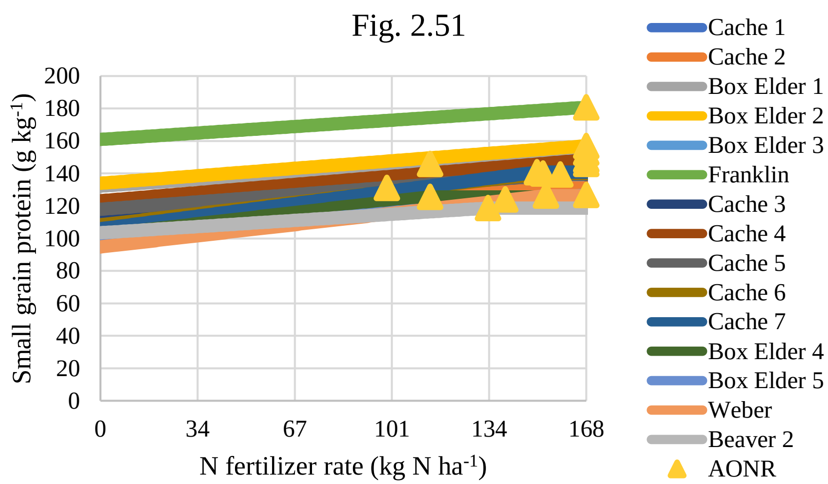


Figure 2.51: Regression models for each responsive site. AONR (Agronomic optimum N rate) for protein values shown (Yellow triangle).

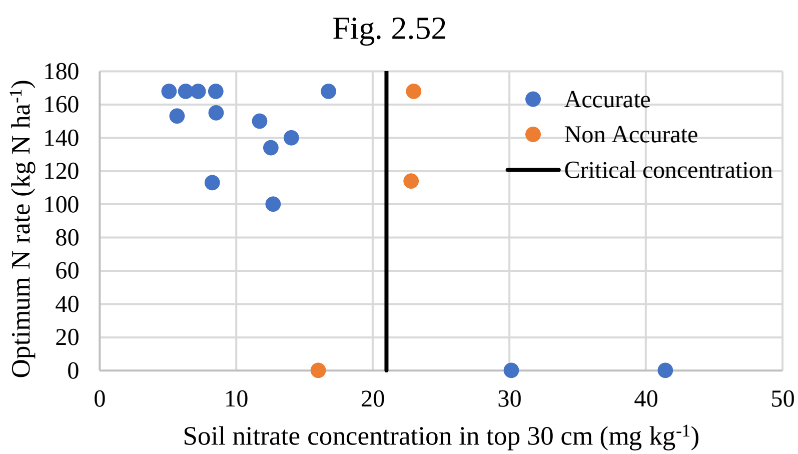


Figure 2.52: Relationship between spring soil nitrate in the top 30 cm and fertilizer N rates that agronomically optimized protein for each of the 17 small grain site-years in Idaho, Utah, and Colorado. A critical concentration of 21 mg kg^{-1} was used to gauge if additional N was required to achieve optimum levels. This prediction test was accurate in 82% of the sites.

CHAPTER 3

NITROGEN FERTILIZER NEEDS OF FIRST-YEAR SMALL GRAIN FORAGES FOLLOWING ALFALFA

1 MATERIALS AND METHODS

1.1 Site Characteristics

On-farm trials were established at 12 sites in Utah. Ten trials were conducted in 2018 in Box Elder, Uintah, Millard, Carbon, Sevier, Iron, and Kane counties, and an additional two were conducted in 2019 in Sevier and Piute counties. Trials were established in the spring between March and May. Cooperating growers planted either a single small grain cultivar or a mix of multiple cultivars. The cultivars used included wheat, barley, oats, triticale, and rye (*Secale cereal*). Pest management, irrigation, and all other agronomic operations besides N fertilization were managed by cooperating growers and consequently differed among sites (Tables 3.1-3.2).

Management characteristics were recorded where possible. Irrigation types varied among sites; 42% were irrigated by wheel line, 33% by pivot, and 25% by flood irrigation (Table 3.1). Irrigation rates and methods within each site were constant. Alfalfa stand age at time of termination ranged from 3-15 yr, with an average of seven years. Stand establishment occurred in the fall at 67% of the sites and in the spring at 33% of the sites. Termination methods for the alfalfa stand varied between chemical and physical means, but was constant within each site. Alfalfa stands were terminated in the fall or spring at 58 and 42% of the sites, respectively (Table 3.3). Small grain planting occurred on half the sites in the fall and the other half in the spring according to (Table 3.2).

Planting timing was dependent on weather and other grower-specific operational needs (Table 3.2).

Weeds and volunteer alfalfa were adequately controlled by us or cooperating growers at all but one site. One of the sites in Kane County (site Kane 2) did not have adequate control because the grower elected not to apply herbicide. An estimation of the harvested volunteer alfalfa to small grain ratio was calculated by harvesting six randomly selected plots and separating and independently measuring yield for volunteer alfalfa and small grain forage. Volunteer alfalfa (average of 20% of the total dry biomass) was subtracted from the total biomass so that only small grain forage yield response to N could be assessed. Cooperating growers terminated volunteer alfalfa at eight sites. At three sites where growers normally do not terminate volunteer alfalfa, 2, 4-dichlorophenoxyacetic acid (2, 4-D) and 3, 6-dichloro-*o*-anisic acid (Dicamba) were applied at 191 and 48 ml a.i. ha^{-1}, respectively, using a CO_2 pressurized backpack sprayer with a 3 m hand-held boom when weeds and volunteer alfalfa were 15 to 45cm tall.

Soil classification and textural group were obtained from the University of California-Davis SoilWeb (casoilresource.lawr.ucdavis.edu/gmap/) (Table 3.1). Soil pH, organic matter, P, and K concentrations were measured as the average of four composite samples, one per replication (15 cm deep × 1.9 cm i.d.) collected prior to N fertilization (Table 3.1). The samples were analyzed at the Environmental Analytical Lab at Brigham Young University in Provo, UT. Soil pH was determined on a saturated paste (Rhodes, J.D. 1982), organic matter by Walkley-Black dichromate oxidation (Walkley & Black, 1934), P concentrations by extraction with 0.5 M sodium bicarbonate (Olsen, Cole, Watanabe, & Dean, 1954), and K concentrations by extraction with 0.5 M sodium

bicarbonate and analyzed by an AAnalyst 200 machine (PerkinElmer, Waltham, MA; Schoenau & Karamonos, 1993). If P or K deficiencies were detected [according to Utah State University Extension fertilizer guidelines for small grains (Cardon, Kotuby-Amacher, Hole, & Koenig, 2008)], potash and/or triple superphosphate were surface-broadcasted by hand at recommended rates. Daily cumulative precipitation (Figure 3.11) and average air temperatures (Figure 3.21) were obtained from the nearest National Weather Station through the Utah Climate Center Database (https://climate.usu.edu).

1.2 Nitrogen Treatments

Nitrogen fertilizer treatments were arranged in a randomized complete block design at each site. Four replications of all N rates were applied in plots measuring 3 × 9 m each. Nitrogen fertilizer was applied in March through May depending on planting time and weather conditions at 0, 34, 67, 101, 134, and 168 kg N ha^{-1} (Table 3.2). All fertilizer N treatments were surface-broadcasted as granular NH_4NO_3. This source was chosen due to its decreased risk of volatilization due to it not being incorporated. Fertilizer was applied either by hand spreading a pre-measured amount or by a calibrated 1.5 m Gandy Drop Spreader (Gandy, Owatonna, MN) towed behind an ATV.

1.3 Prediction Tool: Spring Soil Nitrate

Prior to spring fertilization and in the non-fertilized treatment, an additional set of soil samples (30 cm deep × 1.9 cm i.d.) were collected to measure NO_3^- concentration (Table 3.1). A single composite sample consisting of ten cores was collected and analyzed for each replicate at each site, then an average was calculated to get one value per site. Soil nitrate concentration was measured by chromotropic acid analysis (Sims &

Jackson, 1971) to determine if it could be used as a reliable indicator of N fertilizer need using the same critical nitrate concentration of 21 mg kg^{-1} that is commonly used for corn (Andraski & Bundy, 2002; Blackmer et al., 2013; Rehm et al., 2013).

