Comparison of Private and Public Lab Fertilizer Recommendation Impacts on Field Crop Production and Soil Test Results

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COMPARISON OF PRIVATE AND PUBLIC LAB FERTILIZER RECOMMENDATION IMPACTS ON FIELD CROP PRODUCTION AND SOIL TEST RESULTS

by

Megan Baker

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

of

MASTER OF SCIENCE

in

Plant Science

Approved:

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UTAH STATE UNIVERSITY
Logan, Utah

2024

ABSTRACT

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by

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Utah State University, 2024

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There are many sources that growers utilize to determine fertilizer needs for crops such as private and public labs, crop advisors, and fertilizer dealers. In many cases, these sources provide recommendations for a specific crop that can vary greatly, which can lead to large differences in cost. An experiment was established in 2021 with 12 sites across the state of Utah in alfalfa, small grains, and corn to test and compare fertilizer recommendations from five labs. The recommendations tested were from two public labs (Utah State University and the University of Idaho) and three commercial labs located in the Western United States. A composite soil sample was sent to multiple labs for analysis and the corresponding macronutrient and micronutrient rates recommended by each lab were applied at each site. Yield and forage quality data were collected from sites from 2021-2023 to evaluate treatment impacts. Fertilizer treatments had little to no impact at silage corn or alfalfa sites, but differences in yield and forage quality were observed at small grain forage sites.

High variability in reported soil test results for the same composite soil samples was observed from three commercial soil testing labs. Differences in soil test results are sometimes due to the accuracy of each lab's analyses, but they are also influenced by different chemical procedures being used to determine nutrient levels. Fertilizer recommendations from the five laboratories varied greatly, both for types of nutrients and rates being recommended. This is likely due to a combination of differences in soil test values (minor influence) and the fertilizer recommendation philosophies (major influence) utilized by each lab. When the recommendations were applied in field trials, higher application rates often resulted in increases in soil nutrient concentrations, but the ratio of the application rate to changes in nutrient levels varied greatly among sites and treatments. Applying higher rates to increase soil nutrient levels doesn't work for all nutrients and situations and is often not economical. The results of this study demonstrate that growers should use caution when selecting fertilizer recommendations and that there is opportunity for greater public-private coordination of fertilizer recommendations.

(119 pages)

PUBLIC ABSTRACT

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ACKNOWLEDGMENTS

I first want to thank my friends and family for all of their support and for helping me to get here. I would also like to thank my committee members, Drs. Matt Yost, J. Earl Creech and Grant Cardon for their support and direction throughout this process. Special thanks to my advisor, Dr. Matt Yost, for introducing me to the world of research and always being willing to help and provide guidance. Also, for giving me the opportunity to do this work, which I have greatly enjoyed.

I also appreciate the support and help with field work from everyone in the Yost lab: Clara Anderson, Kasey Battson, Dakota Boren, Naomi Boren, Brad Crookston, Jenae Dean, Kayla Erickson, Elisa Flint, Chase Harris, Jonno Holt, Dan Isom, LuRee Johnson, Melanie Mills, and Tina Sullivan. I also could not have done this project without the help of the USU Extension agents, Jody Gale, Mark Nelson, Mike Pace, Steve Price, Randall Violett, Reagan Wytsalucy, Cody Zesiger, and all the cooperating growers who were gracious enough to let me conduct research on their farms. I would also like to thank the Utah Department of Agriculture and Food for their funding and support that made this project possible.

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COMPARISON OF PRIVATE AND PUBLIC LAB FERTILIZER RECOMMENDATION IMPACTS ON FIELD CROP PRODUCTION AND SOIL TEST RESULTS: AN INTRODUCTION

Fertilizer is a crucial tool for global food production, with roughly 30 to 50% of crop yields being attributable to commercial fertilizer nutrient inputs (Stewart et al., 2005). Increases in crop productivity due to inputs such as fertilizer have been key to growing enough food to support growing populations. In the United States, four major crops (corn, cotton, soybeans, and wheat) account for about 60 percent of the principal crop acreage and receive over 60 percent of the nitrogen (N), phosphate (P), and potash (K) used in the nation (Weibe & Gollehon, 2006). Increased fertilizer consumption accounts for one-third of the growth in world cereal production in the 1970s and 1980s (Weibe, 2003).

The use of mineral fertilizers is important in crop production, but also one of the highest input costs for many agricultural operations. It accounts for nearly one-fifth of U.S. farm cash costs and can have massive impacts on farm profits. In some crops such as wheat and corn, fertilizer costs are even higher, accounting for about thirty-five and thirty-six percent of farm operating costs respectively (Jones & Nti, 2022). High fertilizer prices often prompt farmers to reevaluate their current nutrient management strategies and methods.

There are many sources that growers can utilize to determine fertilizer recommendations, with many relying on commercial (private) or public soil testing labs, crop advisors, fertilizer dealers, or university extension services. Universities and soil testing labs provide soil testing services with the goal of measuring nutrient levels in the soil and using this information to formulate site-specific fertilizer recommendations that will maximize or optimize crop yields. Different interpretations of soil test results and recommendation philosophies can cause fertilizer recommendations for the same crop to vary greatly.

The purpose of this thesis is to evaluate and compare fertilizer recommendations from soil testing laboratories and universities in the Western United States and their resulting impacts on crop production and soil test results. Fertilizer recommendations were compared based on cost, yield, and forage quality in alfalfa, small grains, and corn (Chapter 2). Soil samples were sent to several laboratories for analysis and fertilizer recommendations and compared to identify variability in soil test results and recommended nutrients and rates. Soil samples were collected each year and changes in soil test results due to treatments were evaluated (Chapter 3).

CHAPTER II

IMPACTS OF FERTILIZER RECOMMENDATIONS FROM PRIVATE AND PUBLIC LABS ON FIELD CROP PRODUCTION

2.1 | INTRODUCTION

Fertilizer is a crucial tool for global food production, with roughly 30 to 50% of crop yields being attributable to commercial fertilizer nutrient inputs (Stewart et al., 2005). Increases in crop productivity due to inputs such as fertilizer have been key to growing adequate food to support growing populations. In the United States, four major crops (corn, cotton, soybeans, and wheat) account for about 60 percent of the principal crop acreage and receive over 60 percent of the nitrogen (N), phosphate (P), and potash (K) fertilizer used in the nation (Weibe & Gollehon, 2006). Increased fertilizer consumption accounts for one-third of the growth in world cereal production in the 1970s and 1980s (Weibe, 2003).

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Growing environmental concerns about mineral fertilizers in crop production have contributed to the need for reduced or more-efficient fertilizer use. When fertilizers are not managed properly, excess nutrients are lost from fields and end up in downstream waters through runoff or leaching and can increase the risk of eutrophication. This occurs when elevated levels of N and P in water stimulate the growth of algae and aquatic plants, which reduces the dissolved oxygen content of the water (Crosby, 2016). Eutrophication can lead to hypoxia ("dead zones"), where fish and aquatic species are suffocated because of a lack of oxygen in the water. Harmful algal blooms also occur in freshwater systems, which can harm wildlife and produce toxins that impact humans (Keena, 2022). Many of these environmental risks can be reduced by managing nutrient inputs efficiently.

Efforts to minimize negative environmental impacts of fertilizer use prompted research into the "4R" approach, which refers to the use of the right source (matching fertilizer source to specific plant nutrient needs), right rate (matching amount of fertilizers to crop needs), right time (ensuring that nutrients are available when needed most), and right place (placing nutrients where crops can use them) in nutrient management (The Fertilizer Institute, 2017). The goal of 4R nutrient stewardship is to match nutrient supply with crop requirements to reduce nutrient losses from fields. The 4R framework supports cropping systems and landscapes that are both environmentally and economically sustainable, optimizing inputs while protecting natural resources for each unique set of conditions.

Fertilizer is a key tool in crop production and finding the balance between minimizing input costs and not reducing yields is crucial but difficult. In times when fertilizer prices are high, nutrient management decisions become even more important. Soaring prices in 2022 prompted many farmers to minimize fertilizer expenditures by skipping applications, applying lower rates, planting alternative crops that require less fertilizer, or reducing total planted acres. All these methods are effective for reducing fertilizer costs, but they are often accompanied by reduced yields or profits. Finding the optimal fertilizer rates that maximize productivity while minimizing costs is incredibly difficult, causing many farmers to look to outside sources for help.

Soil Testing Lab Comparisons

There are many sources that growers can utilize to determine fertilizer recommendations, with many relying on commercial or public soil testing labs, crop advisors, fertilizer dealers, or university extension services. Universities and soil testing labs provide soil testing services with the goal of measuring nutrients levels in the soil and using this information to formulate site-specific fertilizer recommendations that will optimize or maximize crop yields. Different interpretations of soil test results and recommendation philosophies cause fertilizer recommendations for the same crop to vary greatly (Follett & Westfall, 1986). Commercial labs are sometimes criticized for being too liberal with their fertilizer recommendations and public or University labs for being too conservative. Public and private advisors actively try to avoid or correct nutrient deficiencies to help growers thwart yield and profit loss, these efforts can sometimes lead to excessive and unprofitable fertilizer recommendations.

Many universities have downsized or discontinued their soil testing laboratories, causing many to look to the private sector to fulfill their soil testing and fertilizer recommendation needs. Comparisons of common commercial and public recommendation sources are important for providing transparency for users and for quality assurance. There have been several studies to compare soil testing laboratories and fertilizer recommendations from different sources, all finding large variation among laboratories (Follett & Westfall, 1986; Follett et al., 1987; Jacobsen at al., 2002; Liuzza et al., 2020; Olson et al., 1982).

A study conducted by Colorado State University Extension from 1984-1986 compared soil test recommendations from six laboratories over three years in irrigated corn (*Zea mays* L.) (Follett et al., 1987). The soil test results and fertilizer recommendations from Colorado State University's Soil Testing Laboratory (Fort Collins, CO, USA) were compared to five commercial soil testing laboratories. Soil test results, fertilizer recommendations, costs, and resulting yields were all collected from each treatment throughout the span of the study. This study found that there were substantial differences in fertilizer recommendations among labs, but little differences in the resulting yields. It was also concluded that the more conservative recommendations made by state university soil testing laboratories result in the highest economic returns on fertilizer investment. Similar results were found in a 2020 study in Louisiana (Liuzza et al., 2020) comparing nutrient recommendations based on soil and tissue analyses from two commercial laboratories and two university laboratories located in the southern Unites States. The commercial laboratories recommended higher nutrient input rates for corn and soybean (*Glycine max*) than the university labs in both years, but these higher rates did not increase overall crop yields. Comparisons of fertilizer recommendations from public and commercial laboratories have consistently found that commercial laboratories recommend more nutrients and at higher rates than the university recommendations. The higher rates are often accompanied by higher costs, but rarely the increased returns to justify them.

Fertilizer Recommendation Strategies

There are several different strategies that are utilized by soil testing labs and crop consultants when making fertilizer recommendations. Sufficiency, maintenance, build-up, or a combination of build-up and maintain methods are most often used. There are often major differences in the resulting recommended fertilizer rates between these methods.

The sufficiency approach is also referred to as the Percent Sufficiency concept or Crop Nutrient Requirement concept. The goal of this philosophy is to ensure that the plant has the amount of nutrient required to grow that season, with fertilizer supplementing whatever the soil is not able to provide. In this system, soil test values are interpreted as fitting within a range of categories that determine the amount of nutrient that should be added.

Sufficiency levels are determined through yield response trials. These trials are used to determine critical values, where the addition of fertilizer no longer increases yield. Every crop has its own sufficiency level for each nutrient, and each state or geographic region often has their own research to determine these sufficiency levels. This research is often done by universities and in crops and soils that are most common to specific areas (Macnack et al., 2017). Subsequently, this approach is the one most used by universities to determine fertilizer recommendations, and it is also often the most conservative approach. It maximizes yield while minimizing annual inputs.

The maintenance approach adheres to the philosophy that nutrients removed by the crop at harvest should be replaced. This approach does not recommend fertilizer application when soil nutrient levels are above critical levels, often in the high or very high categories. This is another philosophy used by universities, while not as conservative as the sufficiency approach, large amounts of fertilizers are rarely recommended. Yield is maximized while also ensuring that the soil nutrient values are not diminished (Hochmuth et al., 2018).

The build-up approach is used in cases where the goal of fertilization is to build the concentration of a nutrient within the soil to the point where it will not be limiting. This allows farmers to potentially skip fertilization in years where prices are high. Fertilizer is applied at a rate higher than what is needed by the plant in order to increase the nutrient concentration within the soil. The buildup approach recommends much higher rates of fertilizer than some of the others, with the goal of keeping soil nutrient levels at the high and very high levels. This is a method often used by commercial labs and fertilizer consultants to ensure no risk of nutrient deficiencies.

A study conducted in Nebraska from 1973-1980 compared several recommendation philosophies and the resulting yields and changes in soil test results (Olson et al., 1982). This study compared the sufficiency, maintenance, and cation saturation ratio. The cation saturation ratio approach follows the logic that to maximize yields, soils should have an ideal ratio of the soil exchangeable cations: calcium (Ca), magnesium (Mg), and Potassium (K). This system does not make recommendations for nitrogen (N), phosphorus (P), sulfur (S), or micronutrients (Rehm, 1994). This Nebraska study found that the cation balance in soil is not essential for estimating crop nutrient needs and that the maintenance concept is not financially feasible in soils already containing more than adequate nutrients. The sufficiency approach, when properly calibrated, is the most efficient method for maximizing yields while minimizing costs and environmental impact. The sufficiency approach is the one most often utilized by universities, which is why they are often criticized for being “too conservative” with their fertilizer recommendations.

Fertilizer is one of the most important crop inputs in many farming operations – having significant impacts on crop yields and farm profits. The 4R approach to nutrient management helps to optimize inputs while protecting natural resources and should be considered in crop management decisions. Variations in soil test results among soil testing laboratories, lab analysis accuracy, recommendation approaches, and financial gain can all contribute to differences in fertilizer recommendations among public and private sources. These large differences in fertilizer recommendations can be costly to the farmer and often do not result in increased profits to justify this additional cost. Ongoing and regional comparisons of recommendations are needed for a variety of crops in the Intermountain West to assist growers and possibly synchronize collective nutrient management efforts. Therefore, the objective of this study was to compare the impact of five fertilizer recommendations from public and private sources on corn, small grains, and alfalfa (*Medicago sativa*) yield, quality, and economic returns.

2.2 | MATERIALS AND METHODS

2.2.1 Site Characteristics

An experiment was conducted in 12 fields on commercial farming operations across Utah and Wyoming starting in 2021. Trials were established in the following counties in Utah: Box Elder, Weber, Carbon, Beaver, Sevier, Iron, San Juan, and in Lincoln County, Wyoming (Table 2.1). Crops included alfalfa, small grains forage, and corn. The age of alfalfa stands at trial establishment varied from 1-5 years among sites, as did the crop rotation patterns leading up to the corn and small grains sites. Soil, pest, irrigation, and crop management practices other than fertilization were managed by the cooperating growers.

For almost all sites, no fertilizers, manure, or compost were applied over the plots by the growers during the study period or for at least two years prior. Inability to avoid fertigation through pivot irrigation systems resulted in some sites having nitrogen fertilizers applied over the entire trial areas (Table 2.2). All sites with annual crops were conventionally tilled prior to planting except for site 2, which was no-till. Two of the small grain forage sites (sites 2 and 3) were fall-planted with a 4-way seed blend and double cropped each year. The second crop, usually oats (*Avena sativa*), was planted mid-summer shortly after the first harvest and harvested in the late fall. Harvest samples were only collected from the first harvest each year. Site 1 was planted in the spring with a 4-way blend and harvested once each year. Seed blends varied among sites and between years, but most blends contained the following crops: oats, wheat (*Triticum aestivum),* barley (*Hordeum vulgare),* and triticale (*Triticolsecale)* (Table 2.2).

Soil classification and textural group data were obtained from the Natural Resource Conservation Service (NRCS) Web Soil Survey Tool (NRCS, n.d.; Table 2.1). A single, large composite soil sample was collected from each site in the spring of 2021.

Composite samples (~1 kg) consisted of soil cores measuring 30 cm × 1.9 cm i.d.. Samples were air-dried for 6-10 days (d) until dry and then ground to 2 mm using a DC-5 Dynacrush Soil Crusher (Custom Laboratory Equipment Inc., Orange City, FL, USA). Each sample was thoroughly mixed to ensure uniformity and split into four subsamples (200-400 g) that were shipped to each soil testing laboratory with relevant crop management information for analysis and fertilizer recommendations.

Soil samples were originally collected from twenty-one sites for these trials in 2021, but viable forage data were only collected from twelve of them (sites 1-12). Soil samples collected from sites 13-21 were processed and analyzed with the rest, but due to the nature of on-farm trials and many uncontrollable factors, these sites were either not set up or dropped from the study. Though they did not provide forage data, the soil test results and fertilizer recommendations from each of these sites were still used for the comparison of soil testing laboratories and fertilizer recommendations.

2.2.2 Treatments

The recommendations tested were from two public labs, Utah State University (Logan, UT, USA) and University of Idaho (Moscow, ID, USA) and three commercial soil testing laboratories located in the western United States. The three commercial soil testing laboratories are referred to as labs A, B, and C for anonymity. Due to analysis turnaround times, soil samples were not sent to Utah State University (USU) and University of Idaho's (UOI) analytical labs. Instead, University recommendations (Brown et al., 2009; Cardon et al., 2008; Mahler, 2005a; Mahler, 2005b) were calculated using the soil test results from one of the commercial labs (lab A). This also reduced variation in soil test results and allowed for a more controlled comparison of fertilizer recommendations. It was not possible to do this with all commercial labs because their rate formulations and critical soil test values are not publicly available. Soil samples were submitted to each lab so that none of the labs were aware that their services were to be utilized in a fertilizer recommendation study. Each lab was given relevant crop management information such as previous crop, current crop to be grown, and yield goals for calculating fertilizer recommendations. Yield goals for crops submitted were determined by cooperating growers. At the small grain forage sites, University fertilizer recommendations for grass hay were used.

Fertilizer treatments from each lab consisted of all nutrients recommended by each of the labs applied as a blend. All fertilizer products were broadcast-applied by hand in the spring of 2021 as dry granular products due to product availability, and time and logistical restrictions. It was not possible to incorporate fertilizers because crop stands were already established. Fertilizer products were chosen to isolate nutrients as much as possible so that precise amounts of nutrients could be applied together. For example, triple super phosphate (0-45-0) and ammonium nitrate (34-0-0) were used to isolate P and N rather than more commonly used fertilizer blends (Table 2.3).

The five fertilizer recommendation treatments and nonfertilized control were arranged in a randomized complete block design at each site, with four replications of each treatment. No fertilizer was applied to control plots except in cases where fertigation through irrigation systems could not be avoided (sites 1, 9-12). Plot dimensions varied among but not within sites and plot widths were often set to accommodate field-scale harvesting equipment utilized by growers. In alfalfa, plots ranged from 3-5 m wide and 9-

14 m long. Small grains plots were 5 × 14 m at each site. Corn plots were 3 × 10 m with each plot consisting of six rows and all sites were planted at a 76 cm row spacing.

Seven of these trials were repeated in 2022 and four of those were then repeated in 2023. In the spring of 2022 and 2023, six soil cores (30 cm deep × 1.9 cm i.d.) were collected from each replicate of the six treatments and composited by treatment for a total of six samples per site with 24 cores each. Samples were processed the same as in 2021 and were again submitted to the three commercial labs for analysis. The recommended fertilizer rates for all macro and micronutrients were applied again each year to the same plots based on the soil test results from that year. In 2022 and 2023, the dry, granular micronutrients (Zn, Mn, B, and Cu) were replaced with liquid chelated forms of the isolated micronutrients to provide more uniform application of the micronutrients over the plots. Liquid micronutrients were diluted with water and applied using a backpack sprayer with a 60 cm boom.

2.2.3 Crop Yield and Quality

Alfalfa

Alfalfa harvest timing varied among farms because of differing management styles, water availability, weather conditions, and harvest methods. A BCS 718 Model walk-behind tractor with a sickle bar head (1.1 m) (BCS America, Oregon City, OR, USA) was used to harvest forage at sites where plot width differed from commercial equipment width. At sites where the walk-behind sickle-bar mower was used (site 6 and first harvest at site 4); plots were harvested 1-3 d before the cooperating growers cut the rest of the field. At sites where plots were cut by the cooperating grower’s swather (5, 7, 8, and 4 for every harvest after first), harvests occurred 1-2 d after the field was cut and before they were raked or baled. Two to four cuts of alfalfa were harvested from each site through the season. The number of cuts depended on the site environment and each farmer's crop management systems. Data were not collected from some cuts because of cutting errors that resulted in the mixing of treatments.

At sites where the sickle-bar mower was used, a 1.17 × 7.98 m strip was collected and weighed from the center of each plot for a harvest area of 9.34 m^2. At sites where plots were cut using the grower's swather, the center 3 m of the windrow in each plot was collected and weighed and harvest areas ranged from 8.36-14.4 m^2 depending on plot width. Bulk samples from each plot were weighed using an Inficon Wey-TEK Refrigerant Charging scale (Inficon, Santa Clara, CA, USA). A representative subsample (roughly 300 g) was collected from each plot and weighed in the field, dried in a forced-air oven at 60°C for 7-10 d or until mass was constant, and then weighed again to determine dry matter yield. Dried samples were ground to pass through a 1 mm sieve using a Thomas-Wiley Laboratory Mill Model 4 (Thomas Scientific, Swedesboro, NJ, USA) and then analyzed for forage quality.

Forage quality was analyzed with near-infrared reflectance spectroscopy (NIRS) using a FOSS NIRS DS2500 F Feed Analyzer (Foss North America Inc., Eden Prairie, MN, USA) at the Utah State University Analytical Laboratory (Logan, UT, USA). The legume hay NIRS consortium equations (NIRS Forage and Feed Consortium, Berea, KY, USA) were used to estimate dry matter, ash, crude protein (CP), acid detergent fiber (ADF), neutral detergent fiber (NDF), P, and K. Total Digestible Nutrients (TDN), Relative Feed Value (RFV), Relative Forage Quality (RFQ), in-vitro true dry matter digestibility 48-hr (IVTDMD48), and 48-hr neutral detergent fiber digestibility

(NDFD48) were calculated as well. Alfalfa forage quality was analyzed using equations 1–4 in 2021 and 5–8 in 2022 and 2023:

[Eq. 1] $NDFD48 = 100 - (100 - IVTDMD48) / NDF \times 100$

[Eq. 2] $TDN = (100 - (NDF - 2 + CP + Fat + Ash)) \times 0.93 + (Fat - 1) \times 0.97 \times 2.25 + (NDF - 2) \times NDFD48 / 100 - 7$

[Eq. 3] $RFV = ((120 / NDF) \times (88.9 - 0.779 \times ADF)) / 1.29$

[Eq. 4] $RFQ = ((0.012 \times 1350 / (NDF / 100) + (NDFD48 - 45) \times 0.374) / 1350 \times 100) \times TDN / 1.23$

[Eq. 5] $NDFD48 = dNDFD48 / NDF \times 100$

[Eq. 6] $TDN = (100 - NDF - 2 + CP + Fat + Ash) \times 0.98 + CP \times 0.93 + (Fat - 1) \times 0.97 \times 2.25 + NDF \times 0.93 \times NDFD48 / 100 - 7$

[Eq. 7] $RFV = ((120 / NDF) + (NDFD48 - 45) \times 0.374 / 1350 \times 100) \times (88.9 - 0.779 \times ADF)) / 1.29$

[Eq. 8] $RFQ = ((120 / NDF) + (NDFD48 - 45) \times 0.374 / 1350 \times 100) \times TDN / 1.23$

Small Grain Forage

Small grains grown for forage were harvested and processed similar to alfalfa, but all were harvested using the swather method and each site only had one harvest per season. Forage quality was analyzed with the same NIRS instrument as alfalfa using the grass hay NIRS consortium equations (NIRS Forage and Feed Consortium, Berea, KY, USA). These equations were used to estimate dry matter, ash, CP, ADF, and NDF. These values were also used to calculate TDN, RFV, and RFQ. Equations 9-11 were used in 2021 and 12-15 used in 2022 and 2023:

[Eq. 9] $RFV = ((120 / NDF) \times (88.9 - 0.779 \times ADF)) / 1.29$

[Eq. 10] $RFQ = (-2.318 + 0.442 \times CP - 0.01 \times CP \times CP - 0.0638 \times TDN + 0.000922 \times TDN \times TDN) \times TDN / 1.23$

[Eq. 11] $TDN = (100 - (NDF - 2 + CP + 2.5 + Ash)) \times 0.98 + CP \times 0.87 + 1.5 \times 0.97 \times 2.25 + (NDF - 2) \times (NDFD48 \times 0.664 + 22.7) / 100 - 10$

[Eq. 12] $DMI = (-2.318 + 0.442 \times CP - 0.01 \times CP \times CP - 0.0638 \times TDN + 0.000922 \times TDN \times TDN + ADF - 0.00196 \times ADF \times ADF - 0.00529 \times ADF)$

[Eq. 13] $RFV = DMI \times (88.9 - 0.779 \times ADF) / 1.29$

[Eq. 14] $RFQ = DMI \times TDN / 1.23$

[Eq. 15] $TDN = (100 - (NDF - 2 + CP + 2.5 + Ash)) \times 0.98 + CP \times 0.87 + (Fat - 1) \times 0.97 \times 2.25 + NDF \times 0.93 \times (22.7 + 0.664 \times NDFD48) / 100 - 10$

Silage Corn

Corn was harvested as silage corn from all sites for uniformity, though two of the fields were grown for grain corn production. Corn was harvested by hand shortly before the growers' harvests. Plants were cut 10-15 cm above the soil surface in 3 m of the center two rows of each plot for a harvest area of $1.52 \times 3.05\ m^2$. All cut plants were weighed in the field, and then a subsample of four plants was chipped in an Echo Bear Cat SC3206 Chipper Shredder (Crary Industries, West Fargo, ND, USA). Subsamples of chipped corn (roughly 500 g) were weighed and dried in a forced-air oven at 60°C, being stirred every 1-2 ds to prevent molding, until samples reached a constant mass and were then reweighed to determine dry matter yields. Dried samples were ground to pass through a 1-mm sieve and analyzed for forage quality using the same equipment as the alfalfa and small grains samples. The unfermented silage corn NIRS consortium equations (NIRS Forage and Feed Consortium, Berea, KY, USA) were used to estimate dry matter, ash, CP, ADF, NDF, starch, and to calculate TDN. TDN was calculated using the following equations, equation 16 was used in 2021 and equation 17 in 2022:

[Eq. 16] $TDN = (100 - (NDF - 2 + CP + Fat + Ash)) \times 0.98 + CP \times 0.93 + (Fat - 1) \times 0.97 \times 2.25 + (NDF - 2) \times NDFD48 / 100 - 7$

[Eq. 17] $TDN = 31.4 + 53.1 \times (1.044 - 0.0124 \times ADF)$

2.2.4 Soil Analysis Methods

Soil analysis extractants and methods were similar among the three commercial labs (Table 2.4). Extractants and methods used are detailed in *Soil, Plant, and Water Reference Methods for the Western Region 4th Edition* (Gavlak et al., 2013). Labs used the same methods for some nutrients but differed for others. Analytical methods used by each of the labs are provided (Table 2.4).

2.2.5 Fertilizer Costs

Fertilizer costs were based on local fertilizer prices paid in the spring of each year (Table 2.3). Separate fertilizer prices were used for each year to reflect the economic conditions of each of the study years. There was an exceptionally substantial increase in fertilizer prices between 2021 and 2022. The need to isolate nutrients for these trials meant that many of the fertilizers used are not ones commonly used by growers. This is reflected in the cost per unit of some of the nutrients being higher than a grower might pay. Small quantities of fertilizers were purchased for the study, but bulk pricing was used whenever possible for accuracy.

2.2.6 Data Analysis

Experiments were conducted at 12 sites in 2021, 7 sites in 2022, and 4 sites in 2023. Each experiment was a randomized complete block design with whole plots being grouped into four blocks or replications and randomly assigned to one of the six treatments. Data were analyzed at each site using the MIXED procedure of SAS (SAS Version 9.4 SAS Institute Inc., Cary, NC, USA) at $P \leq 0.05$. Sites were analyzed separately because site characteristics, crop grown, number of harvests, and other management factors varied among sites. Dependent variables were yield and specific quality factors pertinent to the crop being analyzed. At sites with one year of data, treatment was the only fixed factor, with replicate as a random effect. At the sites with multiple years of data, year, treatment, and their interaction were considered fixed effects, while replicate and interactions involving replicate were considered random. Year was also considered a repeated measure with the first-order autoregressive covariance structure. Residuals were inspected for normality and common variance visually using Q-Q plots of residuals versus predicted values. The PDIFF procedure of SAS was used to conduct mean separations using Fisher's protected LSD at $\alpha = 0.05$.

2.3 | RESULTS AND DISCUSSION

2.3.1 Variability in Soil Test Results

Split composite soil samples from twenty-one locations were sent to three commercial soil testing laboratories for analysis and fertilizer recommendations in 2021.

Reported soil test results for the submitted samples varied greatly among laboratories for some analyses, with an average CV of 26% for pH, organic matter (OM), electrical conductivity (EC), and all macro (N, P, K, S) and micronutrients (Zn, Fe, Mn, Cu, B) evaluated in this study. The CVs ranged from 1.6% for pH and 61.3% for S (Figure 2.1). This variation in reported soil test values is consistent with studies comparing the variability of soil test results from different laboratories (e.g., Jacobsen et al., 2002). Some of this variation is due to sampling error as the same soil cannot be analyzed twice, slight differences in soil test methods and procedures among labs, and analysis variability.

2.3.2 Fertilizer Recommendations

The fertilizer recommendations provided by the three commercial laboratories and calculated using university fertilizer guidelines varied considerably in both the types of nutrients and rates recommended. The observed variability in reported soil test values may have influenced the fertilizer recommendations, but it is more likely that most of the differences in the resulting recommendations are due to how the soil test values were interpreted. As seen in similar studies, university recommendations were often much more conservative than the commercial laboratories (Olson et al., 1982).

The differences in nutrients recommended and rates among laboratories were evaluated for the following nutrients: N, P, K, S, Zn, Mn, B, and Cu. The CVs of each of the nutrients were calculated and ranged from 75 to 153% with Cu being the lowest, and Mn the highest (Figure 2.2). Deficiencies in micronutrients such as Zn, Mn, B, and Cu have rarely been documented in Utah, but at least one micronutrient was recommended by one or more labs at all but one site (site 5). Commercial labs A, B, and C recommended at least one micronutrient at 76, 67, and 86% of sites, respectively, compared to the USU and UOI recommending them at 33 and 24% of sites. Zinc was recommended in 42% of fields and was the most frequently recommended micronutrient by all five labs. It was the only micronutrient recommended by USU, because in most cases soil test values were above critical micronutrient values according to USU guidelines (Cardon et al., 2008). Lab B and UOI only ever recommended Zn and B, while Labs A and C recommended all four micronutrients regularly. The ranging critical soil test values for each laboratory are likely explained by their differing soil test calibration methods and data used for estimating crop response to fertilizer.