1.4 Harvest and Sample Analysis

Small grain forage was harvested within a week of when cooperating growers harvested their fields. This occurred between May and July at each site-year (Table 3.2). Within each plot, a 0.5 × 6 m or a 1.2 × 7 m swath was cut in the center of each plot using either a KM 91 R-Z CombiEngine Stihl with a hedger attachment (Stihl inc., Virginia Beach, VA) or a BCS 739 sickle bar mower (BCS, Oregon City, OR), respectively. Biomass harvests were centered within each plot to eliminate border effects, and were made at a height of 8 to 10 cm above the ground. Harvest equipment varied based on availability and site access, but equipment did not vary within a site. Harvested biomass in each plot was weighed in the field using an Inficon Wey-TEK Refrigerant Charging scale (Inficon, Santa Clara, CA). Representative subsamples (approximately 1 kg) were collected and weighed in the field, dried at 60°C until mass was constant, then weighed again to determine dry matter yield. Yield was measured for all sites except one (Piute) where missing dry weight data prevented dry matter calculations. Dried samples from all 12 sites were ground to pass a 1 mm sieve using a Thomas-Wiley Laboratory Mill Model 4 grinder (Thomas Scientific, Swedesboro, NJ) and analyzed for forage quality with a Foss NIRS DS2500 F feed analyzer (FOSS North America inc., Eden Prairie, MN) at the Utah State University Analytical Lab. The following quality parameters were measured or calculated: crude protein (CP), total digestible nutrients

(TDN), relative feed value (RFV), relative feed quality (RFQ), and neutral detergent fiber (NDF).

1.5 Statistical Analysis

The data were analyzed at $P \leq 0.05$ using the MIXED procedure of SAS (SAS Institute, 2016) (Table 3.4). The six dependent variables were forage yield, CP, TDN, RFV, RFQ, and NDF. Site, N rate, and their interaction were considered fixed effects, whereas replicate (nested within site), and interactions involving replicate were considered random effects. The UNIVARIATE procedure of SAS was used to inspect the residuals for normality, and scatterplots of the residuals vs. predicted values were used to assess common variance. In all six analyses, the site × N rate interaction was significant. Therefore, the influence of N rate was evaluated at each site. When N rate significantly influenced yield or quality parameters, regression analysis was used to describe the response of the dependent variables to fertilizer N. Several regression models were evaluated and the model that was significant at $P \leq 0.05$ and produced the smallest residuals that were normally and randomly distributed was selected (Kutner, Nachtsheim, & Neter, 2004). Linear and quadratic regression equations were developed using the MIXED procedure of SAS, and nonlinear regression equations were developed using the NLIN procedure of SAS (Tables 5 and 6). When regression models did not fit the data, Fisher’s protected LSD test ($P \leq 0.05$) was used for mean comparisons.

2 RESULTS AND DISCUSSION

2.1 Weather

Cumulative precipitation during the small grain growing season (1 Oct to 31 Aug) ranged from 94 to 301 mm across sites (Figure 3.11). Millard had the most cumulative precipitation and Uintah 2 had the least, with an average across all sites of 191 mm. When each site-year was compared to its respective 30-year normal values, a wide range of deviations occurred (Figure 3.12). Sevier 3 and Piute sites were both in 2019 and their cumulative precipitation were either at or above their respective 30-year normal for nearly all of the growing season. Piute was up to 95 mm above its 30-year normal throughout the growing season and Sevier 3 had a range of 10 mm below in July and up to 58 mm above its 30-year normal throughout the rest of the growing season. All 10 sites in 2018 had below average cumulative precipitation for the entire growing season. The driest site with the greatest deviation was Kane 2 where the cumulative precipitation reached 209 mm below the 30-year normal. In contrast to precipitation differences among site-years, average daily air temperature was consistent among site-years (Figure 3.21). Temperatures ranged from -8 to 25 °C among all sites throughout the growing season. Each site year also had air temperatures similar to their respective 30-year normal, deviation from the 30-year normal ranged from -14 to 14 °C, with an average of 1 °C (Figure 3.22).

2.3 Forage Yield

Maximum forage dry matter yield ranged widely from 4.46 to 12.79 Mg ha^{-1} across the sites (Table 3.3). This was mainly due to differences in cultivar selection, environment, and cutting management of cooperating growers. The interaction between

site and N rate was significant, signifying that the response to fertilizer N differed among sites. Forage yield was only influenced by N rate at three (Box Elder 7, Sevier 3, and Carbon) of the 11 sites (excluding Piute due to missing data; (Table 3.4, Figure 3.3). All three responsive sites had an average agronomic optimum N rate of 127 kg N ha^{-1} (101-168 kg N ha^{-1}). At these rates, yield increased by 21, 11, and 37% at the Box Elder 7, Sevier 3, and Carbon sites, respectively, compared to the nonfertilized control. Two (Box Elder 7, Carbon) of these three sites were small grains following the oldest alfalfa stands (10 and 11 yr old), which resulted in poorer alfalfa stand conditions and may partially explain why they responded to fertilizer N. The EONR for each responsive site was also calculated using (\$0.25 USD kg^{-1} N) and an estimated market value for small grain forage [\$49.91 USD Mg^{-1} (Stalcup, L., 2004)]. At two sites (Sevier 3 and Carbon), the EONR was 0 kg ha^{-1}, but the third site (Box Elder 7) had an EONR of 67 kg N ha^{-1} (Figure 3.3; Table 3.5).

The responsive site (Box Elder 7) was flood irrigated triticale planted in the fall of 2017. The alfalfa crop was planted in 2008 and terminated in the fall of 2017 by applying glyphosate followed with disk tillage. The soil at this site was classified as a silt loam, fine, mixed, active, mesic Typic Natrixeralfs soil series. Soil pH was 7.6 and soil organic matter was 17.5 g kg^{-1}. Site characteristics (field, small grain, and alfalfa) varied between responsive and non-responsive sites (Tables 3.1, 3.2, and 3.3) and did not explain why this site had an economic response to fertilizer N. Cumulative precipitation had no apparent effect on response or non-response to additional N fertilizer. Furthermore, maximum yield levels overlapped between responsive (average of 8.81 Mg ha^{-1}, range of 5.91-12.79 Mg ha^{-1}) and non-responsive sites (average of 7.52 Mg ha^{-1}, range of 4.46-

10.98 Mg ha^{-1}) suggesting it did not influence N fertilizer need. Alfalfa age at termination and overall timing of release of N from the decaying alfalfa are two suspected factors that could have influenced response to added N fertilizer. Box Elder 7 followed an alfalfa stand that was ten years old and in thin, poor condition. These results coincide with results for corn following alfalfa where corn yield level did not influence N need and older alfalfa stands often increased the likelihood of response to N (Yost et al., 2014; 2015), suggesting that small grain forage growers may want to terminate alfalfa before stands thin enough that the N credit to the following crop is lost or reduced.

Soil nitrate levels in the early spring ranged from 11-44 mg kg^{-1} among sites, with an average across sites of 24 mg kg^{-1}. Based on the same critical concentration of 21 mg kg^{-1} that is often utilized for corn (Andraski & Bundy, 2002; Blackmer et al., 2013; Rehm et al., 2013), soil nitrate levels were able to separate forage yield agronomic response from non-response in 45% of the sites (Figure 3.4). The eight non-responsive sites had an average of 25 mg kg^{-1} (11-44 mg kg^{-1}), while the three sites (Box Elder 7, Sevier 3, and Carbon) with an agronomic yield response had soil nitrate levels of 14, 15, and 37 mg kg^{-1}, respectively, with an average of 22 mg kg^{-1}. This suggests that spring soil nitrate levels are not a reliable prediction test for forage yield, but in the case of Box Elder 7, it had less than 21 mg kg^{-1}, and may have contributed to it being the only site with a positive EONR. The accuracy of soil nitrate for first-year small grains after alfalfa was less than previous reports for wheat in other rotations (Blackmer et al. 2013) or first- or second-year corn following alfalfa (Walker et al., 2017). It is unclear why spring soil nitrate levels did not hold the same high level of accuracy in small grain forages grown after

alfalfa, but may have been influenced by slow release of N from the decaying alfalfa, and the earlier uptake and use of N (prior to July) in small grains compared to corn.

Small grain forages grown in the first year after alfalfa rarely require fertilizer N to economically optimize yield levels. The lack of response occurred over a wide range of conditions including three irrigation types, various termination methods of alfalfa at various ages, and with a wide range of small grain species. This indicates a diverse and common ability of alfalfa to provide all the N that first-year small grain forage might need to optimize yield. Thus, in most cases, growers could often save up to $110 USD ha^{-1} based on current Utah fertilizer guidelines for small grain forage not following alfalfa.