Nitrogen was not the only nutrient with large differences in recommendations among labs, but due to its importance in most cropping systems, these differences were some of the costliest. Fertilizer recommendations for N are usually based on yield goals and occasionally soil nitrate levels, but recommendation adjustments are often made for previous crop, amount/type of residue from previous crop, and the intended purpose of the crop to be grown. Sites 12 and 19 were first-year corn following alfalfa, both having CVs in N recommendations of roughly 72% and the largest average differences across these two sites in recommended rates was 259 kg ha^{-1}. Research indicates that first-year silage or grain corn following alfalfa often does not require nitrogen fertilization because adequate levels are supplied by the previous alfalfa stand (Clark, 2014; Creech et al., 2015; Yost et al., 2014a). Other nutrients besides N must be managed and supplemented with fertilizer where necessary to ensure that they will not be limiting factors for yield in this scenario. Nitrogen fertilizer rates can also be reduced for second-year corn stands following alfalfa in most cases (Yost et al., 2014b). Sites 9 and 21 were second-year corn following alfalfa, with CVs of 70 and 48% for N recommendations among labs respectively, and differences between the highest and lowest recommendations averaging 201 kg ha^{-1} at these two sites. Surprisingly, the CVs for N rates recommended at these sites were similar to the range for most other corn sites. The only site with a higher CV was site 19 (183%), which had uncharacteristically high soil nitrate levels that ranged from 48 to 81 mg kg^{-1} depending on the laboratory analyzing them.

The recommended N rates at the four small grains sites varied greatly with CVs in recommended N rates ranging from 72 to 117% among labs. At the one site following alfalfa (site 3), variation in rates was the largest. In most cases, alfalfa can supply first-year small grains grown for forage with adequate N to optimize yield (Pound et al., 2020). The use of several laboratories and university guidelines almost guarantees that the resulting recommendations will vary, but even more so for a multi-purpose crop like small grains that can be grown for grain or forage.

Lab C recommended N fertilizer on every alfalfa site, with rates ranging from 37 to 117 kg N ha^{-1}. Lab A also recommended N application at 78% of the alfalfa sites, with rates ranging from 11 to 101 kg N ha^{-1}. Nitrogen fertilizer application is often only recommended on seeding or mixed alfalfa stands, and only at low rates ranging 22 to 45 kg N ha^{-1} to provide the crop with N before the bacterial symbiosis develops or to supplement non-legumes in the stand (Undersander et al., 2016). Large applications of N during stand establishment can inhibit bacterial symbiosis and reduce growth of mature plants (Koenig et al., 1999). Site 14 was the only seeding alfalfa stand in this study, and the recommended N rates were no different from those for the established stands.

Phosphorus and K were some of the most frequently recommended nutrients and were usually recommended at high rates. The CVs of the recommended P_2O_5 rates were similar across crops, ranging from 54 to 77% with corn being the lowest and alfalfa the highest. The range between the highest and lowest recommended rates for each site averaged 222 kg ha^{-1} overall, but some sites had differences that exceeded 400 kg ha^{-1}. Recommended K_2O rates differed among crops, with CVs of 47 to 131% for small grains and alfalfa, respectively. Potassium was not recommended as often as P_2O_5 and had a lower average range of 130 kg ha^{-1} between the highest and lowest recommendations. This is likely due to high native K levels in many Utah soils. Alfalfa can take up more K than is necessary for growth in a process known as luxury consumption (Lissbrant et al., 2009). This can potentially result in high-K forage and accelerated K removal from soil. When K concentration in forage is greater than 3% of its dry weight, there is a greatly increased risk for milk fever. Milk fever or periparturient hypocalcemia, most often impacts cows and is a metabolic disorder where Ca homeostatic mechanisms are unable to maintain normal plasma Ca concentrations when lactating (Goff & Horst, 1997). Some of the recommended K rates in alfalfa were quite high, with lab C's recommendations exceeding 200 kg K_2O ha^{-1} at 67% of sites. Recommended K_2O rates should be examined closely to prevent excessive applications that are expensive with much of the nutrient being wasted as luxury consumption or that are potentially dangerous to the animals consuming the forage.

Sulfate-sulfur recommended rates had the highest average CV (119%) of any of the macronutrients and was recommended by at least one of the labs at 95% of sites. Recommended rates in corn were the most variable with a CV of 150%, followed by small grains at 138%, and alfalfa at 84%. There have been many studies evaluating various extraction methods for S, but most are unable to accurately measure the amount of plant-available S (or SO_4^{2-}) in soils (Ajwa & Tabatabai, 1993; Hoque et al., 1987; Ketterings et al., 2011). Sulfur is a mobile in the soil and is a difficult nutrient to measure and calibrate soil tests for, so this level of variation is not surprising. Lab C did not recommend sulfate-sulfur at many sites but did recommend elemental S for soil conditioning at all sites except one. In the case of this trial, elemental S was not considered a nutrient source because labs did not account for the S in elemental S but rather recommended it separately for soil conditioning.

The commercial laboratories occasionally recommended soil amendments in addition to the nutrients. Lab A recommended gypsum at 14% of sites, with rates ranging 560 to 2242 kg ha^{-1}. Elemental S was also often recommended for soils deemed excessively calcareous. Recommendations for elemental sulfur had the highest CV of any recommended fertilizer at 202%. Lab A recommended elemental S at 19% of sites at rates of 56 to 392 kg ha^{-1}, and lab C recommended it at 95% of sites at rates ranging 28 to 599 kg ha^{-1}. Elemental S must oxidize to the plant available SO_4^{2-} before plants are able to uptake the nutrient. There are many factors that influence the speed of oxidation, making fertilizer effectiveness variable and difficult to predict.

2.3.3 Fertilizer Recommendation Costs

The soil test results, recommended nutrients, and recommended rates from each of the laboratories were often quite different, which resulted in very wide-ranging fertilizer costs for each site. Across all sites, the difference between the highest and lowest treatment costs ranged from \$528 - \$2,024 ha^{-1}. Alfalfa fertilizer costs were the most variable with an average CV of costs of 106% and an average range of \$1233 ha^{-1}. This average CV was much higher because site 15 had a CV of 286%, with a range of \$802 ha^{-1} among lab recommendations. When this site is excluded, the average CV for alfalfa sites was 83%. The CV of small grain forage fertilizer costs was similar at 81%, and recommendation ranges averaged \$790 ha^{-1}. Fertilizer recommendation costs for corn had an average CV of 61% and range of \$1283 ha^{-1}.

The cost of treatments from some of the laboratories were consistently much higher than the others. Lab C had the most expensive recommendations at 91% of sites, or all except for two small grains sites (sites 2 and 3). This was to be expected with the number of nutrients and rates consistently recommended by this lab. Universities are often quite conservative with their fertilizer recommendations, especially compared to commercial laboratories. This was evident in this study as USU's recommendations were often some of the least expensive and had the lowest fertilizer costs at 14 of the sites. This is consistent with findings from over three decades ago from Colorado State University studies comparing university recommendations to those from commercial laboratories (Follett et al., 1987). Lab B had the lowest fertilizer costs at 7 of the 21 sites, and was often among the least expensive recommendations. Lab A was usually one of the most expensive recommendations, which was again consistent with the nutrients and rates recommended. The UOI recommendation fertilizer costs were consistently towards the middle of the recommendations, and often slightly lower than average costs across labs. These differences in costs for the fertilizer recommendations for the same soil are quite large, and the more-expensive recommendations may be justified if accompanied by higher yields or forage quality.

2.3.4 Yield and Forage Quality Results

Forage data were collected from twelve of the sites (sites 1-12), and the six treatments were evaluated based on yield and the pertinent quality factors for each crop. The following quality factors were examined for all three crops: CP, ADF, NDF, and TDN. Each crop also had their own quality parameters of importance that were analyzed to determine forage quality. Protein is an important nutrient for animals and a major structural component of animal tissues and protein synthesis and is essential for many maintaining life processes (Cherian, 2019). Protein in forage quality is often measured CP, which is equal to the nitrate content of the forage × 6.25. ADF and NDF are used to calculate digestibility and predict potential intake. They represent much of the indigestible or slowly digestible components of the feed; lower values for each of these measures is desirable. TDN is an estimate of the energy content of the feed and often estimated using ADF, but TDN formulas vary depending on analysis method. Forage quality values often fall into standard ranges that determine the marketability of the crop, but these ranges vary depending on the crop and source.

Silage Corn

Silage corn was not significantly impacted by any of the fertilizer recommendation treatments at any site in either year of the study (Table 2.5). Two of these sites (sites 9 and 12) were grown for silage corn and had one year of data. The other two corn sites (sites 10 and 11) were grown for grain corn, and each had two years of data. Due to differences in cultivar selection, environment, and crop management, the yields across all sites ranged from 7.44 to 23.09 Mg ha^{-1}. The following quality factors were evaluated for corn: CP, ADF, NDF, TDN, and starch. Corn silage is typically composed of 25-35% starch, and higher values are desired (NRC, 2001). Silage corn is not typically sold based on forage quality results, but these differences are important when calculating feed rations.

None of the forage quality factors were significantly impacted by any of the treatments at any site in either year (Table 2.5). All of the fertilizer recommendation and control treatments usually resulted in values that were within typical ranges for each quality measure. The following averages and ranges were calculated using all six site-years of corn data. Crude protein content averaged 8.82% and ranged from 7.29 to 10.8%. Sites grown for silage corn often had higher protein contents than those grown for grain. ADF values averaged 21.3% (15.3 - 26.46%) and NDF averaged 39.54% (30.99 to 48.24%) across treatments and sites. TDN values averaged 72.81% and ranged from 69.41 to 76.76%. Starch ranged 24.72 to 42.83% and averaged 30.17%. The sites grown for grain corn had much higher starch contents compared to those grown for silage.

The large differences in costs across treatments were not reflected in the resulting yield and forage quality, indicating that the higher fertilizer recommendations applied were not financially feasible. Even though the differences in yield between the nonfertilized control and fertilizer treatments were not significant, this does not indicate that corn does not need fertilizer. Nitrogen is the most important plant nutrient for corn production, and all of the control plots in this study received N through fertigation because it could not be avoided. It is likely that more of a response to the fertilizer treatments would have been observed when compared to a true nonfertilized control. However, the results indicated that all the other fertilizers had no short-term impacts on corn production in this study.

Small Grain Forage

Small grain forage yield and quality were occasionally influenced by the fertilizer recommendation treatments (Table 2.6). Sites could not be compared directly to one another because each site had a different number of site-years, small grain forage varieties being grown, environments, and crop management systems. The following quality factors were evaluated: protein, ADF, NDF, TDN, relative feed value (RFV), and relative forage quality (RFQ). RFV is an index for ranking forages based on combining digestibility and intake potential and RFQ is an index for ranking forages based on TDN and intake potential. It is a better indicator of animal performance than RFV for a wide range of forages. Higher RFV and RFQ values are desired.

Forage yield at site 2 was significantly influenced by the fertilizer treatments (Figure 2.3), with all labs except for lab C increasing the yield compared to the control (4.06 Mg ha^{-1}). Yields ranged from 3.83 to 6.36 Mg ha^{-1}, with USU and lab A both increasing yield the most by 53 and 57%, respectively.

At sites with multiple site-years, treatment, year, and their interaction were analyzed. At sites 1 and 3, the year × treatment interaction did not significantly impact yield at either site, but both treatment and yield main effects were significant. Site 1 had two site-years and yields across years ranged from 5.40 to 7.29 Mg ha^{-1}. All fertilizer treatments increased yield compared to the control, with USU being the highest and increasing yield by 35% (Figure 2.3).

Yield response to treatment at site 3 varied from year to year but was only significant across years. Treatment yields ranged from 7.75 to 10.66 Mg ha^{-1} with all treatments besides one increasing yield compared to the control: lab B decreased yield by

10%. Lab A yielded the highest and increased yield by 24% compared to the control, but USU and UOI's recommendations yielded similarly and increased yield by 13% (Figure 2.3).

Forage quality parameters were often influenced by fertilizer treatments at sites 1 and 3 where yield was impacted. Site 2 was not significantly affected by treatment for any quality parameters (Table 2.6). Maximum small grain CP levels ranged from 13.6 to 17.7% and averaged 12.3% across all three sites. Small grain CP was influenced by the year × treatment interaction at site 3 (Figure 2.4). In 2021 and 2022, all treatments increased CP compared to the control, with UOI increasing it the most by 42% in 2021 and lab C increasing it by 95% in 2022. In 2023, lab B and UOI decreased CP compared to the control by 6%, while lab C was the highest and increased by 31%. At site 1, treatment and year effects were significant, but their interaction was not. When averaged over the two years, all treatments increased protein concentrations. UOI, USU, and lab C increased CP compared to the control by 18 - 21%.

ADF values ranged from 28.1 to 36.2% across sites, with site 1 averaging the lowest (29.8%). The year × treatment interaction was only significant at site 3, and the main effect of treatment did not influence ADF percentage at the other two small grain sites (Table 2.6). Response to treatment was not consistent, with the control not having the highest or lowest ADF values in any case. At site 3 in 2021, ADF values ranged from 32.4% for UOI to 34.0% for lab C. In 2022, UOI had the highest ADF at 36.2% and lab C was the lowest at 35.2%. Lab B was the highest in 2023 at 35.9% and lab C the lowest at 30.9%. The overall range was 30.9 to 36.2% for all treatments, which is relatively narrow and indicates that the fertilizer treatments did not greatly influence ADF. Across the three small grain sites, NDF values ranged from 50.5 to 66.9%, with site 1 again averaging the lowest at 52.7%. The year × treatment interaction was not significant at either site (site 1 and 3) where analyzed, nor was the main effect of treatment at any of the three sites (Table 2.6).

At site 3, the year × treatment interaction significantly affected TDN (Table 2.6). In 2021, UOI had the highest TDN of 65.6% and lab C was the lowest with 64.1%. In 2022, treatments ranged from 54.9 to 58.6%, with the control being the highest and lab C again the lowest. In 2023, TDN values ranged from 60.7 to 63.5% with lab A being the highest and UOI the lowest. The control treatment resulted in the highest or second highest in all three years. At site 1, the small grain TDN differed by year, but were not significantly impacted by treatments (Table 2.6).

For RFV, the year × treatment interaction was significant at site 3, but not at site 1. At site 3, RFV values increased each year from 2021 to 2023 and averaged 98.42, 110.75, and 136.81, respectively. In 2021, UOI was the highest with an RFV of 100.71 compared to the low of 97.0 from lab C. In 2022, lab C was the highest and lab B the lowest, with values ranging from 101.4 to 116.89. In 2023, RFV ranged from 126.28 to 145.73, with lab A being the highest and UOI the lowest. Feed values were influenced differently by treatments in each year.

The year × treatment interaction was significant at both sites 1 and 3 for RFQ. At site 1, there was a large difference in treatment impact on RFQ between 2021 and 2022. In 2021, all fertilizer treatments increased yield compared to the control, with values ranging from 69.86 to 95.54. In 2022, RFQ values ranged from 113.76 to 137.06, with control being the highest and UOI the lowest. At site 3, values in 2021 were quite low and ranged from 27.57 to 70.03, with all fertilizer treatments increasing feed quality compared to the control. In 2022, values ranged from 100.38 to 110.21 in 2022, with USU being the highest and lab B the lowest. In 2023, lab A was the highest and UOI the lowest, ranging from 131.58 to 151.19.

Small grain forage yield and quality were frequently impacted by fertilizer treatments, which can influence the profitability of the crop. Small grain forage is usually sold based on weight, with forage quality having little impact on price received. The treatment cost and yields were used to determine the economic returns on fertilizer investment, with application and all other production costs not being considered. Because prices can be variable due to many factors, the prices used for small grain forage are an average of price received for non-alfalfa hay in Utah from 2021-2023 (USDA-NASS, 2023). When this average price of \$445.55 Mg^{-1} is used, the USU fertilizer recommendation had the greatest return among all treatments across years at sites 1 and 3, and lab B's recommendations had the greatest at site 2. At site 3, the two university recommendations and the control were very similar, only ranging \$40 Mg^{-1} among treatments. The difference between the highest and lowest return was \$662.70, \$1261.95, and \$1159.41 Mg^{-1} for sites 1, 2, and 3, respectively. The nonfertilized control was often one of the most profitable treatments. When the price received for small grain forage is increased by \$50 Mg^{-1}, the treatments with the greatest returns stayed the same as using the average price. If the price received decreased by \$50 Mg^{-1} from the average price, the control treatment becomes the most profitable at site 3. At this lower price received, lab C's recommendations have the lowest return because the yields are not increased enough to justify the higher fertilizer costs. At several price points, the treatments recommending the most fertilizer were often some of the least profitable, indicating that higher rates do not necessarily mean higher economic returns.

Small grain forage was generally more responsive to the fertilizer treatments than the silage corn sites. Yield was impacted by treatments at all three sites and forage quality was often improved. Fertilizer recommendations determined using the sufficiency approach did not maximize crop yields, but instead maximized the economic returns for the crop. Small grain forage yield and quality are often influenced by fertilizer use, but other crop management factors are also very important. Small grain forages often face heavy weed pressure, and if not managed properly, can greatly reduce crop yields.

Alfalfa

Yields from each cut were summed for an annual yield for each treatment. Due to harvesting difficulties, reported yields did not include all cuttings from sites 4 and 8. One cut is missing from 2021 and 2022 for site 4, and one cut is missing from 2022 and two from 2023 for site 8. These missing cuts and differing conditions meant that alfalfa sites could not be compared directly to one another.

At the two sites with one year of data (sites 5 and 6), treatment impact on yield was not significant (Table 2.7). At site 5, yields ranged 5.22 to 8.09 Mg ha^{-1} and 12.74 to 15.73 Mg ha^{-1} at site 6. Site 5 is in an area with a short growing season and gets two cuttings per year while site 6 is in a much warmer climate and gets four cuttings per year water-permitting.

At alfalfa sites with multiple years of data (sites 4, 7, 8), treatment, year, and year × treatment interaction effects were evaluated. The year × treatment interaction was not significant at any of these sites, but differences in yield due to treatment were significant at one site. At site 7, alfalfa yields averaged 10.01, 14.08, and 13.86 Mg ha^{-1} for 2021-2023, respectively (Figure 2.5). Tall fescue (*Festuca arundinacea* L.) was inter-seeded into the alfalfa in late-summer of 2021 and contributed to the higher yields observed in 2022 and 2023. All fertilizer treatments increased yield compared to the control across years (Table 2.8) Treatments increased yield by 0.5 to 2 Mg ha^{-1}, with lab C yielded the highest and increased yield by 17%.

Yield was not significantly affected by the main effect of treatment at any of the other alfalfa sites (sites 4, 5, 6, and 8). At site 4, yields averaged 13.17, 10.78, and 12.69 Mg ha^{-1} in 2021-2023, respectively. At site 8, the missing cuts make year-to-year comparisons of treatments inaccurate because the average yields for each year vary widely. For example, the average yield for 2021 is 12.81 Mg ha^{-1} compared to 3.59 Mg ha^{-1} in 2023. These results show that alfalfa rarely responded to fertilizer in this trial. This does not indicate that fertilizer can be withheld indefinitely but points to fact that critical soil test values and corresponding nutrient guidelines may need to be updated. It also highlights the disparity among fertilizer recommendations and signifies that growers need to use caution and evaluate several sources when evaluating fertilizer recommendations.

Forage quality is one of the most important price determinants of alfalfa hay due to its importance in animal nutrition. The USDA Agricultural Marketing Service created a set of Alfalfa Hay Designation Guidelines for forage quality to designate price categories (USDA, 2003). Alfalfa hay is ranked on a scale of “utility” to “supreme,” with ADF, NDF, RFV, TDN, and CP being the determining quality factors. The goal of these guidelines is to standardize feed pricing information and give better indicators of the quality of feed. The following forage quality parameters were evaluated for alfalfa:

Protein, ADF, NDF, TDN, RFV, RFQ, P, K, INVTDMD48, and NDFD48. Phosphorus and K concentration were used to evaluate whether fertilizer treatments impacted nutrient uptake. Further, K concentration is also important because of the risk of milk fever with high-K hay. In vitro dry matter digestibility 48-hr (INVTDMD48) is a quality index that simulates in vitro processes taking place in the rumen of cattle during plant digestion. Neutral detergent fiber digestibility (NDFD48) is a measure of the percentage of NFD that could be digested within a 48-hour period. Higher values for these two factors are sought because higher INVTDMD values indicate faster decomposition rates and higher NDFD48 values indicate greater digestibility (Ball et al., 2001; Barrios, n.d.).

Alfalfa CP was not significantly impacted by any of the fertilizer treatments at any site (Table 2.7). Minimum CP levels ranged from 20.9 to 25.8% depending on the site. Overall, treatments at all sites except one had "supreme" levels of protein (>22%). ADF results were similar, with none of the differences between treatments being significant. Maximum ADF values for overall treatments ranged from 23.39 to 27.83% across sites. "Supreme" alfalfa hay is defined as having less than 27% ADF, while "premium" hay has 27 to 29%. All treatments resulted in "supreme" ADF values overall except for at site 5. At site 4, ADF values ranged from 30.12 to 31.6% in 2021, but were below 26% for the other two years. At site 8, ADF differed from year to year, but was consistently under 25%.

No significant differences due to treatment were also observed at any of the sites for NDF, and maximum values from treatments ranged from 25.5 to 33.1% across sites. "Supreme" hay has an NDF of less than 34%, which is a criterion that all sites met. At site 4, NDF values were the highest in 2021, ranging from 33.0 to 34.7% compared to

26.0 to 28.7% for 2022 and 2023. At site 7, NDF values increased each year, with average NDF values across treatments raising from 29.4 to 35.6% from 2021 to 2023. This was likely due to the increased tall fescue content in the hay each year. At site 8, NDF decreased each year and was much lower than most other sites. In 2021, ADF averaged 26.2% compared to 2023 where average ADF was 23.8%. Although treatment differences were not apparent, different alfalfa quality categories in some years could result in much lower prices received.

Minimum TDN values ranged from 68.9 to 72.1% for across treatments and sites indicating that all sites would have been rated as “supreme” alfalfa (TDN > 62%). Differences in TDN values due to treatment were not significant at any of the five alfalfa sites (Table 2.7). For a forage to be deemed “supreme,” it must have an RFV greater than 185. The minimum RFV across treatments and sites ranged from 201 to 293. Further, RFV response to treatment was not significant at any site (Table 2.8). Most of the alfalfa in this study tested “supreme” according to forage quality guidelines, with only a few cases of the “premium” category.

RFQ is similar to RFV in many ways and is sometimes substituted for RFV for pricing but can be used in a broader range of crops. RFQ was not significantly influenced by treatments at any of the alfalfa sites (Table 2.7). Average RFQ values ranged from 194 to 339 depending on the site and year.

Phosphorus concentrations in alfalfa were sometimes affected by the fertilizer treatments. At site 7, the year × treatment interaction was significant, with all fertilizer treatments increasing P concentrations compared to the control every year (Table 2.8). In 2021, USU and lab C were the same as the control, with lab B being the highest. Lab C increased P concentrations the most in 2022 and 2023 by 9.8 and 7.4 percent compared to the control, respectively. At site 6, P concentration was influenced by all the fertilizer treatments, and lab C was the highest with a 7.4% increase. The ranges for differences in actual P concentration due to treatments were often quite small, often only ranging 0.05 to 0.1% across all site-years. All the fertilizer treatments had increased P concentrations compared to the nonfertilized control. But the higher rates of P fertilizer applied in some recommendations were not reflected in higher forage P concentrations.

Due to concerns of milk fever, forage K concentrations of less than 3% of dry matter are desired. At site 7, the year × treatment interaction was significant (Table 2.7), with the K concentration increasing each year. In 2021, K concentrations ranged from 1.99 to 2.21%, with lab C being the highest and increasing K by 11%. In subsequent years, USU was the lowest, with lab C and lab A being the highest in 2022 and 2023, respectively. Only one treatment went over the 3% threshold; lab A had 3.01% in 2023. At sites 4 and 8, the year × treatment interaction was not significant, but differences in K concentration due to treatment were significant. At site 4, K concentrations ranged from 2.46 to 2.89%, with lab C increasing K by 18% compared to the control. At site 8, K concentrations ranged from 2.47 to 2.72% and lab C was again the highest and increased K by 10%. At sites with one year of data, no differences in K concentration due to treatment were observed (Table 2.7). Though only one treatment in one year went over the 3% K concentration threshold, some were close to 3%, indicating that excessive K fertilizer applications should be avoided.

INVTDMD48 and NDFD48 are forage quality factors that are calculated to help predict animal performance. They are not usually used for pricing feed but can be a key component when calculating rations. They give better indicators of the true digestibility of forages for animals compared to NDF or ADF. INVTDMD48 was not significantly impacted by the treatments at any of the alfalfa sites (Table 2.7).

The year × treatment interaction influenced the NDFD48 of alfalfa at one of the alfalfa sites (Table 2.7). At site 7, NDFD48 increased each year, averaging 50.9, 67.5, and 71.0% for 2021 through 2023, respectively. In 2022 and 2023, lab A resulted in the highest NDFD48 value, and it was also the second highest in 2021. There was no consistent pattern for any of the other treatments; the control, USU, or lab B were all the lowest in different years. The three commercial labs were the highest or towards the top in other years. At sites 4 and 8, the average NDFD48 varied each year. At site 4, it ranged from 46.2 to 59.0% across years and from 51.8 to 62.5% at site 11.

Statistically significant differences among forage quality parameters due to treatment do not always mean significant differences in the quality designation of the forage. There were several cases where differences in treatments were not significant, but the number value of quality factor caused the treatment to be designated to a different forage ranking. This can influence the marketability of a crop and the resulting price received for it. There was no consistent pattern of certain labs testing much higher than the rest and resulting in a much higher forage quality than the others. Alfalfa was deemed “supreme” or “premium” at every site in this study, which means that prices received would likely be similar or the same for the different treatments.

At site 7, the one alfalfa site where yield was significantly impacted by treatment, economic returns on fertilizer were calculated. All treatments were within the same forage quality category, so forage quality did not impact the price received for the crop.

When the average price of \$566.21 Mg^{-1} for alfalfa in Utah from 2021-2023 (USDA-NASS, 2023) is used with yield across years to compare treatments, lab B's fertilizer recommendation resulted in the highest returns (\$6698.10 ha^{-1}), and lab C the lowest (\$5438.22 ha^{-1}). The other treatments all had returns within \$200 ha^{-1} of lab B at this price. When the price received is increased by \$50 ha^{-1}, lab B is again the highest, but the overall difference between treatments is smaller. If the price received is decreased by \$50 ha^{-1}, the nonfertilized control treatment results in the highest returns, with lab B and the university treatments within \$100 ha^{-1}. The fertilizer recommendations from lab C resulted in the highest yield, but it was not the most profitable treatment. The more conservative fertilizer recommendations resulted in higher returns at all three price points considered, indicating that it is important to ensure that the rates being applied are economically feasible.

2.4 | CONCLUSIONS

This study compared soil test results and fertilizer recommendations from three commercial and two public soil testing laboratories located in the Western United States. Recommended nutrients and rates, yield, forage quality, and cost were evaluated for each of the five fertilizer treatments and nonfertilized control. Large variation in reported soil test results, fertilizer recommendations, and associated fertilizer costs were observed, with few impacts on resulting yield or forage quality.

Silage corn was not impacted by fertilizer treatments at any site in either yield or quality, but fertilizer recommendations and cost differed greatly. Differences may have been larger if the control plots had not received N through unavoidable fertigation. By contrast, small grain forage yield was consistently increased by treatments at three sites, as were several of the quality factors. At site 2, all fertilizer treatments except for lab C increased yield compared to the control. At sites with multiple years (sites 1 and 3), year × treatment interaction did not significantly impact yield at either site, but both treatment and yield main effects were significant. At site 1, fertilizer treatments increased yield compared to the control, with USU being the highest and increasing yield by 35%. At site 2, all treatments besides, one increased yield compared to the control: lab B decreased yield by 10%. Lab A yielded the highest and increased yield by 24% compared to the control, but USU and UOI's recommendations yielded similarly and increased yield by 13%. Treatment impacts on quality were not consistent across sites, but CP was increased at both sites with multiple years of data. Fertilizer treatments increased yield at one alfalfa site, but no impacts were observed at the other four. Treatments occasionally influenced forage P, K, and NDFD48, with K being significant at all sites with multiple years of data. While the increases in quality were occasionally significant, the differences would have had no or minor impact on the market value of the alfalfa.

The cost of fertilizer recommendations varied greatly among treatments and sites, but the resulting similar crop responses indicate that the higher rates were rarely justified. The fertilization philosophy and recommendation calculation methods likely had the largest impact on the fertilizer recommendations from each laboratory. Recommendations from the Universities were often more conservative than the commercial laboratories, but crop response to these fertilizer treatments was similar. These treatments were often the most economical, with yields being increased similarly with much lower inputs. But commercial laboratories do not always recommend excessive fertilizer applications, commercial lab B recommended similar rates to USU and UOI in many cases.

Fertilizer is a large input cost for many agricultural operations and can greatly influence resulting profits. Comparison studies like this provide transparency for the possible fertilizer recommendation sources used by growers. While the nonfertilized control yielded similar to fertilized treatments, this does not indicate that fertilizers are not needed for crop production. Rather it indicates that more-efficient fertilizer rates can optimize crop production while minimizing costs and negative environmental impacts. Finally, this study also highlights the pressing need for improved coordination of fertilizer recommendations among public and commercial labs, and the need to continuously update recommendations to ensure accuracy and ideal profitability for growers.

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Table 2.1 Site properties for 12 sites in Utah and Wyoming in 2021 to 2023 including site, year, location, elevation, soil texture, soil pH, and soil organic matter.