2.4 Forage Quality: Crude Protein

Proteins are an essential nutrient to livestock, which support microbial activity in the rumen that aids in breaking down forage. Along with microbial support proteins are also essential in creating amino acids, which have multiple life essential roles. Crude protein is an indirect measure of the N concentration of the forage multiplied by 6.25 (Trammell & Walker, 2019).

Maximum crude protein levels ranged from 88 to 195 g kg^{-1}, with an average of 150 g kg^{-1}, across all sites. The interaction between site and N rate was significant, indicating that the response to fertilizer N differed among sites. All sites but Kane 2 showed a CP response to N rate (Table 3.4). The average agronomically optimum N rate for responsive sites was 132 kg N ha^{-1} (78-168 kg N ha^{-1}) which, when applied, resulted in an average 37% (9-72%) increase in CP compared to the non-fertilized control (Table 3.6). Multiple site characteristics were analyzed for their ability to separate sites that had

the most increase in CP compared to those with the least. Those characteristics were alfalfa stand age at termination, alfalfa termination type and time, small grain planting time, soil type, and soil organic matter. Sites that terminated their alfalfa in the fall and immediately planted small grain forages had the greatest percent increase in CP, showing that planting small grains immediately following alfalfa termination in the fall may play a role in CP values in the small grain forage.

Increases in CP often do not have an economic benefit in the Intermountain West because much of the small grain forage is fed on the farm and not sold. Even in cases where it is sold, most farmers have reported that they are not paid incentives for higher protein. If incentives do exist for elevated protein, EONR's could be calculated for protein.

Kane 2 had a maximum CP of 174, however, it did not have adequate weed and volunteer alfalfa control, which may explain the lack of response to additional N fertilizer. It had oats planted in the spring of 2018 and followed a nine-year-old alfalfa stand. The site was irrigated with wheel lines on a loam soil with a naplene-teromote-arboles-oxyaquic Ustifluvetns Complex soil series. This site had a pH of 7.6 and an organic matter of 29 g kg^{-1} (Tables 3.1, 3.2, and 3.3).

Soil nitrate concentration and leaf chlorophyll ratios were also assessed for their ability to separate all five forage quality parameters utilizing the same critical levels used for yield. Responsive sites had an average spring soil nitrate level of 22 mg kg^{-1} (11-41 mg kg^{-1}), and soil nitrate levels were able to separate response from non-response in 67% of the sites. The relative accuracy of the soil nitrate test for protein was opposite of yield.

In the case of forage protein response to N, soil nitrate was a reliable predictor of response.

2.5 Forage Quality: Total Digestible Nutrients

TDN represents overall digestibility or energy value of the forage, it is calculated from the ADF value (Trammell & Walker, 2019). Maximum TDN levels of the small grain forage ranged from 580 to 707 g kg^{-1}, with an average of 648 g kg^{-1}, across all 12 sites. The interaction between site and N rate was significant, signifying that the response to fertilizer N differed among sites. Only 2 (Sevier 1 and Uintah 2) of 12 sites showed a TDN response to N fertilizer (Table 3.4). At the Sevier 1 site, 101 kg N ha^{-1} increased TDN up to 662 g kg^{-1} TDN (3.8% increase) compared to the non-fertilized control (Table 3.6). No regression model fit the TDN data at the Uintah 2 site and there was variability in mean separations. The following N rates statistically were indifferent, 0, 34, 67, and 168 kg N ha^{-1}, while 101 and 134 kg N ha^{-1} rates were different from each other but not from the others, showing no consistent benefit of applying fertilizer. Sevier 1 had a soil texture of silt loam and is classified as fine-silty, carbonatic, mesic Xeric Torrifluvents with a pH of 7.3 and OM of 19 g kg^{-1}. It was irrigated by a lateral pivot line. It is unclear why this site responded while the others did not.

Non-responsive sites had an average maximum TDN of 648 g kg^{-1} (580–707 g kg^{-1}). Site characteristics (field, small grain, and alfalfa) varied between non-responsive sites (Tables 3.1, 3.2, and 3.3) and could not explain why all did not respond.

The two responsive sites (Sevier 1 and Uintah 2) had spring soil nitrate levels of 14 and 41 mg kg^{-1}, respectively. Non-responsive sites had an average spring soil nitrate level of 23 mg kg^{-1} (11–44 mg kg^{-1}). Soil nitrate levels were able to separate response

from non-response in 42% of the sites. This suggests that spring soil nitrate tests are not a reliable test for predicting additional N fertilizer need for small grain forage TDN. However, similar to CP, there is currently few economic incentives for increased TDN in the Intermountain West.

2.6 Forage Quality: Neutral Detergent Fiber

The total fiber fraction of forages is measured as NDF. The fiber fraction is made up of three structures in the cell wall of the plant: cellulose, hemicellulose, and lignin. This range can vary from 10% is grain to 80% is grass straw. Lower NDF values are more ideal, meaning there are less fibers for the animal to breakdown in the forage. Legumes typically have higher NDF values than grasses (Trammell & Walker, 2019).

Maximum NDF levels ranged from 565 to 699 g kg^{-1}, with an average of 619 g kg^{-1}. The interaction between site and N rate was significant, signifying that the response to fertilizer N differed among sites. Box Elder 7 was the only site to respond in NDF to additional N fertilizer (Table 3.4). This site had an agronomically optimum N rate of 111 kg N ha^{-1}, which resulted in an NDF value of 699, which was an 8% increase when compared to the non-fertilized control (Table 3.6).

Box Elder 7 was fall triticale established during the first-year after alfalfa. It was flood irrigated and planted on a silt loam soil with a fine, mixed, active, mesic Typic Natrixeralfs soil series. The soil had a pH of 7.6, an organic matter of 17.5 g kg^{-1}, with 14 mg kg^{-1} soil nitrate. The previous alfalfa crop was 10 years old. Effects of alfalfa age and spring soil nitrate content together may explain why this site responded while others did not.

Soil nitrate was able to separate response from non-response in 33% of cases, meaning that is not a reliable test for predicting NDF response to additional N fertilizer.

2.7 Forage Quality: Relative Feed Value

Similar to TDN, RFV represents the forages digestibility, but also represents intake potential. RFV is calculated from ADF and NDF and is typically nutritionally applicable to alfalfa hay that is fed free-choice to dairy cows. However, it can be used in marketing all types of hay, as it has been in small grain forages (Trammell & Walker, 2019).

Maximum RFV of the small grain forage ranged from 83 to 107 across all 12 sites, with the average of 97. The influence of N fertilizer on RFV varied by site. Relative feed value increased as N rate increased at only 2 of 12 sites (Box Elder 7 and Sevier 1) (Table 3.4), indicating that the previous alfalfa crop adequately supplied optimum N levels in most cases. At Box Elder 7 and Sevier 1, 116 and 168 kg N ha^{-1} were required to optimize RFV, respectively (Table 3.6). Compared to the non-fertilized control, RFV increased 11% and 8% up to 96 and 99 RFV with the optimum fertilizer rate at the Box Elder 2 and Sevier 1 sites, respectively. Non-responsive sites had an average maximum RFV of 97 (83-107). Site characteristics varied between responsive and non-responsive sites (Tables 3.1, 3.2, and 3.3), and it was not clear what underlying factors caused only two sites to respond in RFV.

The two responsive sites (Box Elder 7 and Sevier 1) had spring soil nitrate levels of 37 and 14 mg kg^{-1}, respectively. Non-responsive sites had an average spring soil nitrate level of 23 mg kg^{-1} (11-44 mg kg^{-1}). Similar to the poor performance for other

metrics, soil nitrate levels were able to separate response from non-response in only 42% of the sites.

2.8 Forage Quality: Relative Forage Quality

RFQ is another measure of relative nutritive value and holds similar properties to RFV. Unlike RFV, RFQ accounts for digestible fibers. Also, it is more often used to describe the nutritive value of grass hays and is a good indicator of how a forage may perform in an animal's diet (Trammell & Walker, 2019).

Maximum RFQ values of the small grain forage ranged from 52 to 101, with an average of 74, across all 11 sites where it was measured (excluding Box Elder 7 where data were out of range). The interaction between site and N rate was significant, signifying that the response to fertilizer N differed among sites. Nine of 11 sites had an RFQ response to N fertilizer (Table 3.4), with an average agronomically optimum N rate of 121 kg N ha^{-1} (68-168 kg N ha^{-1}) (Table 3.6), which resulted in an average 91% unit increase (33-181%) in RFQ when compared to the non-fertilized control. Non-responsive sites (Millard and Kane 2) had average RFQ values of 63 and 94, respectively. There were no site characteristics (Tables 3.1, 3.2, and 3.3) about these two sites that distinguished them from the sites that responded to N. Soil nitrate was able to separate response from non-response in 67% of cases. This indicates that soil nitrate tests be a reliable test for predicting N fertilizer need for small grain forage RFQ.