Site	Year(s)	County	Coordinates	Elevation (m)	Soil Texture	pH	Soil OM (%)
1	2021-2022	Beaver	(38.300256, -112.656962)	1818	Manderfield Loam (Fine-loamy over sandy or sandy-skeletal, mixed, mesic Calcic Argixerolls)	7.6	3.13
2	2021	Carbon	(39.492229, -110.775926)	1688	Billings silty clay loam (Fine-silty, mixed, calcareous, mesic Typic Torrifluvents)	8.1	2.89
3	2021-2023	Carbon	(39.491011, -110.787813)	1706	Billings silty clay loam (Fine-silty, mixed, calcareous, mesic Typic Torrifluvents)	8.1	2.48
4	2021-2023	Weber	(41.174268, -112.126257)	1292	Syracuse loamy fine sand (Coarse-loamy, mixed, superactive, mesic Oxyaquic Calcixerolls)	7.7	0.92
5	2021	Lincoln	(41.820626, -111.043608)	1900	bereniceton silt loam (Fine-loamy, mixed, calcareous, frigid Xeric Torriorthents)	8.2	2.59
6	2021	San Juan	(37.601761, -109.465473)	1807	Monticello very fine sandy loam (Fine-silty, mixed, superactive, mesic Typic Argiustolls)	7.8	1.91
7	2021-2023	Sevier	(38.635644, -112.154381)	1642	Escalante gravelly sandy loam (Coarse-loamy, mixed, superactive, mesic Xeric Haplocalcids)	8	1.84
8	2021-2023	Iron	(37.874388, -112.860410)	1760	Calcross silty clay loam (Fine-silty, mixed (calcareous), mesic Xeric Torriorthents)	8	1.89
9	2021	Beaver	(38.293218, -112.992531)	1551	Rustico silty clay loam (Fine-silty, mixed, superactive, mesic Cumulic Haploxerolls)	7.9	2.46
10	2021-2022	Box Elder	(41.758104, -112.174760)	1343	Kidman loam (Coarse-loamy, mixed, superactive, mesic Calcic Haploxerolls)	7.5	2.97
11	2021-2022	Box Elder	(41.763810, -112.172659)	1338	Parley's loam (Fine-silty, mixed, superactive, mesic Calcic Argixerolls)	8.2	2.18
12	2021	Iron	(38.017778, -112.707795)	1774	Antelope Spring's loam (Fine-loamy, mixed, mesic Xeric Natrargids)	8.1	2.48

Table 2.2 Management characteristics for twelve on-farm trial sites in 2021-2023 including crop grown, yield goals, stand age (if applicable), previous crops, N fertilizer applied through fertigation, and irrigation type

Site	Crop Grown 2021-2023	Yield Goal	Stand Age	2019 Crop	2020 Crop	N Fertilizer Applied	Irrigation Type
		Mg ha^{-1}	yr			kg ha^{-1}	
1	Small Grains	9	n/a	Unknown	Small Grains	10	Pivot
2	Small Grains	6	n/a	Corn	Oats	0	Pivot
3	Small Grains	6	n/a	Alfalfa	Alfalfa	0	Wheel line
4	Alfalfa	17	3	Alfalfa	Alfalfa	0	Flood
5	Alfalfa	10	3	Alfalfa	Alfalfa	0	Pivot
6	Alfalfa	13	1	Fallow	Fallow	0	Wheel line
7	Alfalfa	13	4	Alfalfa	Alfalfa	0	Pivot
8	Alfalfa	13	2	Alfalfa	Alfalfa	0	Wheel line
9	Silage Corn	63	n/a	Alfalfa	Corn	22	Pivot
10	Grain Corn	20	n/a	Corn	Corn	45	Pivot
11	Grain Corn	20	n/a	Wheat	Wheat	45	Pivot
12	Silage Corn	72	n/a	Alfalfa	Alfalfa	11	Pivot

Table 2.3 Fertilizer sources used in recommendation studies in 2021-2023 including nutrient, fertilizer source, analysis of fertilizer, additional S, and cost per kg and Mg per unit of nutrient for each year of study

Nutrient	**Source**	**Fertilizer Analysis**	**Additional Sulfur**	**2021 Cost**	**2022 Cost**	**2023 Cost**
		% of target nutrient	% S	$ kg^{-1} of Nutrient	$ kg^{-1} of Nutrient	$ kg^{-1} of Nutrient
Nitrogen (N)	Ammonium Nitrate	34%		1.62	2.89	2.89
Phosphorus (P)	Triple Super Phosphate	45%		2.16	4.15	3.55
Potassium (K)	Potash	60%		1.35	1.35	1.26
Sulfur (S)	Elemental Sulfur	90%		0.48	0.48	0.63
Sulfur-sulfate (SO_4^{2-})	2021 Gypsum	64%	12%	0.13		
Zinc (Zn)	Zinc Sulfate	36%		4.92		
Manganese (Mn)	Manganese	8%	6%	35.83		
Boron (B)	Boron	14%		14.96		
Copper (Cu)	Copper Sulfate	25%		20.85		
Sulfur-sulfate (SO_4^{2-})	22-23 Gypsum	97%	17.5%		0.14	0.14
Zinc (Zn)	Chelated Zinc	9%			41.20	41.20
Manganese (Mn)	Manganese	5%			66.36	66.36
Boron (B)	Boron	10%			32.07	32.07
Copper (Cu)	Copper	8%			42.76	42.76

Table 2.4 Soil analytical methods and extractants used by three commercial soil testing laboratories for the following parameters: pH, Organic Matter (OM), Electrical Conductivity (EC), N, P, K, SO_4^{2-}, Zn, Fe, Mn, Cu, and B. Method numbers reference Soil, Plant, and Water Reference Methods For the Western Region 4th Edition (Gavlak et al., 2013).

	Lab A		**Lab B**		**Lab C**	
Parameter	**Method Number**	**Methods**	**Method Number**	**Methods**	**Method Number**	**Methods**
pH	S-2.20	1:1 (soil:water)	S-2.20	1:1 (soil:water)	S-2.10	1:2 (soil:water)
OM	S-9.20 adjusted	Loss on Ignition adjusted to Walkley Black	S-9.10	Walkley Black	S-9.20	Loss on Ignition
EC	S-2.30 adjusted	1:1 (soil:water) adjusted to saturated paste	S-2.20	1:1 (soil:water)	not provided	methods not provided
N	S-3.10	KCl Extraction /Cadmium reduction	S-3.10	KCl Extraction / Cadmium reduction	S-3.10	KCl Extraction / Cadmium reduction
P	modified S-4.60	Olsen modified by AA-NH_4F Kewlona extraction	S-4.10	Olsen-Sodium Bicarbonate	S-4.10	Olsen-Sodium Bicarbonate
K	S-5.10 adjusted	AA 1:10 extraction adjusted to bicarbonate	S-5.10	Ammonium Acetate / ICP	S-5.10	Ammonium Acetate / ICP
SO_4^{2-}	S-4.60	AA-NH_4F Kewlona extraction	S-6.11	DTPA / Sorbitol / ICP	S-5.10	Ammonium Acetate / ICP
Zn	S-6.10	DTPA Extraction	S-6.11	DTPA / Sorbitol / ICP	S-6.10	DTPA Extraction
Fe	S-6.10	DTPA Extraction	S-6.11	DTPA / Sorbitol / ICP	S-6.10	DTPA Extraction
Mn	S-6.10	DTPA Extraction	S-6.11	DTPA / Sorbitol / ICP	S-6.10	DTPA Extraction
Cu	S-6.10	DTPA Extraction	S-6.11	DTPA / Sorbitol / ICP	S-6.10	DTPA Extraction

B	S-4.60	AA-NH4F Kewlona extraction	S-6.11	DTPA / Sorbitol / ICP	S-6.10	DTPA / Sorbitol / ICP

Abbreviations: DTPA, diethylenetriaminepentaacetic acid; ICP, Inductive Coupled Plasma

Table 2.5 Significance of *F* tests for the fixed effects of year (Y), fertilizer treatments (Trt), and their interaction (Y × Trt) where applicable (sites 10 and 11), on forage dry matter yield and quality parameters (CP, Protein; ADF, Acid Detergent Fiber; NDF, Neutral Detergent Fiber; TDN, Total Digestible Nutrients; Starch) at four corn sites.

Site	**Effects**	**Yield**	**CP**	**ADF**	**NDF**	**TDN**	**Starch**
		------------------	------------------	------------------ *P* > *F*	------------------	------------------	------------------
9	Trt	ns	ns	ns	ns	ns	ns
10	Y	**<0.0001**	**0.0113**	**<0.0001**	**<0.0001**	**<0.0001**	**<0.0001**
	Trt	ns	ns	ns	ns	ns	ns
	Y × Trt	ns	ns	ns	ns	ns	ns
11	Y	ns	**<0.0001**	**<0.0001**	**<0.0001**	**<0.0001**	**<0.0001**
	Trt	ns	ns	ns	ns	ns	ns
	Y × Trt	ns	ns	ns	ns	ns	ns
12	Trt	ns	ns	ns	ns	ns	ns

Note: ns, not significant at $P < 0.05$.

Table 2.6 Significance of *F* tests for the fixed effects of fertilizer treatments (Trt), year (Y), and their interaction (Y × Trt) where applicable (sites 2 and 3), on forage dry matter yield and quality parameters (CP, Protein; ADF, Acid Detergent Fiber; NDF, Neutral Detergent Fiber; TDN, Total Digestible Nutrients; RFV, Relative Feed Value; RFQ, Relative Forage Quality) at three small grain forage sites.

Site	**Effects**	**Yield**	**CP**	**ADF**	**NDF**	**TDN**	**RFV**	**RFQ**
		----------	----------	----------	*P* > *F*	----------	----------	----------
1	Y	<0.0001	0.0037	0.0021	<0.0001	<0.0001	<0.0001	<0.0001
	Trt	0.0297	0.0132	ns	ns	ns	ns	ns
	Y × Trt	0.0947	ns	ns	ns	ns	ns	0.0266
2	Trt	0.0276	ns	ns	ns	ns	ns	ns
3	Y	<0.0001	0.003	0.0187	0.0001	<0.0001	<0.0001	<0.0001
	Trt	<0.0001	0.0151	ns	ns	ns	0.0354	ns
	Y × Trt	ns	0.0008	0.0001	ns	0.0018	0.0005	<0.0001

Note: ns, not significant at *P* < 0.05.

Table 2.7 Significance of F tests for the fixed effects of year (Y), fertilizer treatments (Trt), and their interaction (Y × Trt) where applicable (sites 5,7, and 8), on forage dry matter yield and quality parameters (CP, Protein; ADF, Acid Detergent Fiber; NDF, Neutral Detergent Fiber; TDN, Total Digestible Nutrients; RFV, Relative Feed Value; RFQ, Relative Forage Quality; P, K, INVTDMD48, In Vitro Dry Matter Digestibility 48-hour; NDFD48, Neutral Detergent Fiber Digestibility 48-hr) at five alfalfa sites.

Site	**Effects**	**Yield**	**CP**	**ADF**	**NDF**	**TDN**	**RFV**	**RFQ**	**P**	**K**	**INVTDMD 48**	**NDFD 48**
		------------------------------ P > F ------------------------------										
4	Y	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	<0.0001	0.0002	ns	<0.0001	<0.0001
	Trt	ns	ns	ns	ns	ns	ns	ns	ns	0.0006	ns	ns
	Y × Trt	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
5	Trt	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns
6	Trt	ns	ns	ns	ns	ns	ns	ns	0.0011	ns	ns	ns
7	Y	<0.0001	ns	ns	0.0073	0.0241	ns	ns	<0.0001	<0.0001	<0.0001	<0.0001
	Trt	0.0012	ns	ns	ns	ns	ns	ns	0.0031	0.0012	ns	0.014
	Y × Trt	ns	ns	ns	ns	ns	ns	ns	0.0009	0.0234	ns	0.0051
8	Y	<0.0001	ns	0.0005	0.0199	0.0185	0.0002	0.0004	0.0391	0.004	<0.0001	<0.0001
	Trt	ns	ns	ns	ns	ns	ns	ns	ns	0.0067	ns	ns
	Y × Trt	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns	ns

Note: ns, not significant at $P < 0.05$.

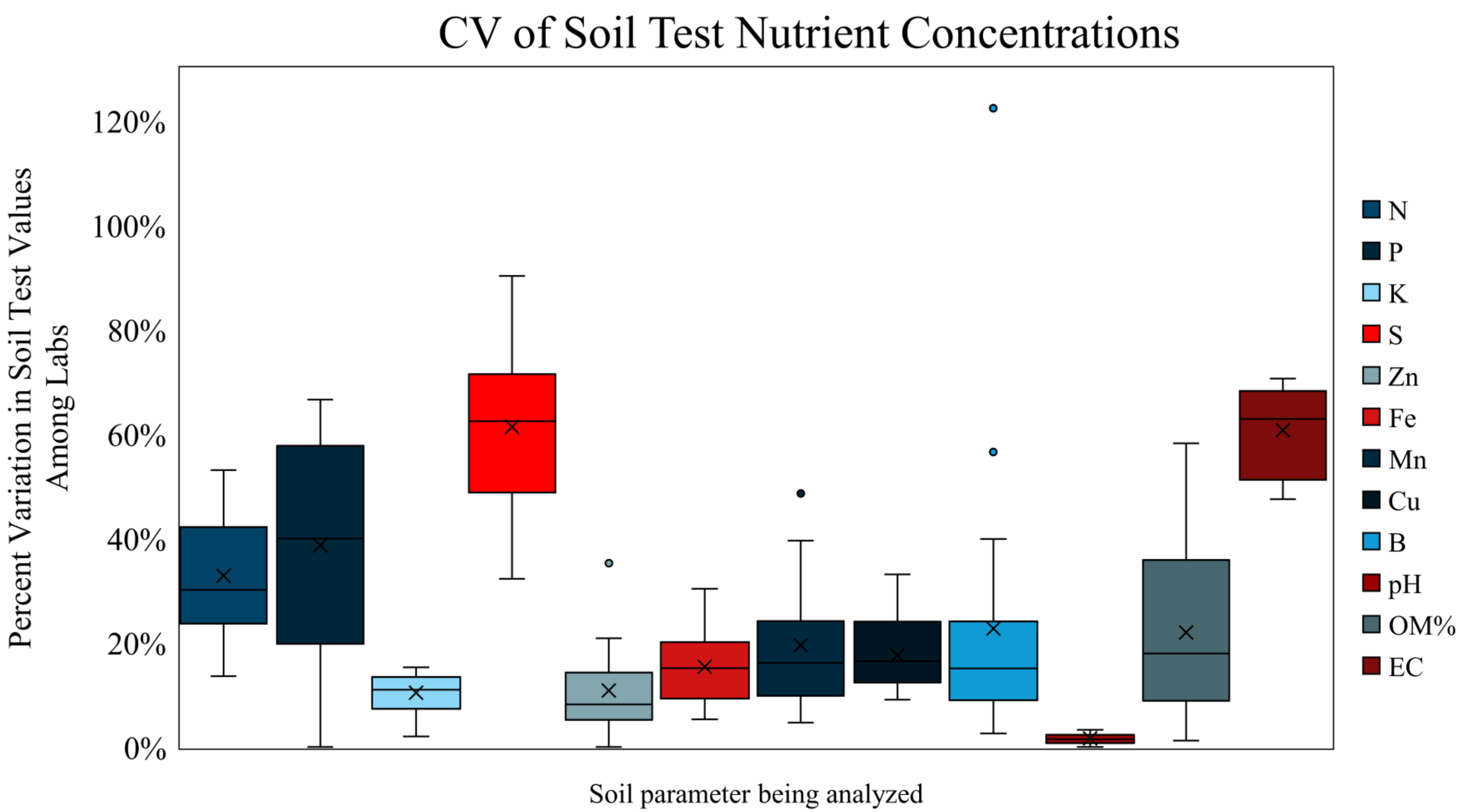

Figure 2.1 Calculated CVs for reported soil test results for soil samples from twenty-one sites sent to three commercial soil testing laboratories for analysis.

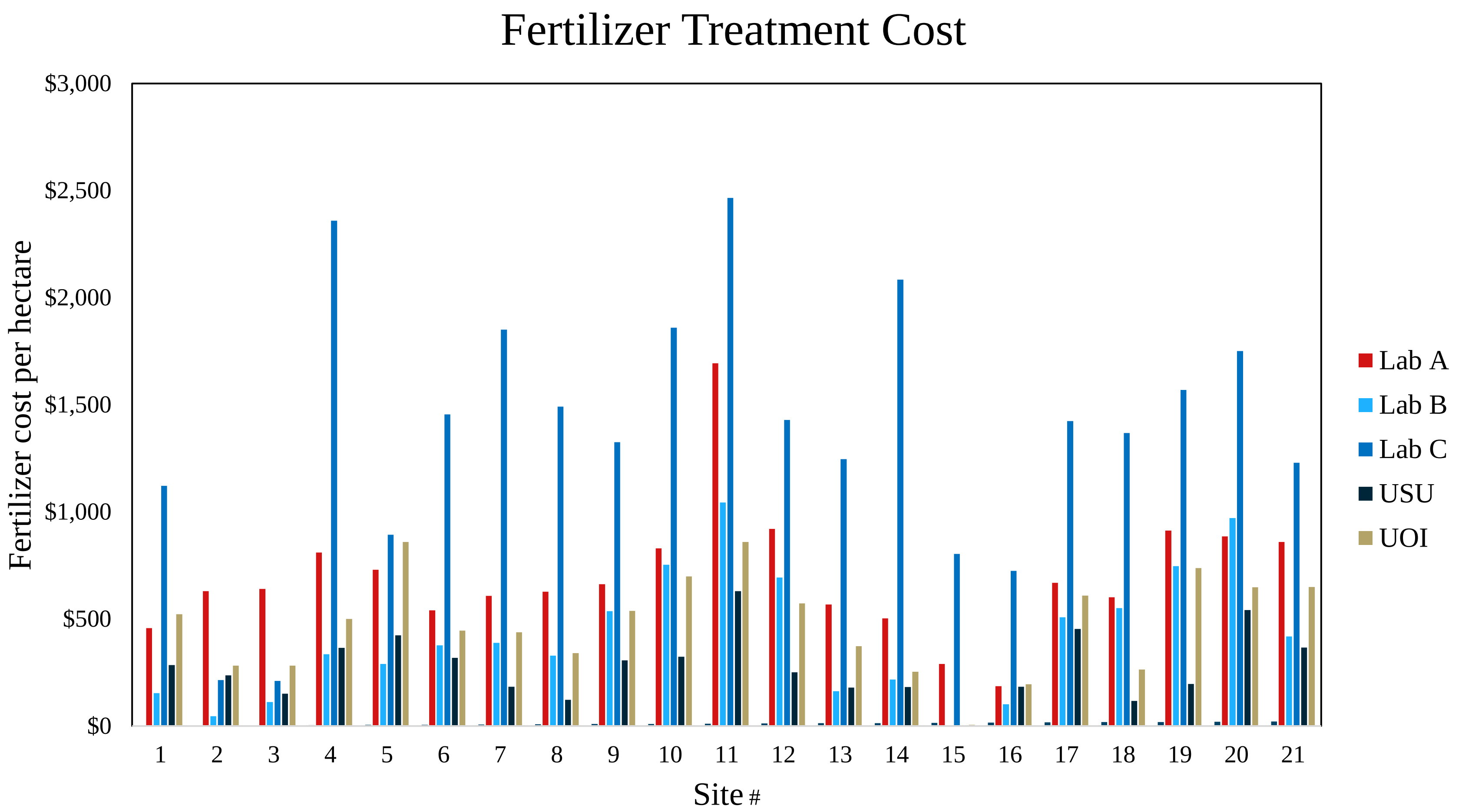

Figure 2.2 Treatment cost per hectare in 2021 for fertilizer recommendations from three commercial laboratories and two universities from twenty-one sites.