2.9 Overall Forage Quality

Eleven of the 12 sites had at least one of the five forage quality parameters that was influenced by N fertilizer (Table 3.4), showing that the previous alfalfa crop did not

adequately supply the needed N for overall forage quality levels. Crude protein and RFQ were the two parameters that most consistently benefited from N fertilizer applications; the other three forage quality parameters (TDN, RFV, and NDF) were rarely impacted by N rate. There are no studies that we are aware of that look at quality response to additional N fertilizer in small grain forages grown after alfalfa, although, there are studies that evaluate small grain forage quality response to N fertilizer in other rotations. These other studies have also found that CP has a high probability of response to increased N rates, while NDF did not respond or responded negatively to increased N rates (Moreira, 1989; Collins, Brinkman, & Salman, 1990; Harmoney & Thompson, 2005). Literature has also shown that digestibility of small grain forages responds to additional N fertilizer rates at or above 90 kg N ha^{-1} (Morey, Walker, Marchant, & Lowrey, 1969) but others have shown lack of response in the digestibility of small grain forage (Cazzato et al, 2013).

Applying additional N fertilizer to boost small grain forage quality would have to be matched with an economic benefit; if not, then growers could withhold additional N fertilizer. If incentives do exist for enhanced forage quality, growers might consider applying N fertilizer to first-year small grains. Given large variability in the level and frequency of response of the five forage quality parameters to N fertilizer, it is difficult to settle on rates that optimize forage quality. The average N fertilizer rate that agronomically optimized each of the five parameters was 101 to 142 kg N ha^{-1}. However, the superior approach to guide N fertilizer applications for quality in first-year small grains would be to utilize the quality parameter that would increase the value of the forage and calculate a tailored EONR.

Kane 2 was the only site that did not respond in any of the quality indicators. Lack of weed and volunteer alfalfa control most likely contributed to this level of non-response. The volunteer alfalfa and weeds that were growing with the small grains were estimated at 20% of the total crop and competed for irrigation, sun light, and nutrients. This suggests that adequate weed and volunteer alfalfa control necessary to help achieve optimal quality conditions.

Soil nitrate tests did not consistently separate responsiveness to N among the five forage quality parameters. Soil nitrate was superior for CP and RFV (67% accurate).

3 CONCLUSION

Alfalfa of various ages, irrigated by various methods (pivot, wheel line, and flood), terminated in various ways in the fall and spring, almost always supplied all the N needed to optimize forage yield of various species of small grains. Nitrogen fertilizer economically increased yield with 67 kg N ha^{-1} at a single site that was a small grain following an older (10 yrs. old) and thinning alfalfa stand. Another two sites had an agronomic, but not economic (at stated price ratios) response to fertilizer. In contrast to yield, N fertilizer (average of 126 kg N ha^{-1}) was often needed to optimize two of the five measured forage quality parameters (CP and RFV). Soil nitrate tests were not able to accurately predict yield responsiveness to N fertilizer; however, they were for CP and RFV. This suggests that this test may have merit in this rotation when economic incentives are present. Based on these results, growers can often withhold N to first-year small grains following alfalfa or when incentives for forage quality (CP or RFV) outweigh the cost of fertilizer, apply up to 67 kg N ha^{-1}.

TABLE 3.1 Site and soil characteristics for 12 on-farm sites in Utah during 2018 to 2019 including year, site (coordinates) dominant soil series (classification), soil pH, soil OM, soil P, soil K, soil nitrate, and irrigation type.

Year	Site (Coordinates)	Soil Texture (Classification)	Soil pH	Soil OM	Soil P	Soil K	Soil Nitrate	Irrigation Type[a]
				g kg^{-1}	mg kg^{-1}	mg kg^{-1}	mg kg^{-1}	
2018	Box Elder 6 (41.536048, -112.160194)	Fine sandy loam (Coarse-loamy, mixed, superactive, mesic Aquic Calcixerolls)	7.4	14.3	51	239	17	F
	Box Elder 7 (41.533734, -112.068273)	Silt loam (Fine, mixed, active, mesic Typic Natrixeralfs)	7.6	17.5	12	270	14	F
	Uintah 2 (40.460002, -109.564288)	Clay loam (Fine-loamy, mixed, superactive, calcareous, mesic Oxyaquic Torriorthents)	7.6	22.8	13	50	41	WL
	Millard (39.113147, -112.330504)	Loam (Fine-loamy, carbonatic, mesic Xeric Haplocalcids)	7.5	22.3	10	62	33	P
	Carbon (39.516684, -110.783929)	Loam (Fine-silty, mixed, active, calcareous, mesic Typic Torrifluvents)	7.5	21	13	250	37	WL
	Sevier 1 (38.948181, -111.902987)	Silt loam (Fine-silty, carbonatic, mesic Xeric Torrifluvents)	7.3	19	142	72	18	P
	Sevier 2 (38.831161, -112.018238)	Silt loam (Fine-silty, carbonatic, mesic Xeric Torrifluvents)	7.4	12.5	25	92	14	P
	Iron (37.860920, -112.848117)	Loam (Fine-loamy, mixed, superactive, calcareous, mesic Xeric Torriorthents)	7.3	18.8	11	64	11	WL
	Kane 1 (37.438193, -112.487685)	Loam (Naplene-Teromote-Arboles-Oxyaquic Ustifluvents complex)	7.4	39	70	170	44	WL
	Kane 2 (37.254464, -112.676495)	Loam (Naplene-Teromote-Arboles-Oxyaquic Ustifluvents complex)	7.6	29	10	136	18	WL
2019	Sevier 3 (38.828880, -112.023413)	Silt loam (Fine-silty, carbonatic, mesic Xeric Torrifluvents)	7.6	27.6	70	164	15	P
	Piute (38.170398, -112.284500)	Fine sandy loam (Coarse-loamy, mixed, superactive, calcareous, mesic Xeric Torrifluvents)	7.6	24	26	187	23	F

[a] WL, wheel line; P, pivot; F, flood.

TABLE 3.2 Small grain forage characteristics and N trial information for 12 on-farm site-years in Utah during 2018 to 2019 including year, site, small grain species (varieties), seeding date, seeding rate, spring N fertilization date, harvest date, maximum yield.

Year	Site	Small Grain Species (varieties)[a]	Seeding date[b]	Seeding rate	Spring N fertilization date	Harvest date	Max yield[c]
				kg ha^{-1}			Mg DM ha^{-1}
2018	Box Elder 6	Wheat (Ovation)	Fall 2017	145	13 Mar	18 Jun	12.9
	Box Elder 7	Triticale (141)	Fall 2017	112	13 Mar	18 Jun	14.8
	Uintah 2	Barley (Goldeneye)	20 Apr 2018	112	24 Apr	9 Jul	7.8
	Millard	Wheat, Barley, Oats	27 Mar 2018	112	20 Apr	21 Jun	7
	Carbon	Oats (Monidas)	Apr 2018	123	8 May	2 Jul	6.7
	Sevier 1	Oats, Barley, Wheat	15 Mar 2018	135	21 Mar	15 Jun	6.7
	Sevier 2	Wheat (Willow Creek), Triticale	Fall 2017	135	21 Mar	15 Jun	8.5
	Iron	Wheat (Willow Creek, Brundage), Triticale (Forerunner)	19 Oct 2017	118	27 Apr	1 Jun	9.5
	Kane 1	Wheat, Barley, Triticale	Fall 2017	101	20 Mar	12 Jun	6.2
	Kane 2	Oats (Monidas)	3 Apr 2018	112	10 Apr	22 Jun	6.1
2019	Sevier 3	Triticale	Fall 2018	135	4 Apr	14 May	8.5
	Piute	Oats, Barley, Rye	25 Apr 2019	145	14 May	15 Jul	.

[a] Varieties and their respective varieties are listed where possible.

[b] If exact date was not known, a season and/or a year was provided.

[c] Max dry matter (DM) forage yield could not be calculated at the Piute site. Maximum yield for responsive sites is the maximum value of the dependent variable predicted by the regression equation, for non-responsive sites, it is the average yield level attained.

TABLE 3.3 Alfalfa characteristics for 12 on-farm site-years in Utah during 2018 to 2019 including year, site, seeding date, termination date, stand age, termination type, and stand condition.