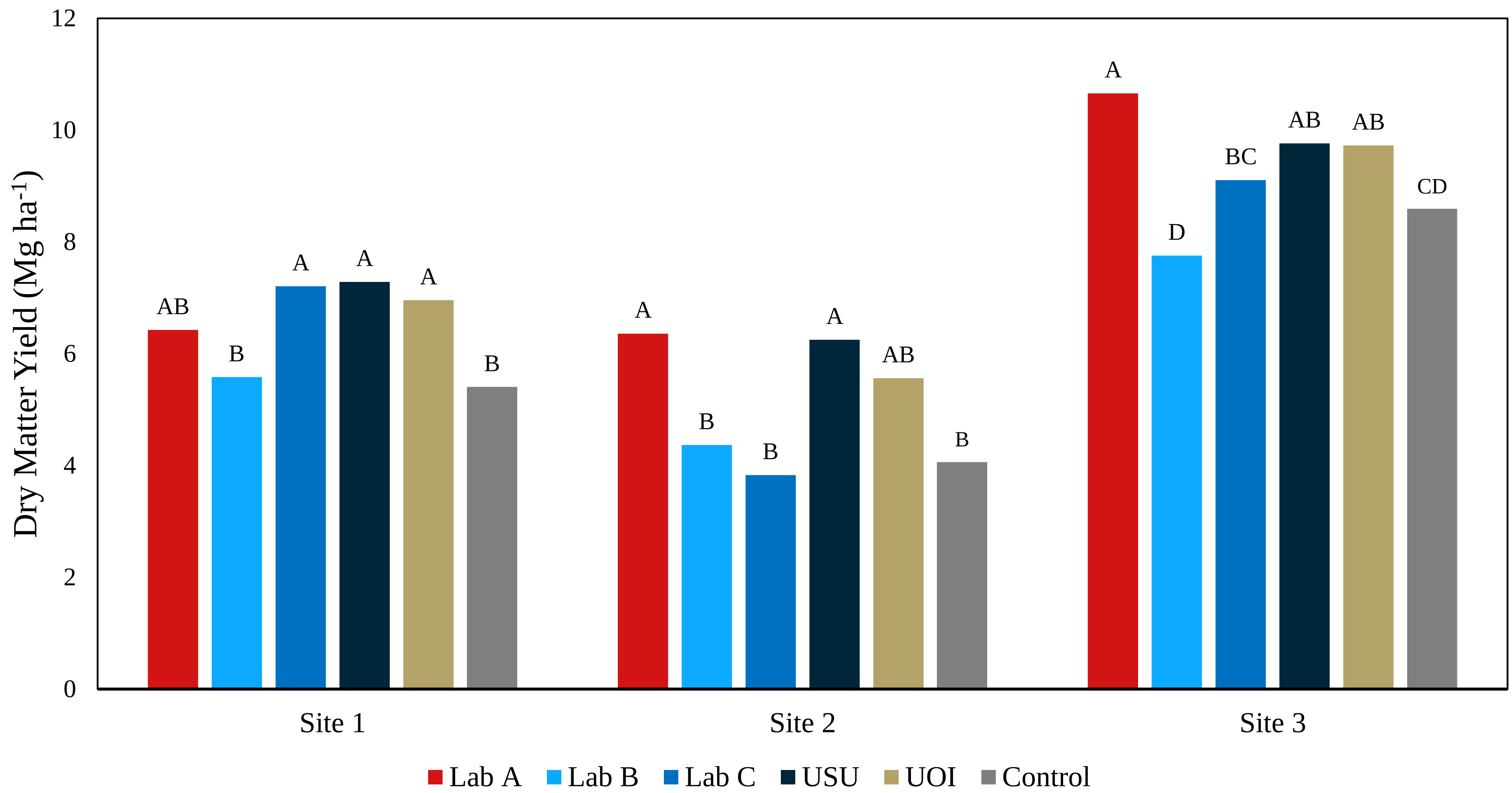

Figure 2.3 Impacts of fertilizer treatments on small grain forage yield across years at three sites across Utah.

Note: Treatment impacts were compared within sites and not across sites and each site had a different number of years where data was collected. Site 2 had one, Site 1 had two, and Site 3 had three years of yield data collected.

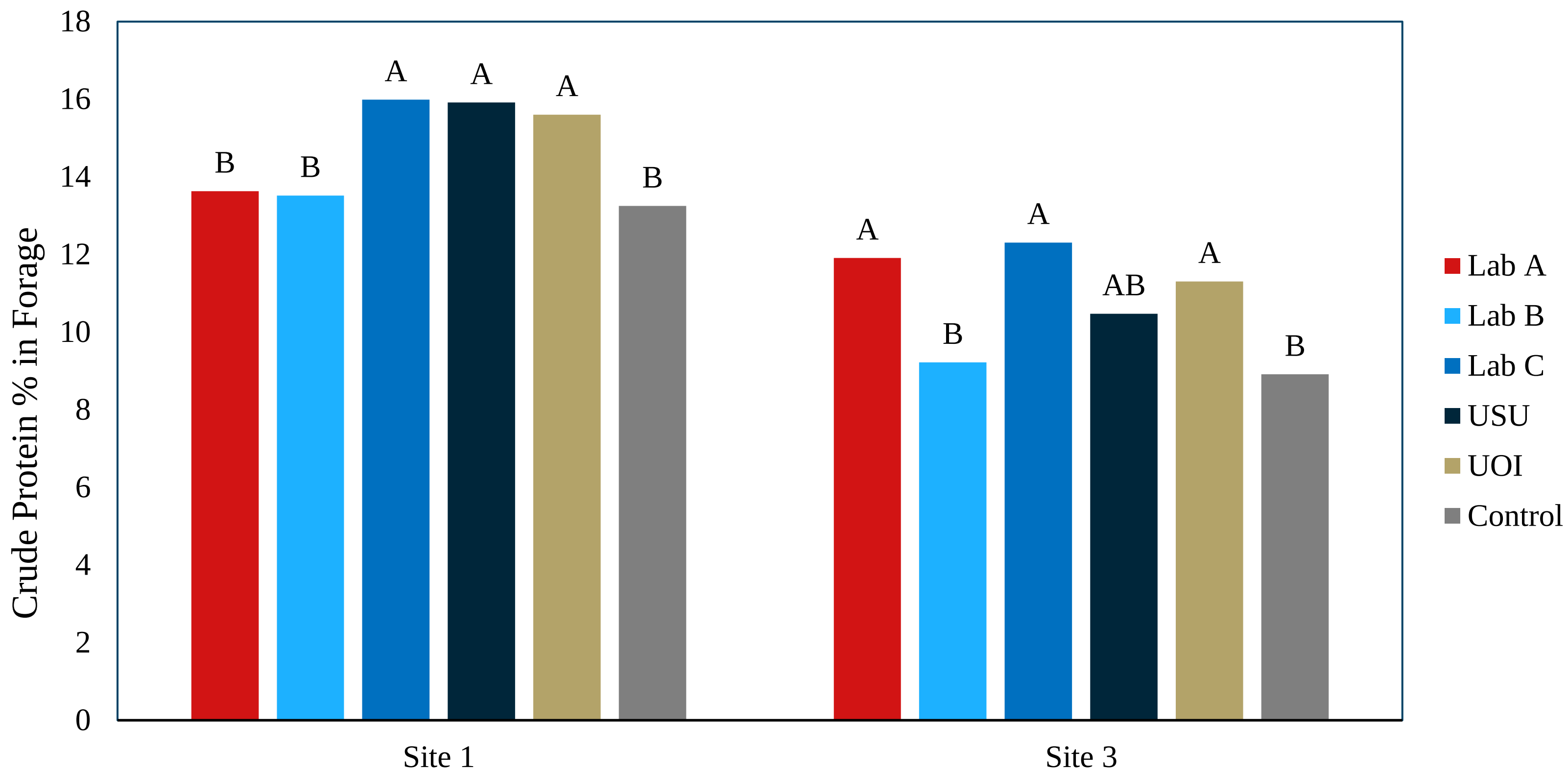

Figure 2.4 Crude Protein (CP) measurements for each treatment across years at small grain forage Sites 1 and 3.

Note: Site 1 had two years of data and Site 3 had three years of data.

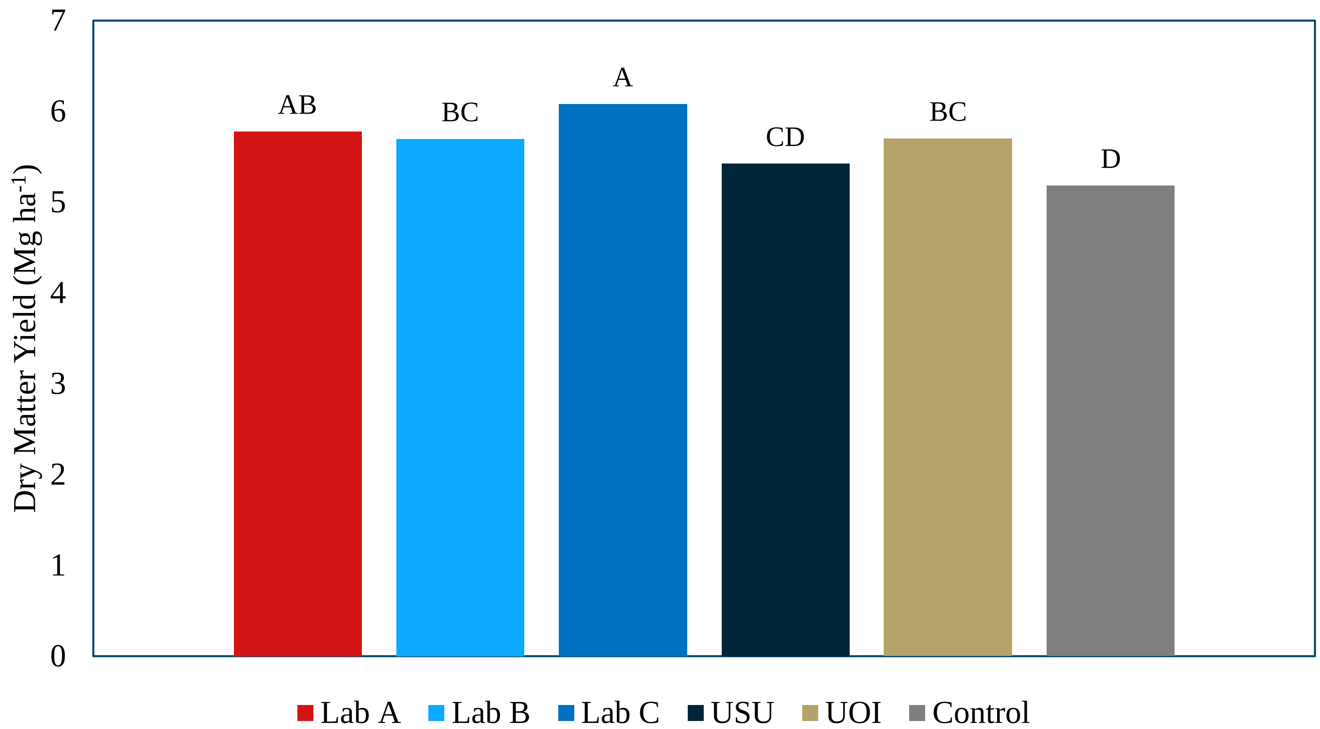

Figure 2.5 Impacts of fertilizer treatments on forage yield from 2021-2023 at Site 7.

CHAPTER III

COMPARING SOIL TEST RESULTS AND FERTILIZER RECOMMENDATIONS FROM VARIOUS SOIL TESTING LABS AND THEIR IMPACTS ON SOIL

3.1 | INTRODUCTION

A balanced nutrient management system is one where the fertilizer rate applied will maximize yield, but not at an excessive rate that will cause economic or environmental harm. Farmers can utilize many sources for fertilizer recommendations such as crop advisors, fertilizer dealers, extension agents, or soil testing laboratories. These sources often utilize soil testing to determine the needed nutrients and fertilizer rates to achieve desired crop yields. Having accurate soil test results is critical to making fertilizer recommendations that match crop needs as closely as possible. Due to many universities downsizing or discontinuing their analytical laboratories, commercial laboratories have become a more common option for soil analysis and fertilizer recommendations.

Large differences in fertilizer recommendations from public and commercial laboratories have been observed, with commercial laboratories often recommending more nutrients and at much higher rates. In comparison, universities are often accused of being too conservative with their fertilizer recommendations and not maximizing the potential of the crop (Olson et al., 1982). Much of the difference in recommendations is attributed to differences in fertilization philosophies when calculating recommendations. Universities often utilize the sufficiency approach, where nutrients are added to ensure that the crop has the nutrients needed to optimize yield. Commercial laboratories often utilize the maintenance, build, or a combination of the two methods where nutrients are added to maintain the soil's fertility level or at excess levels to build a high concentration of the nutrient within the soil (Macnack et al., 2017). These different philosophies can result in drastically different fertilizer recommendations, which is often not ideal for the grower.

Unbiased comparisons of the most common fertilizer recommendations from public and private sources are needed to help growers improve their nutrient management practices. Several studies comparing soil testing laboratories and the resulting fertilizer recommendations have found large variations among laboratories (Follett et al., 1987; Liuzza et al., 2020; Olson et al., 1982).

Soil tests are designed to measure the amount of bioavailable nutrient present within a soil that plants can potentially use. Soil tests are calibrated to predict the probability of a response from applying a specific nutrient rate. Soil tests are often calibrated by determining the correlation between nutrients extracted from soil by a laboratory test and nutrient uptake by plants (Van Der Paauw, 1956). Soil tests must be calibrated on a relatively local basis or to specific soil conditions to accurately measure response to fertilization at given soil test values. Universities and some commercial labs often do their own research to determine critical values and crop response to nutrient rates when creating their fertilizer recommendation guidelines.