Year	Site	Seeding date[a]	Termination date[a]	Stand age[b]	Termination type[c]	Stand condition[d]
				yr		
2018	Box Elder 6	Spring 2014	Fall 2017	4	TH	Good
	Box Elder 7	Fall 2008	Fall 2017	10	TH	Fair
	Uintah 2	Spring 2016	March 2018	3	T	Good
	Millard	July 2012	September 2017	6	H	Poor
	Carbon	Spring 2008	Spring 2018	11	T	Poor
	Sevier 1	Fall 2012	Fall 2017	5	T	Good
	Sevier 2	August 2011	Fall 2017	6	T	Good
	Iron	26 June 2012	Fall 2017	6	TH	Poor
	Kane 1	August 2012	August 2017	5	T	Poor
	Kane 2	Fall 2009	Spring 2018	9	T	Fair
2019	Sevier 3	August 2014	Fall 2018	4	TH	Good
	Piute	2004	April 2019	15	T	Poor

[a] If exact date was not known, a season and/or year was provided.
[b] Establishment year included if planted in the spring.
[c] T, tillage; H, herbicide. Tillage included various combinations of disk and turbo chisel. Herbicide included either glyphosate or 2, 4-D.
[d] Stand condition was based on visual ratings by cooperating growers.

TABLE 3.4 Significance of *F* tests for the fixed effects of site, spring N, and their interaction on forage dry matter yield and quality parameters (CP, Crude Protein; TDN, Total Digestible Nutrients; NDF, Neutral Detergent Fiber; RFV, Relative Feed Value; RFQ, Relative Forage Quality) across all sites, along with the effect of spring N at each site-year.

Parameter	**Yield**	**CP**	**TDN**	**NDF**	**RFV**	**RFQ**
	---------- $P > F$ ----------					
Site	<0.001	<0.001	<0.001	<0.001	<0.001	<0.001
N	<0.001	<0.001	0.267	0.594	0.497	<0.001
Site*N	0.036	<0.001	0.002	0.001	0.003	<0.001
			(Analysis of fixed effect of N by site)			
Site	**Yield**	**CP**	**TDN**	**NDF**	**RFV**	**RFQ**
	---------- $P > F$ ----------					
Box Elder 6	0.170	<0.001	0.675	0.193	0.359	0.010
Box Elder 7	0.042	0.005	0.056	0.003	0.007	.[b]
Uintah 2	0.942	0.026	0.013	0.124	0.060	0.043
Millard	0.321	0.025	0.093	0.098	0.078	0.572
Carbon	<0.001	0.008	0.326	0.051	0.085	0.013
Sevier 1	0.431	<0.001	0.004	0.053	0.021	<0.001
Sevier 2	0.407	0.002	0.095	0.314	0.233	<0.001
Iron	0.200	<0.001	0.447	0.326	0.341	0.001
Kane 1	0.544	<0.001	0.132	0.190	0.152	0.002
Kane 2	0.856	0.255	0.851	0.720	0.766	0.572
Sevier 3	0.005	<0.001	0.189	0.079	0.139	<0.001
Piute	.[a]	0.013	0.191	0.232	0.217	0.015

[a] Yield data were missing for this site.
[b] RFQ data was out of range for this site.

TABLE 3.5 Parameter estimates and significance for regression models used to describe the response of forage dry matter (DM) yield to fertilizer N, along with the corresponding economic optimum N rate (EONR) for forage yield at a fertilizer N cost: small grain forage price ratio of 0.25 US$ kg^{-1} N per 49.91 US$ Mg^{-1} (0.55 US$ lb^{-1} N per 55 US$ ton^{-1}). Regression models were not shown for sites where there was no response to N or where regression models did not fit the data.

		Parameter estimates[a]							
Dependent variable	**Site**	**Model**	$\hat{\beta}_0$	$\hat{\beta}_1$	$\hat{\beta}_2$	X_0	***Model significance***	Y_{max}[b]	**EONR**
						kg N ha^{-1}	$P > F$	Mg DM ha^{-1}	kg N ha^{-1}
Forage yield, Mg DM ha^{-1}	Box Elder 7	Q	10.51	0.044	-0.00021	103	0.061	12.79	67
	Carbon	LP	4.24	0.017		101	<0.001	5.91	0
	Sevier 3	L	6.77	0.006		168	0.011	7.72	0

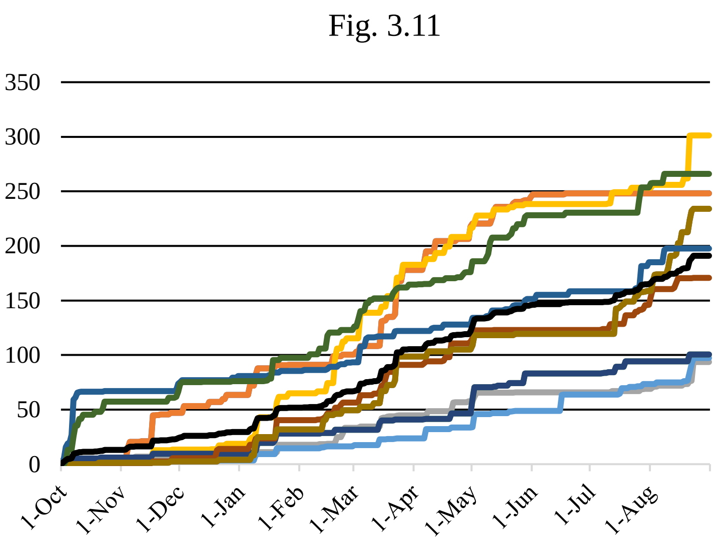
[a] L, linear; LP, linear plateau; Q, quadratic; $\hat{\beta}_0$, intercept; $\hat{\beta}_1$, linear coefficient; $\hat{\beta}_2$, quadratic coefficient, X_0, fertilizer N rate at the junction of the linear/quadratic segment and plateau segment of the nonlinear regression models.
[b] Y_{max}, is the maximum value of the dependent variable predicted by the regression equation.

TABLE 3.6 Parameter estimates and significance for regression models used to describe the response of forage quality to fertilizer N. Regression models were not shown for sites where there was no response to N or where regression models did not fit the data.

		Parameter estimates[a]						
Dependent variable	**Site**	**Model**	$\hat{\beta}_0$	$\hat{\beta}_1$	$\hat{\beta}_2$	X_0	***Model significance***	Y_{max}[b]
						kg N ha^{-1}	$P > F$	
Crude protein, g kg^{-1}	Box Elder 6	L	75.11	0.254		168	<0.001	118
	Box Elder 7	L	63.15	0.151		168	0.001	88
	Uintah 2	L	110.28	0.125		168	<0.001	131
	Millard	LP	135.45	0.126		119	0.032	150
	Carbon	L	111.01	0.201		168	0.002	145
	Sevier 1	LP	118.57	0.387		104	<0.001	159
	Sevier 2	QP	104.58	1.323	-0.00837	79	<0.001	157
	Iron	QP	103.14	1.227	-0.00449	137	<0.001	187
	Kane 1	LP	148.38	0.603		78	<0.001	195
	Sevier 3	LP	106.14	0.507		95	<0.001	154
	Piute	L	125.35	0.105		168	0.026	143
TDN, g kg^{-1}	Sevier 1	LP	637.88	0.237		101	0.012	662
NDF, g kg^{-1}	Box Elder 7	QP	647.58	0.929	-0.00417	111	<0.001	699
RFV	Box Elder 7	QP	86.61	0.188	-0.00090	116	<0.001	96
	Sevier 1	L	92.09	0.046		168	0.016	99
RFQ	Box Elder 6	LP	19.00	0.277		134	<0.001	52
	Uintah 2	L	35.37	0.140		168	0.002	57
	Carbon	L	40.41	0.174		168	0.003	67
	Sevier 1	LP	49.26	0.344		101	<0.001	80
	Sevier 2	QP	33.64	1.477	-0.01207	68	<0.001	79
	Iron	QP	38.57	0.999	-0.00492	102	<0.001	89
	Kane 1	QP	74.84	0.871	-0.00740	66	<0.001	101
	Sevier 3	LP	27.40	0.487		91	<0.001	67
	Piute	L	56.16	0.095		168	0.046	70

[a] L, linear; LP, linear plateau; QP, quadratic plateau; $\hat{\beta}_0$, intercept; $\hat{\beta}_1$, linear coefficient; $\hat{\beta}_2$, quadratic coefficient, X_0, fertilizer N rate at the junction of the linear/quadratic segment and plateau segment of the nonlinear regression models.

[b] Y_{max}, is the maximum value of the dependent variable predicted by the regression equation.



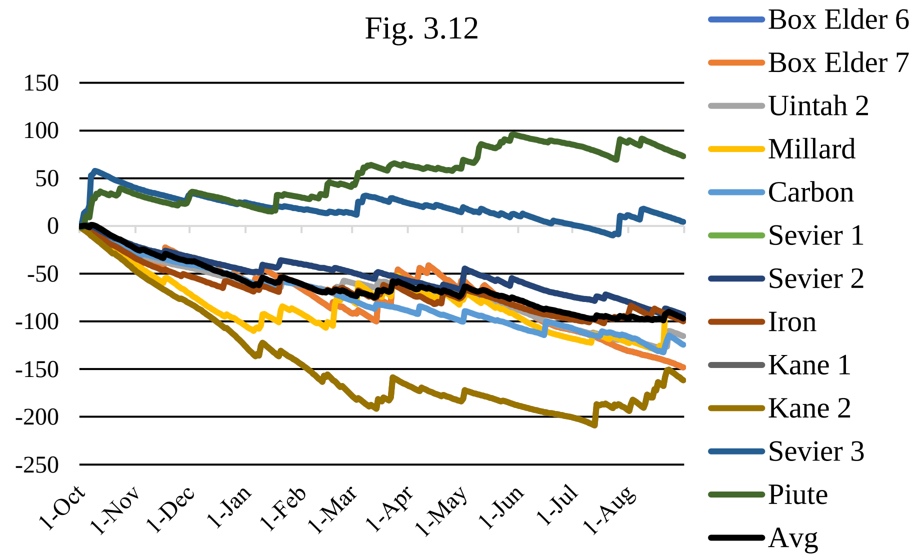
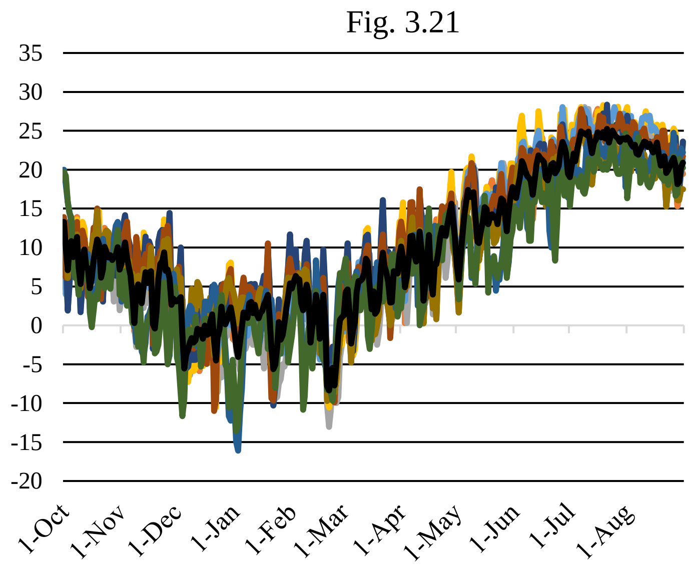


Figure 3.11: Cumulative daily precipitation per site-year (mm), October 1 through August 31 the following year, to cover the growing season of fall and spring planted small grain forages.

Figure 3.12: Cumulative daily precipitation per site-year shown as a percent difference of the 30-year normal (1981-2010), October 1 through August 31 the following year, to cover the growing season of fall and spring planted small grain forages.



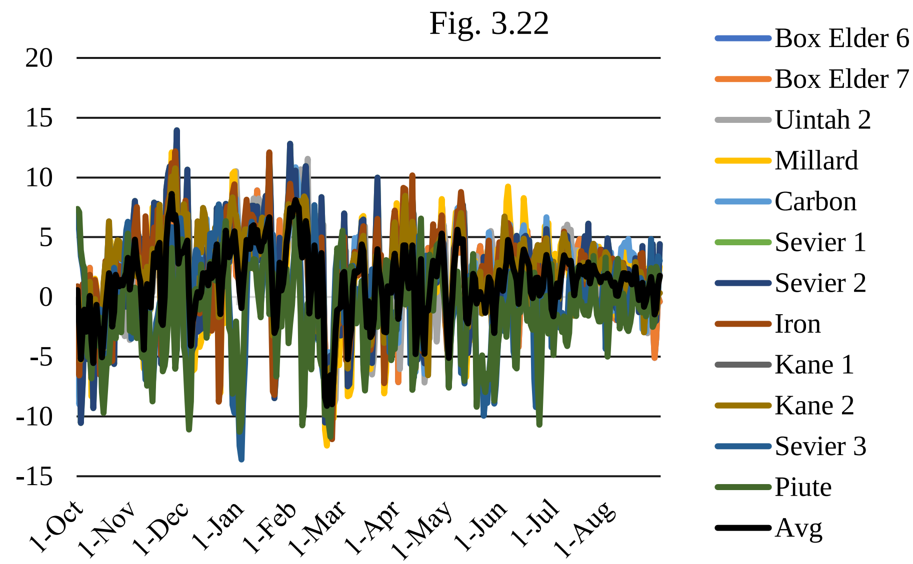


Figure 3.21: Daily average air temperature per site-year (°C). All weather measurements recorded daily, October 1 through August 31 the following year, to cover the growing season of fall and spring planted small grain forages.

Figure 3.22: Daily average air temperature per site-year shown as a percent difference of the 30-year normal (1981-2010). All weather measurements recorded daily, October 1 through August 31 the following year, to cover the growing season of fall and spring planted small grain forages.

Fig. 3.3

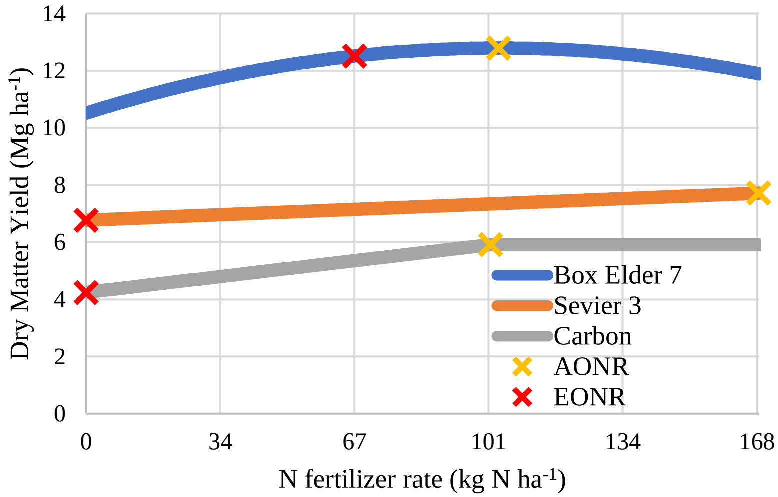


Fig. 3.4

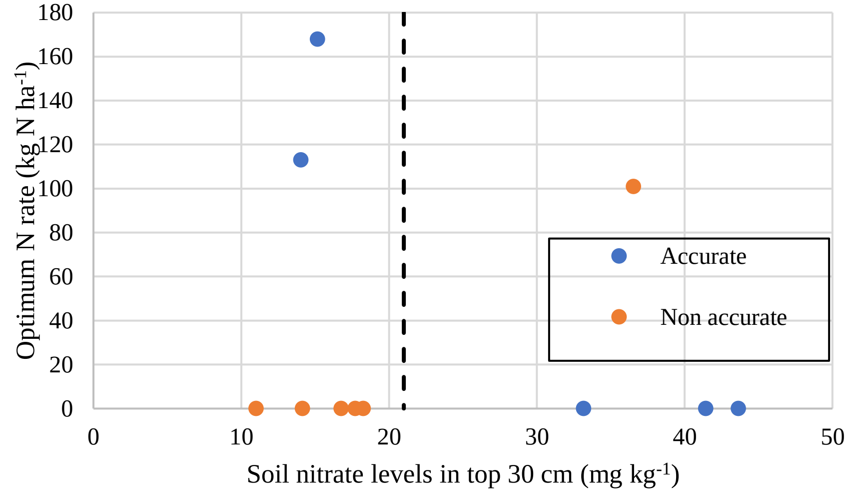


Figure 3.3: Regression models for each responsive site-year. AONR (agronomic optimum N rate) for yield values shown (Orange “X”) and ENOR (economic optimum N rate) (Red “X”). Box Elder 7, Sevier 3, and Carbon sites had AONR values at 113, 168, and 101 kg N ha^{-1}, respectively. Box Elder 7 had an ENOR value of 67 kg N ha^{-1}.