Fertilization philosophy used can result in very different fertilizer recommendations, but variations in soil test results can also impact recommendations. A study conducted by Montana State University found that large variation still exists in soil test values and resulting recommendations among private and public soil testing laboratories (Jacobsen et al., 2002). Soil samples collected from four sites were ground, mixed, split into sub-samples, and sent to eight soil testing laboratories at three-to-four-week intervals for analysis. This process was repeated over the following two years, but with two more labs being added to the study. Some of the variation observed is explained by different analysis methods utilized by soil testing laboratories, but there were also many significant differences between results for identical samples submitted to the same laboratory. The soil test results received by each of the laboratories were compared to one another and to the other identical samples sent to the same lab. They found that electrical conductivity and NO_3-N were some of the most variable parameters being evaluated with CVs at 158% and 44%, respectively. Sending the same sample several times also resulted in different soil test results, which indicated that analytical precision differed greatly between laboratories. N, P, and K repeatability were consistent from year to year, but pH, EC, and OM were not. For pH, the soil:water ratios ranged from 1:1 to 1:2 and some labs used Olsen for P while others used Bray (Jacobsen et al., 2002). These results indicate that laboratory analytical results can vary considerably between and within laboratories.

There are some standards of quality for soil testing labs such as the North American Proficiency Testing (NAPT) certification program, which some but not all labs pursue. This voluntary program operates through the Soil Science Society of America (SSSA) for agricultural and environmental laboratories and evaluates the accuracy of soil, plant, and water sample results and analysis methods. Soil, plant, and water samples are exchanged quarterly across the nation to assess laboratory analysis quality. Quality control and assurance programs like this are key to evaluating the analytical accuracy of soil testing labs and variation among labs.

Studies and programs that test and compare soil test reports produced by soil testing labs are important for ensuring that the users of these labs are aware of the variation that exists within and among labs so that they can make informed decisions when deciding where to send samples. The objective of this study was to compare how soil test results and fertilizer recommendations from three commercial and two public labs in the Western United States impacted soil test values in field trials over three years.

3.2 | MATERIALS AND METHODS

3.2.1 Site Characteristics

On-farm trials were established as a part of a fertilizer recommendation comparison study established in 2021 on twelve commercial farm fields across Utah and Wyoming. Fertilizer recommendations from three commercial soil testing laboratories and two public labs, Utah State University (Logan, UT, USA) and University of Idaho (Moscow, ID, USA), located in the Western United States were used. Trials were established in alfalfa (*Medicago sativa*), small grains forage, and corn (*Zea mays*) in the following counties: Box Elder, Weber, Carbon, Beaver, Sevier, Iron, San Juan, and Lincoln (Table 3.1). Site locations were chosen to represent a variety of soil, environments, and cropping systems. Soil classification and textural group data were obtained from the Natural Resource Conservation Service (NRCS) Web Soil Survey Tool (NRCS, n.d.; Table 3.1).

At almost all sites, no fertilizers, manure, or compost was applied over the plots by the growers during the duration of the study or for at least two years prior. At the corn or small grain sites, small amounts of N were applied through pivot irrigation systems. This fertilizer could not be avoided and was applied over the entire plot areas. All sites were conventionally tilled except for sites 2 and 7, which were no-till. Two of the small grain forage sites (sites 2 and 3), were fall planted with a 5-way seed blend and double cropped with the second crop seeded mid-summer shortly after the first harvest and harvested in the late fall. Site 1 was planted in the spring with a 4-way blend and harvested once each year. Besides fertilization, all other crop management practices were managed by cooperating growers (Table 3.2).

3.2.2 Treatments

A single, large composite soil sample was collected from each site in the spring of 2021. Composite samples (~1 kg) consisted of soil cores measuring (30 cm deep × 1.9 cm i.d.). Samples were air-dried for 6-10 days until dry and then ground to 2 mm using a DC-5 Dynacrush Soil Crusher (Custom Laboratory Equipment Inc., Orange City, FL, USA). Each sample was thoroughly mixed to ensure uniformity and split into four subsamples (200-400 grams each) to be sent to the three commercial soil testing laboratories for analysis. Each soil sample was accompanied with relevant crop information for analysis and recommendation calculation. Crop to be grown, yield goal, and previous crop for each site were provided. Yield goals and crop management information was provided by cooperating growers.

Five fertilizer treatments (from each of the three commercial labs and the two public labs) and a nonfertilized control were arranged in a randomized complete block design at each site with four replications of each treatment. Plot dimensions varied by site and were determined by crop, harvest method, and to match the grower’s commercial harvesting equipment whenever possible. The three commercial laboratories are referred to as labs A, B, and C rather than by their names or locations for anonymity.

Recommendations for Utah State University (USU) and University of Idaho (UOI) were calculated using the Universities' fertilizer guidelines (Cardon et al., 2008; Mahler, 2005a; Mahler, 2005b; Brown et al., 2009). Soil test results from one of the commercial labs were used with these guidelines for the university treatments to increase turnaround time and to reduce error associated with soil test variation. All fertilizer products were broadcast-applied by hand in the spring of 2021 as dry granular products due to product availability, and time and logistical restrictions. It was not possible to incorporate fertilizers because crop stands were already established. Fertilizer products containing isolated nutrients were used whenever possible for ease of creating recommendation blends (Table 3.3). Yield and forage quality data were collected from twelve of the sites throughout the growing season.

Samples were collected from twenty-one sites originally, but fertilizer trials were not established at all locations. The other nine sites were used for comparing soil testing labs and fertilizer recommendations, but no forage samples were collected (Table 3.4). Site characteristics and crop management information was still collected for these sites (Table 3.5).

In 2022, the fertilizer recommendation trials were repeated at eleven of the twelve sites, and four were continued through 2023. While the recommendation trials were not repeated at all sites, sites were monitored for soil test changes due to fertilizer treatments wherever possible. Eleven of the sites were resampled in the spring of 2022 and six were resampled in 2023. A composite sample of 24 soil cores (30 cm deep × 1.9 cm i.d.) was collected from each treatment – as six cores from each of the four replicates. Soil samples were processed in 2022 and 2023 using the same methods and equipment as 2021, except for samples not being split and sent to different labs. The sample collected for each treatment was processed and sent to its respective soil testing laboratory for analysis and fertilizer recommendations. The samples from the USU, UOI, and nonfertilized control plots were sent to one of the commercial labs for analysis. The resulting soil test values were used with the University fertilizer guidelines to determine their recommendations. Recommended nutrients and rates were applied on their respective plots, with no fertilizer being applied on the control plots. The dry, granular micronutrients (Zn, Mn, B, Cu) were replaced with liquid chelated forms of the isolated nutrients in 2022 and 2023 to provide a more uniform application of the nutrients over the plots. The liquid micronutrients were diluted with water and applied over plots using a backpack sprayer with a 60 cm boom.

Soil samples for each treatment were collected and compared each year to identify changes in soil test results due to the fertilizer recommendation treatments applied. Soil test results were also compared to those from the nonfertilized control to see how the application of various fertilizer rates can impact soil test results over time.

3.2.3 Laboratory Analysis Methods

Observed differences in soil test results are sometimes due to the accuracy of each lab's analyses, but they are also largely influenced by analysis methods used. Soil analysis methods and extractions used by laboratories were compared for each nutrient (Table 3.6). These laboratories were all located within the same region, so many of the methods used were similar. Methods used by all labs were from the *Soil, Plant, and Water Reference Methods for the Western Region* (Gavlak et al., 2013).

Some of the differences in soil test results may be due to laboratory analysis quality, but the methods used can also have a large impact. It is also worth noting that each of these laboratories cited different editions of *Soil, Plant, and Water Reference Methods for the Western Region* for their analyses. There are minimal differences between these editions, but there are slight changes in analysis methods over time. Labs A, B, and C cites the third, fourth, and first editions, respectively (Gavlak et al., 1994; Gavlak et al., 2005; Gavlak et al., 2013).

3.2.4 Price Justification

Fertilizer prices were based on local fertilizer prices paid in the spring of each year of the study (Table 3.3). There was a substantial increase in fertilizer prices between 2021 and 2022, so different prices were used for each year to account for this variability. The isolated nutrients used for these trials are not the typical fertilizers used by commercial growers. This is reflected in the cost per unit of several of the nutrients being higher than those of common sources. Small quantities of fertilizers were purchased for this study, but bulk pricing was used whenever possible.

3.2.5 Data Analysis

Soil test results and fertilizer recommendations were given or calculated for twenty-one on-farm trial sites in 2021, 11 sites in 2022, and 6 sites in 2023. Each site with a study implemented (site 1-12) was arranged in a randomized block with six treatments and four replications of each. The variability of soil test results and fertilizer recommendations from the five labs were compared at each site by calculating their coefficient of variations (CV). This allowed for the comparison of treatments across sites even though each site had unique results and ranges. Soil nutrient results were compared using CVs to determine the degree of variability among the three soil testing laboratories. Fertilizer rates and treatment costs were also compared using their respective CVs because this method helped illustrate common trends and patterns for each treatment across sites. The CVs for each site were calculated using standard deviation divided by the mean.

3.3 | RESULTS AND DISCUSSION

3.3.1 Variability in Soil Test Results

Composite soil samples from twenty-one locations were split and sent to three commercial soil testing laboratories for analysis and fertilizer recommendations. Reported soil test values (STV) for the submitted samples varied greatly among laboratories for some nutrients, with an average CV of 26% across the nutrients compared in this study. CVs ranged from 1.6 – 61.3% among all nutrients and soil tests (N, P, K, S, Zn, Fe, Mn, Cu, B, pH, EC, and OM) with pH being the lowest and S the highest (Figure 3.1). Many laboratories utilize different analytical methods for the same nutrient, which can result in different soil test results. The variation in soil test results in this study is not a comparison of analytical methods, but a comparison of results received when submitting samples to various laboratories. This represents what a grower might experience when submitting soil samples.

Sulfur was the most variable nutrient, with CVs ranging from 32 to 90% among sites and averaging 61.3% across sites. The plant-available form of S is SO_4-2, which is the oxidized form of S (Franzen, 2023), and the form that soil test results and fertilizer recommendations measure and report. Site 12 had the highest level of variation and soil test values (STV) ranged from 7 to 36 mg kg^{-1}. Lab C reported the highest soil test S levels at every site. This high level of variability in soil S levels is not surprising because each of the labs used different analysis methods. A Cornell study compared six S extraction methods to determine which methods could accurately identify changes in plant-available S in soils in response to fertilizer applications. While extractable S concentrations increased for all extracting solutions and detection methods, there was a lot of variation in reported S concentrations among methods (Ketterings et al., 2011). Several other studies evaluating various extraction methods for plant-available S have resulted in many different methods being recommended (Ajwa & Tabatabai, 1993; Shen et al., 1997). None of these soil analysis methods for S are best suited for every situation, and soil type, environmental conditions, and forms of S present are important determinants for the most accurate extraction type.

Variation in P soil test values (STV) averaged 38.6% among the three labs, with two sites having relatively consistent results and varying less than 10% (sites 9 and 15). All three commercial labs reported the same P STV at site 15 (22 mg kg^{-1}). There are several common different extractants used to measure P levels in soil, with Bray-1, Olsen, and Mehlich III being some of the most common. The Olsen and Olsen modified with AA-NH_4F Kelowna Extraction were used by these laboratories. The modified Kelowna method produces values that are highly correlated to those from the Olsen test, indicating that these methods should result in similar P STVs (Liang & Karamanos, 1991). Various extractants are used because different minerals control phosphate concentrations at different soil pH levels. The accuracy of soil test results is heavily dependent on extractants used, and it is important to ensure that the laboratory being used is utilizing the correct one for the soil. This can also influence fertilizer recommendations because they often specify to which extraction method they are calibrated.

Zinc had the lowest variability among labs of any of the nutrients at 10.9%. The other micronutrients were relatively consistent as well, with averages ranging from 15.4 to 22.7% for Fe, Mn, Cu, and B. Lab C often reported higher Zn and B STVs than the other labs, while lab A reported higher Mn and Cu values. Results varied for Fe, but lab B often reported higher levels than the other two. The DTPA micronutrient extraction method is often used to determine available Zn, Cu, Mn, and Fe within a soil (Lindsay & Norvell, 1978). Lab B used the DTPA-Sorbitol extraction method, which can result in values 5-8% lower than the standard DTPA extraction procedure (Gavlak et al., 2013). The variability among labs in this study is common for micronutrient analyses among various laboratories, though other studies have compared many more labs and found greater variability (Dias et al., 2015).

There was some variability with N and K, with the CVs across labs averaging 32.8 and 10.4%, respectively. The plant-available form of N is nitrate (NO_3), which is the form that soil test results and fertilizer recommendations are given in. The three laboratories used the same analysis method for determining soil nitrate, so variability is not explained by differing extractants. Little variation in K results was expected because the laboratories used the same extractant and analytical methods. Differences in reported amounts of these nutrients can often have a larger impact on crop production and profit than micronutrients because they are recommended much more frequently and at much higher rates.

Due to the range of possible analytical methods being utilized by different laboratories, caution must be exercised when comparing the accuracy of soil test results. Large differences in results can be observed when different chemical procedures are used for evaluating the levels of some nutrients within a soil (Jacobsen et al., 2002). To truly compare the accuracy of soil testing laboratories, it must first be determined that they are using the same methods for their analyses. The purpose of comparing soil test results from several laboratories in this study is not to compare accuracy of these labs' analytical procedures, but instead to illustrate the possible variability of results depending on where samples are sent for analysis.

3.3.2 Variation in Fertilizer Recommendations

The resulting fertilizer recommendations from the three commercial laboratories and two universities varied greatly, both for types of nutrients and the rates being recommended. This is likely due to a combination of differences in soil test values and recommendation philosophies utilized by each lab. Labs recommending based on maintenance or build-up fertilizer strategies are more likely to recommend higher rates than those using a sufficiency approach. Both universities in this study, USU and UOI, recommend fertilizer based on the sufficiency concept.

Of the main macronutrients, recommendations for N were the most variable, with CVs averaging 118% across sites and the range between the highest and lowest rates ranging from 44 to 282 kg N ha^{-1} (Figure 3.2). Recommendations were the most variable in alfalfa (173%), which was mostly because one of the labs recommended N application for every site. Variation was lower for corn and small grains, averaging 65 and 98%, respectively. Soil test N values varied 32.8%, which may have contributed to differences in recommendations, but differing recommendation philosophies have much more influence.

Recommendations for P and K did not vary as much as N overall, but some individual sites had very large differences among recommendations. Fertilizer recommendations for P and K are given for their oxidized forms of P_2O_5 and K_2O, respectively. Recommended P_2O_5 rates varied 68% on average with a difference of 222 kg P_2O_5 ha^{-1} between the highest and lowest rates, but some sites had differences of over 400 kg P_2O_5 ha^{-1}. Potassium was more variable, averaging 91% across all five recommendations, but alfalfa recommendations were much more variable at 131%, compared to 47 and 68% for small grains and corn, respectively. Some sites had extremely high rates applied, with site 4 having 477 kg K_2O ha^{-1} being recommended by lab C. The variation in recommended K_2O rates compared to the variation in soil test results (10.4%) indicates that the recommendation sources likely utilize vastly different critical values and soil test calibrations.

The frequency and rates of micronutrient recommendations were quite variable, with CVs for recommended rates ranging from 75 to 153% across all five recommendations, with Cu being the lowest and Mn the highest. The commercial laboratories often recommended micronutrients at more sites and at higher rates than the university labs. Micronutrients are required by plants in much lower quantities than the macronutrients, so the recommended rates are much smaller and usually range between 1 to 25 kg ha^{-1}. Recommendations for S were given in the SO_4^{-2} form because it is the form utilized by plants. Variation in sulfate-sulfur recommendation rates averaged 119%, with much higher variation in small grains and corn than alfalfa, at 138 and 150% compared to

84%. Similar average rates were recommended in corn and alfalfa at 20.3 and 23.5 kg SO_4^{-2} ha^{-1} respectively, but there was more variation in the recommended rates for small grains and corn. Recommendations for elemental S and gypsum were often made by the commercial laboratories, but usually as soil amendments and not to meet plant nutrient needs. These amendments both contained large percentages of S or SO_4^{-2}, meaning that higher S rates were applied than just the S fertilizer recommendations.