Figure 3.4: Relationship between spring soil nitrate in the top 30 cm and agronomic optimal fertilizer N rates for yield at each of the 11 small grain forage site-years in Utah. A critical concentration of 21 mg kg^{-1} was used to gauge if additional N was required to achieve optimum levels. This prediction test was accurate in 45% of the site-years.

LITERATURE CITED

Abad, A., Michelena, A., & Lloveras, J. (2005). Effects of nitrogen supply on wheat and on soil nitrate. *Agronomy for Sustainable Development*, *25*, 439-446.

Andraski, T. W., & Bundy, L. G. (2002). Using the presidedress soil nitrate test and organic nitrogen crediting to improve corn nitrogen recommendations. *Agronomy Journal*, *94*, 1411-1418.

Alcoz, M. M., Hons, F. M., & Haby, V. A. (1993). Nitrogen fertilization timing effect on wheat production, nitrogen uptake efficiency, and residual soil nitrogen. *Agronomy Journal*, *85*, 1198-1203.

Arregui, L. M., Lasa, B., Lafarga, A., Iraneta, I., Baroja, E., & Quemada, M. (2006). Evaluation of chlorophyll meters as tools for N fertilization in winter wheat under humid Mediterranean conditions. *European Journal of Agronomy*, *24*, 140-148.

Ballesta, A. & Lloveras, J. (2010). Nitrogen replacement value of alfalfa to corn and wheat. *Spanish Journal of Agricultural Research, 8,* 159-169.

Blackmer, A. M., Pottker, D., Cerrato, M. E., & Webb, J. (2013). Correlations between soil nitrate concentrations in late spring and corn yields in Iowa. *Journal of Production Agriculture*, *2*, 103.

Brown, B. D., & Petrie, S. (2006). Irrigated hard winter wheat response to fall, spring, and late season applied nitrogen. *Field Crops Research*, *96*, 260-268.

Bullied, W. J., Entz, M. H., Smith Jr., S. R., & Bamford, K. C. (2002). Grain yield and N benefits to sequential wheat and barley crops from single-year alfalfa, berseem and red clover, chickling vetch and lentil. *Canadian Journal of Plant Science*, *82*, 53-65.

Bulman, P., & Smith, D. L. (1993). Grain Protein Response of Spring Barley to High Rates and Post-Anthesis Application of Fertilizer Nitrogen. *Agronomy Journal*, *85*, 1109-1113.

Cardon, G. E., Kotuby-Amacher, J., Hole, P., & Koenig, R. (2008). Understanding your soil test report. Utah State Cooperative Extension Service AG/Soils/2008-01pr. http://extenion.usu.edu/fi les/publications/publication/ AG_Soils_2008-01pr.pdf/

Cazzato, E., Tufarelli, V., Laudadio, V., Stellacci, A. M., Selvaggi, M., Leoni, B., & Troccoli, C. (2013). Forage yield and quality of emmer (*Triticum dicoccum* Schübler) and spelt (*Triticum spelta* L.) as affected by harvest period and nitrogen fertilization. *Acta Agriculturae Scandinavica, Section B – Soil & Plant Science*, *63*, 571-578.

Clark, J. (2014). Yield and quality of first-year corn silage following alfalfa stand termination as affected by tillage, herbicide, and nitrogen fertilizer. Thesis. Dept. Plants, Soils, Climate. Utah State University.

Collins, M., Brinkman, M. A., & Salman, A. A, (1990). Forage yield and quality of oat cultivars with increasing rates of nitrogen fertilizer. *Agronomy Journal*, *82*, 724-728.

Creech, E., Yost, M., Cardon, G., Ransom, C. & Clark, J. (2020). Considerations for crop rotation from alfalfa to corn. Utah State Univ. Ext. AG/Crops/2020-01pr. https://digitalcommons.usu.edu/cgi/viewcontent.cgi?article=3117&context=extension_curall.

Dogan, R., & Bilgili, U. (2010). Effects of previous crop and N-fertilization on seed yield of winter wheat (*Triticum Aestivum* L.) under rain-fed Mediterranean conditions. *Bulgarian Journal of Agricultural Science*, *16*, 733-739.

Doyle, A. D. & Shapland, R. A. (1991). Effect of split nitrogen applications on the yield and protein content of dryland wheat in northern New South Wales. *Australian Journal of Experimental Agriculture* 31, 85-92. https://doi.org/10.1071/EA9910085

Entz, M. H., Bullied, W. J., Forster, D. A., Gulden, R., & Vessey, J. K. (2001). Extraction of subsoil nitrogen by alfalfa, alfalfa-wheat, and perennial grass systems. *Agronomy Journal*, *93*, 495-503.

Fox, R. H., Roth, G. W., Iversen, K. V., & Piekielek, W. P. (2010). Soil and Tissue Nitrate Tests Compared for Predicting Soil Nitrogen Availability to Corn. *Agronomy Journal*, *81*, 971.

Forster, D. A. (1998). Rotational benefits associated with alfalfa. M. S. thesis. Dept. of Plant Sci., Univ. of Manitoba, Winnipeg, MB, Canada.

Gooding, M. J., Kettlewell, P. S., & Hocking, T. J. (1991). Effects of urea alone or with fungicide on the yield and breadmaking quality of wheat when sprayed at flag leaf and ear emergence. *The Journal of Agricultural Science*, *117*, 149-155.

Harmoney, K. R. & Thompson, C. A. (2005). Fertilizer rate and placement alters triticale forage yield and quality. *Forage Grazinglands*, *3*, 1-11.

Hill, R. W., Miner, D., & Hinton, A. (2002). Sprinkler, crop water use, and irrigation time in Utah county. *Utah State University Extension Electronic Publication*, ENGR/BIE/WM/28.

Holford, I. C. R., & Doyle, A. G. (1992). Yield responses and nitrogen fertilizer requirements of wheat in relation to soil nitrate levels at various depths. *Australian Journal of Soil Research, 30*, 683-694.

Holford, I. C. R., Doyle, A. D., & Leckie, C. C. (1992). Nitrogen response characteristics of wheat protein in relation to yield response and their interactions with phosphorus. *Australian Journal of Agricultural Research*, *43*, 969-986.

Huber, D. M. (1971). Spring versus fall nitrogen fertilization and take-all of spring wheat. *Phytopathology*, *62*, 434-436.

Jackson, G. (1998). Predicting spring wheat yield and protein response to nitrogen. *Montana State University Fertilizer Facts*, Number 17.

Jackson, G., & Engel, R. (2006). Winter wheat response to nitrogen and sulfur fertilization. *Fertilizer Facts*, 41. Montana State University Extension.

James, D. W. & Topper, K. F. (2010). Utah fertilizer guide. https://extension.usu.edu/waterquality/files-ou/Agriculture-and-Water-Quality/Fertilizer/AG-431.pdf

Johnson, P. & McClure, S. (2015). Maximizing winter wheat returns with nitrogen and fungicides. *Crops and Soils*, *48*, 20-25.

Johnson, V. A., Dreier, A. F., & Grabouski, P. H. (1973). Yield and protein responses to nitrogen fertilizer of two winter wheat differing in inherent protein content of their grain. *Agronomy Journal*, *65*, 259-263.

Jones, C. (2017). Crop and fertilizer management practices to minimize nitrate leaching. *A Self-Learning Resource from MSU Extension*, MT201103AG.

Kaiser, D. E., Lamb, J. A., Sims, A., & Wiersma, J. (2013). Fertilizing Wheat in Minnesota. Univ. Minnesota Ext. (AG-FO-3814-C): 1–6.

Kanwar, R. S., Baker, J. L., & Baker, D. G. (1988). Tillage and split N-fertilization effects on subsurface drainage water quality and crop yields. *Transactions of the ASAE*, *31*,453-461.

Kelling, K. A., Speth, P. E, & Wood, T. (2000). Effect of tillage on alfalfa N credit to winter wheat. In Proceedings: *Wisconsin Fertilizer, Aglime and Pest Management Conference*, *39*, 405.

Kelling, K. A., Speth, P. E., Kilian, K., Wood, T., & Mlynarek, M. (2002). Direct comparison of alfalfa nitrogen credits to corn and wheat. In: Proceedings of the Wisconsin Fertilizer, Aglime, and Pest Management Conference, Madison, WI. 15017 Jan. 2002. University of Wisconsin Extension, Madison.

Khalil, S. K., Khan, F. Rehman, A., Muhammad, R., Amanullha, Khan, A. A., Wahab, S., Akhtar, S., Zubair, M., Khalil, I. H., Shah, M. K., & Khan, H. (2011). Dual purpose wheat for forage and grain yield in response to cutting, seed rate and nitrogen. *Pakistan Journal of Botany*, *43*, 937-947.

Knott, C., Ritchey, E., & Murdock, L. (2015). Reductions of wheat yield and yield components and nitrogen loss following frozen soil nitrogen applications. *Plant and Soil Sciences Research Report*, *4*, No. 1.

Kutner, M. H., Nachtsheim, C. J., & Neter, J. (2004). *Applied Linear Regression Models* (4th ed.). New York, McGraw-Hill.

Lin, E., Putnam, D., Pettygrove, S., Lundy, M., Orloff, S., & Wright, S. (2015). Alfalfa contributes more nitrogen to following crop than previously thought. In Proceedings: Western Nutrient Management Conference. 2015. Vol.11. Reno, NV.

Lory, J. A., Russelle, M. P., & Peterson, T. A. (1995). A comparison of two nitrogen credit methods: Traditional vs. difference. *Agronomy Journal*, *87*, 648-651.

Malhi, S. S., Berkenkamp, W. B., & McBeath, D. K. (2014). Relative nitrogen fertilizer requirements of forage versus grain for barley and oat. *Journal of Plant Nutrition*, *37*, 1514-1521.

Malhi, S. S., Lemke, R., & Schoenau, J. J. (2010). Influence of time and method of alfalfa stand termination on yield, seed quality, N uptake, soil properties and greenhouse gas emissions under different N fertility regimes. *Nutrient Cycling in Agroecosystems*, *86*, 17-38.

Moreira, N. (1989). The effect of seed rate and nitrogen fertilizer on the yield and nutritive value of oat-vetch mixtures. *The Journal of Agricultural Science*, *112*, 57-66.

Morey, D. D., Walker, M. E., Marchent, W. H., & Lowrey, R. S. (1969). Small grain forage production and quality as influenced by rates of nitrogen. *CAB Direct*, *19*, 18.

Munier, D., Kearney, T., Pettygrove, G., Brittan, K., Mathews, M., & Jackson, L. (2006). Fertilization of Small Grains. Small Grain Production Manual. *University of California Division of Agriculture and Natural Resources Publication 8167*.

Mut, Z., Sezer, I., & Gulumser, A. (2005). Effect of different sowing rates and nitrogen levels on grain yield, yield components and some traits of triticale. *Asian Journal of Plant Science*, *4*, 533-539.

NIRS Consortium. (2012). NIRSC calibrations. NIRS Forage and Feed Testing Consortium. http://nirsconsortium.org/ (accessed 04 February 2020).

Olsen, S. R., Cole, C. V., Watanabe, F. S., & Dean, L. A. (1954). Estimations of available phosphorus in soil by extraction with sodium bicarbonate. *USDA Cir. No. 939*.

Orloff, S., Wright, S. & Ottman, M. (2012). Nitrogen management impacts on wheat yield and protein. In Proceedings, California Alfalfa & Grains Symposium, Sacramento, CA, 11-12.

Piekielek, W. P. & Fox, R. H. (1992). Use of a chlorophyll meter to predict sidedress nitrogen requirements for maize. *Agronomy Journal*, *84*, 59-65.

Rehm, G., Schmitt, M., & Eliason, R. 2013. Fertilizing Wheat in Minnesota. Univ. Minnesota Ext. (AG-FO-3814-C): 1–6.

Rhodes, J. D. (1982). Soluble Salts, pp. 167-179. In: A.L. Page (ed), Methods of Soil Analysis Part 2. American Society of Agronomy, Inc. Madison, WI.

Russelle, M. (2004). The environmental impacts of N_2 fixation by alfalfa. In Proceedings: National Alfalfa Symposium, 13-15 December 2004, San Diego, CA.

Saint Pierre, C., Peterson, C. J., Ross, A. S., Ohm, J., Verhoeven, M. C., Larson, M., & Hoefer, B. (2008). White wheat grain quality changes with genotype, nitrogen fertilization, and water stress. *Agronomy Journal*, *100*, 414-420.

SAS Institute. (2016). SAS University Edition 2.8 9.4 M6. Cary, NC: SAS Institute.

Schoenau, J. J., & Karamonos, R. R. (1993). *Sodium Bicarbonate Extractable P, K, and N*. pp. 51-58. In: M.R. Carter (ed.), Soil Sampling and Methods of Analysis. Canadian Society of Soil Science. Ottawa, Ontario, Canada.

Shapiro, C. A. & Bavougian, C. M. (2017). Crop sequence and in-season nitrogen (N) application effects on organic winter wheat (*Triticum aestivum* L.) yield and quality. *Biological Agriculture & Horticulture*, *33*, 158-171.

Simón, M. R., Perelló, A. E., Cordo, C. A., & Struik, P. C. (2002). Influence of *Septoria tritici* on yield, yield components, and test weight of wheat under two nitrogen fertilization conditions. *Crop Science*, *42*, 1974-1981.

Sims, J. R., and Jackson, G. D. (1971). Rapid analysis of soil nitrate with chromotropic acid. *Soil Science Society of America*, *35*, 603-606.

Sowers, K. E., Pan, W. L., Miller, B. C., & Smith, J. L. (1994). Nitrogen use efficiency of split nitrogen applications in soft white winter wheat. *Agronomy Journal*, *86*, 942-948.

Stalcup, L., (2004). Wheat Hay: Cattle Love It. https://www.beefmagazine.com/mag/beef_wheat_hay_cattle

Stanger, T. F., & Lauer, J. G. (2008). Corn grain yield response to crop rotation and nitrogen over 35 years. *Agronomy Journal*, *100*, 643-650.

Stopes, C., Millington, S., & Woodward, L. (1996). Dry matter and nitrogen accumulation by three Leguminous green manure species and the yield of a following wheat crop in an organic production system. *Agriculture, Ecosystems & Environment*, *57*, 189-196.

Stute, J. K., & Posner, J. K. (1995). Synchrony between legume nitrogen release and corn demand in the upper Midwest. *Agronomy Journal*, *87*, 1063-1069.

Trammell, M. & Walker, D. (2019). The basics of forage quality. *Nobel News and Views*, May 2019.

UCDavis NRCS. *SoilWeb*. Casoilresource.lawr.ucdavis.edu/gmap/ Accessed 2018-2020.

USDA-NASS (2018). 2018 Utah Agriculture Statistics and Utah Department of Agriculture and Food Annual Report.

Utah State University Utah Climate Center. https://climate.usu.edu Assessed 2018 and 2019.

Varinderpal-Singh, Yadvinder-Singh, Bijay-Singh, Thind, H. S., Kumar, A., & Vashistha, M. (2011). Calibrating the leaf colour chart for need based fertilizer nitrogen management in different maize (*Zea mays* L.) genotypes. *Science Direct*, *120*, 276-282.

Walkley, A., Black, I.A. (1934). An examination of the Degtjareff method for determining soil organic matter and a proposed modification of the chromic acid titration method. *Soil Science, 37,* 29-38.

Walker, A. T., Coulter, J. A., Russelle, M. P., Venterea, R. T., Mallarino, A. P., Lauer, J. G., & Yost, M. A. (2017). Do soil tests help forecast nitrogen response in first-year corn following alfalfa on fine-textured soils? *Soil Science Society of America Journal, 81*, 1640-1651.

Wang, Z. J., Wang, J. H., Liu, L. Y., Huang, W. J., Zhao, C. J., & Wang, C. G. (2004). Prediction of grain protein content in winter wheat (*Triticum aestivum* L.) using plant pigment ration (PPR). *Field Crops Research*, *90*, 311-321.

Wood, C. W., Reeves, D. W., Duffield, R. R., & Edmisten, K. L. (1992). Field chlorophyll measurements for evaluation of corn nitrogen status. *Journal of Plant Nutrition*, *15*, 487-500.

Yost, M. A., Russelle, M. P., & Coulter, J. A. (2013). Nitrogen requirements of first-year corn following alfalfa were not altered by fall-applied manure. *Agronomy Journal*, *105*, 1061-1069.

Yost, M. A., Russelle, M. P., & Coulter, J. A. (2014). Field-specific fertilizer nitrogen requirements for first-year corn following alfalfa. *Agronomy Journal*, *206*, 645-658.

Yost, M. A., Russelle, M. P., Coulter, J. A., Schmitt, M. A., Sheaffer, C. C., and Randall, G. W. (2015). Stand age affects fertilizer nitrogen response in first-year corn following alfalfa. *Agronomy Journal*, *107*, 486-494.