There was high variation in the recommended nutrients and rates among laboratories, with the universities often being much more conservative than the others. These differences in recommendations are usually due to differing fertilization philosophies among commercial and public labs. Higher rates are often recommended with the goal of maximizing crop yield or to increase concentration of a nutrient within the soil for future crop use. This strategy only works for nutrients such as P, where high concentrations can be built within a soil and remain in a form that plants are able to uptake in the future. For some nutrients, excessive rates can be subject to leaching or luxury-consumption in the cases of N and K, respectively (Hommels et al., 1989; Wang et al., 2019).

3.3.3 Changes in Soil Test Results

Soil samples collected from each treatment in the spring of each year were compared to monitor changes in nutrient levels due to fertilizer recommendations applied. Soil samples were collected from eleven sites in 2022 and six sites in 2023 where the fertilizer recommendations were repeatedly applied to the same research plots. Soil test values were also compared to control plots to determine the influence of fertilizer use on soil fertility.

From 2021 to 2022, Soil P value changes were reflective of applied nutrients, with at least three labs on average increasing P STVs at each site. Phosphorus is relatively immobile in soils, and applied nutrients usually stay close to where they were applied. Sites with high application rates (greater than 450 kg ha^{-1}) often had some of the largest increases in P STVs, but this was not always the case. Site 12 had 240 kg P_2O_5 ha^{-1} recommended, but the STV was also increased by 400%. A common factor for all sites with these high increases was that they all had beginning P levels of less than 4 mg kg^{-1}. Lab C frequently recommended the highest rates and increased P STV by 105%, compared to USU and UOI, which increased values by 32 and 29%, respectively. The control treatment also had higher measured soil P than the previous year at most sites, with an average increase of 24%. This change was likely related to seasonal and spatial variation in STV among the plots.

Soil K values only increased at three sites, with all five fertilizer treatments and the control being higher at site 4, four fertilizer treatments and the control at site 11, and one fertilizer treatment at site 7. The sites with low to marginal STVs (<150 mg kg^{-1}) were more responsive to K fertilizer applications. This is the common critical soil test value for USU and UOI, as well as many other Universities in the region. Changes in K STVs were similar for the fertilizer treatments and the control, indicating that the higher application rates are often not effective for increasing K STV.

Two of the commercial laboratories, labs A and C, increased soil S levels much more frequently than the others, which is consistent with their more frequent and higher fertilizer recommendation rates. Lab C recommended elemental S at all eleven sites, with rates ranging from 28 to 599 kg S ha^{-1}. The labs that were more conservative with their S fertilizer recommendations had results similar to the control, with little to no changes in S STVs. Lab B rarely recommended S and had an average decrease of 31%. Higher S rates often resulted in higher S levels within the soil in the following year.

No consistent patterns were observed for changes in soil test values from micronutrient fertilizer application after one year. Zinc, Mn, B, and Cu levels were similar in both years across all sites and treatments. The nonfertilized control plots did not decrease soil test values any more than any of the other treatments. Micronutrients are required in much smaller quantities than other nutrients, and the differences between deficiency and toxicity is quite narrow. Recommended rates are usually only a few kilograms per hectare, resulting in small changes in soil test values.

Soil samples were again collected from six sites where fertilizer trials continued in the spring of 2023 to observe changes in soil test results after two seasons of fertilizer recommendation treatments. Soil P values increased for all treatments except for the nonfertilized control, with average increases ranging from 5 to 283% across treatments. Lab C's recommendations resulted in the largest increases in P soil test values. Increases of over 600% were observed at sites 4 and 10, where over 800 kg P_2O_5 ha^{-1} were applied over the two years. USU had the smallest average increase in P levels (5%), but also recommended the lowest rates. Some of the higher recommended rates were successful in increasing P concentrations within the soil over the span of the study.

Increases in soil K concentrations were observed at several sites and treatments, but usually it was when very high applications were recommended. At site 4, all treatments increased soil K, with total recommended rates in 2021 and 2022 ranging from 224 to 938 kg K_2O ha^{-1}. Lab C's recommendations were much higher than the rest and resulted in increased K levels at four of six sites, with increases ranging from 3 to 96%. Soil K levels in the control treatment decreased 15% on average, with only one site increasing (site 4). Higher K_2O fertilizer application rates may increase soil K concentration, but incredibly high rates are required and are often not economically feasible. Because of the tendency for crops like alfalfa to luxury-consume excess K, less is left in the soil and there is also an increased risk of milk fever (Goff & Horst, 1997).

Soil S levels decreased for every treatment except lab C's recommendations, where they increased 78% on average. The rest of the treatments, including the nonfertilized control, decreased by similar amounts (8 to 30%). Lab C's recommendations included high rates of elemental S, ranging from 28 to 906 kg ha^{-1} over the two years. Higher rates of elemental sulfur can increase soil S levels, but there are many environmental factors that influence oxidation rates and the availability of S for plant uptake (Germida & Janzen, 1993).

Soil Zn levels increased for all the fertilizer treatments (2 to 56%) and decreased in the nonfertilized control (34%). The commercial labs recommended higher rates of Zn, but also resulted in larger increases in Zn soil test values. Changes in Mn soil test values were not reflective of fertilizer rates applied. Lab B, USU, and UOI did not recommend Mn at any site, but changes in soil test values ranged greatly. Soil test results from 2021 to 2023 indicate that lab B's recommendations resulted in a 38% decrease in Mn STV, but that USU and UOI's recommendations increased Mn levels by 17 and 21%, respectively. No Mn was applied as a part of any of these treatments in either year. Boron and Cu soil test levels were similar over the span of the study and changed little in response to fertilizer.

Fertilizer recommendations are often evaluated based on their impacts on yield, quality, and economic returns for a crop. The differing recommended nutrients and rates can have large impacts on soil test results, especially when observed over the span of several years. Increasing nutrient concentrations in the soil is occasionally worth the additional costs, but rarely and only with certain nutrients. Optimizing fertilizer management and using the correct rates for the crop to be grown can reduce environmental risks and increase returns.

3.3.4 Changes in Soil Test Results Classification

The goal of fertilizer application is to supply nutrients to a growing crop or increase concentrations within the soil. Changes in soil nutrient levels were compared to classify responses into one of four categories below:

1. Fertilizer was recommended and applied, and soil nutrient levels increased. This is the intended result of recommendations made with the build-up approach.
2. Neither fertilizer was recommended nor applied, and soil nutrient levels changed. Decreases could be a drawdown of nutrients due to crop removal, but increases in nutrient concentrations were also observed.
3. Fertilizer was recommended and applied, but the soil nutrient level did not change.
4. Fertilizer was recommended and applied, but soil test values decreased. This “drawdown” occurs when the crop uses more nutrients than supplied.

Treatment impacts on these four categories for STV for P, K, S, and Zn were evaluated after one and two years of fertilizer applications (Table 3.6). Nitrogen was not assessed in this context where leaching and external factors such as soil moisture and climate influence residual STVs for the following year. For each nutrient, the number of sites in each category was summed to compare treatment impacts on soil.

Only the five lab treatments were compared at each site because the control plots automatically fit within category 2 because no fertilizer was applied. In the first year, P_2O_5 application was recommended by all labs at 9 of 11 sites and all 6 sites in the second year. At small grain site 2, Labs B and C did not recommend P_2O_5 application and lab C also did not recommend at site 3. For K_2O, the three commercial labs fell into category 2 at roughly half the sites (45-64%) in the first year, while the two public labs did not recommend any fertilizer at 73 and 82% of sites for UOI and USU, respectively. In the second year, Labs A and B were within category 2 at 33% of sites and the university labs at 50% of sites. Zinc was recommended the least, with all labs having at least a third of sites within category 2 (36% to 82%), with the university labs and lab B having the highest percentages. In the second year, lab C recommended Zn at every site while Labs A and B did not recommended Zn at 33 and 50% of sites, respectively. The University recommendations were within category 2 at 67 and 83% of sites for USU and UOI, respectively. Recommendations for S or SO_4^{-2} were counted because both have the potential to increase the S STV. Labs A and C recommended S or SO_4^{-2} as a nutrient or soil amendment at every site, so they were never within category 2 for this nutrient. In the first year, 36% of sites for lab B were within category 2, but no sites in the second year. The university labs were within category 2 at roughly 50% of sites in the first year and 33% of sites in the second.

Category 3, where fertilizer was applied but soil test values remained unchanged, was the least common. In the first year for P, commercial labs were within category 3 at 9% of sites, while university recommendations were at 18% of sites. In the second year, lab A, lab C, and UOI were never in category 3 while lab B and USU were at 33 and 17% of sites, respectively. For K_2O and Zn, there were no recommendations at any site that were within category 3. For S or SO_4^{-2} recommendations, no labs had more than 27% of sites within category 3 in the first year, with labs B and C having none. In the second year, labs A, B, and UOI had 17% of sites in this category, while lab C and USU had 0 and 50%, respectively.

The number of sites within category 4 was not consistent across nutrients or treatments. For P, P_2O_5 applications resulted in drawdown at 5 to 39% of sites across years, with lab B being the lowest and USU the highest. For K, drawdown occurred at 9 to 36% of sites in the first year and 17 to 50% in the second year. Lab C was the only treatment to have sites in category 4 for Zn in both years, at 9 and 17% for the first and second, respectively. For the other labs, 9 to 27% of sites were in category 4 in the first year, and none in the second year. For S or SO_4^{-2}, results were the most variable, but lab C had the fewest sites in category 4 in both years. Commercial labs A and B were higher in the first year at 36 and 64%, respectively. The university recommendations resulted in a drawdown at 9 and 18% of sites for USU and UOI, respectively. In the second year, lab A, USU, and UOI had 50% of sites in category 4, while lab B had 67% of sites in that category.

At sites in category 1, where soil nutrient levels increased as a result of fertilizer recommendations, applied fertilizer rates were divided by changes in soil test results to determine the amount of nutrient in kg ha^{-1} required to increase the soil nutrient level by 1 mg kg^{-1}. When calculating this ratio for changes after two years, fertilizer applied for both years was summed and compared to overall STV changes. From 2021 to 2022, labs A and C increased nutrient levels the most frequently at 43.2 and 56.8% of sites, respectively (Figure 3.3). Fertilizer applications increased soil P levels by over 60.0% on average, with lab A increasing P at 81.8% of sites. From 2021 to 2023, the average increase in P was again over 60.0%, but UOI increased soil test P at the most sites (83.3%; Figure 3.4). Fertilizer applications, especially higher rates, increased P STV across sites, but the rate of increase compared to applied rates was not consistent.

Treatments increased K soil test values at 10.9% of sites after the first year and 33.3% after two years. Increases were observed at only alfalfa sites in the first year, with the ratio of nutrient applied to STV changes ranging from 6.5 to 67.2 kg ha^{-1} required for 1 mg kg^{-1} increase. After two years, increases were observed in alfalfa and the one remaining small grains site. At small grain site 3, labs B and C fertilizer applications increased K STV, but with different applied rates. Lab B increased K levels from 175 to 193 mg kg^{-1} by applying 39.3 kg ha^{-1} over the two years, or 2.2 kg ha^{-1} of fertilizer for each 1 mg kg^{-1} increase in soil test K. Lab C increased levels from 154 to 158 mg kg^{-1}, but the recommended applied fertilizer was 114.3 kg ha^{-1} for a ratio of 29:1. In alfalfa, the ratio of applied fertilizer to STV increase was often lower than or similar for lab C (12:1) compared to the others (12:1 - 37:1), but the recommended application rates were consistently at least double any of the other labs.

Recommendations for sulfate-sulfur as a nutrient were less frequent, but it was often still supplied by the elemental S and gypsum recommended as soil amendments.

Sulfur supplied by elemental S was converted to the sulfate equivalent, and added to the sulfate applied for the nutrient, and the sulfate in gypsum recommended to get total sulfate applied. The addition of the soil amendments made the ratios much higher for labs A and C across crops in comparison to the other lab recommendations. For lab C's recommendations, soil SO_4^{-2} levels increased at every site after one year and at five of the six sites sampled after two years. Sulfate-sulfur was applied as a part of the commercial laboratory treatments much more often than in the university labs. Large changes in S soil test values were not observed, but high fertilizer rates were applied, making the S ratios disproportionally high. The average ratio for SO_4^{-2} across sites in the second year was 1764:1 compared to 24 to 53:1 for the other three nutrients examined. This was skewed by site 11, where lab A recommended large rates of gypsum as a soil amendment in both years and the ratio was 198:1 in the first year and 3406:1 in the second. When supplying S to a crop, it is important to consider what sources may all be supplying the nutrient.

Soil Zn levels were increased at 27.3% of the sites after one year and at 50% of sites after two years. Most of these increases were less than 1 mg kg^{-1}, with 10 to 40 kg ha^{-1} being required to raise levels by 1 mg kg^{-1}. Critical soil test Zn levels at USU are currently 0.8 mg kg^{-1} (Cardon et al., 2008) so increasing soil test Zn by 1 mg kg^{-1} is often not feasible or desired. Scaled differently, the ratio suggests that 10 kg ha^{-1} of Zn may be needed to raise soil test Zn by 0.25 mg kg^{-1} to surpass a critical soil test value. This aligns with many recommendations that commonly suggest around 10 kg Zn ha^{-1} when response to Zn is expected. Zinc levels were increased at most sites where fertilizer was applied, but large rates with the intention of increasing soil test values are often not economically feasible. Zinc levels were not increased at any small grain site in the first year, but levels at site 3 were increased by labs A and B after two years by 0.5 and 0.1 mg kg^{-1} respectively. Zn levels were increased by treatments most frequently in corn both years, with rates of 16 to 38 kg ha^{-1} required to raise STV by 1 mg kg^{-1} in the first year and 9 to 23 kg ha^{-1} after two years. Lab C was the only lab to increase Zn levels in alfalfa in the first year, but labs A, C, and UOI increased levels after two years. At site 7, the application ratio ranged from 16 to 41:1, which is much higher rates than most fertilizer recommendations would be.

Higher fertilizer application rates often resulted in increases in soil nutrient concentrations, but the ratio of the application rate to changes in nutrient levels varied greatly among sites and treatments. Higher ratios indicate that higher nutrient applications are needed to increase soil nutrient concentrations. There was no consistent pattern for these ratios or how much the soil test values changed as a result of the applied fertilizer rates. It also illustrates which nutrients can be built-up within a soil compared to those that cannot. Excessive fertilizer rates are often recommended with the intention of increasing nutrient concentrations within a soil, but these data indicate that soil buffering capacity, soil test levels at the time of fertilization, and other factors vary widely and will influence how soil test values change in response to fertilizer. Another factor that will influence how much fertilizer increases soil test nutrients is nutrient removal by the crops. A companion analysis of this study compared the yield and forage quality responses to the five fertilizer recommendations. In this assessment few treatments impacted yield and yield only increased with treatments at a single alfalfa site (Site 7) and the small grain forage sites. Further, many of the yield differences were small and not economically viable compared to no fertilizer. This suggests that large differences in nutrient removal rates were not the driving force behind different ratios required to increase soil test values at these sites.

3.3.5 Cost to Increase Soil Test Values

The ratio of nutrient applied:soil test change was multiplied by the cost per kg of nutrient for the fertilizers used to determine the cost to increase STV by 1 mg kg^{-1} (Figure 3.5). When cost is considered, increasing STV by applying high rates of fertilizers is often not financially feasible. Cost per kg of nutrient in each year influenced these ratios (Table 3.3). Nutrients that are often applied frequently and at higher rates such as N, P, K, or S, are cheaper per kg than the micronutrients such as Zn, Mn, Cu, or B that are recommended at much lower rates. In 2021, the macronutrient fertilizers ranged \$0.13 to \$2.16 per kilogram of nutrient, with SO_4^{-2} being the lowest and P_2O_5 the highest. In contrast, the micronutrients were much more expensive, ranging from \$4.92 to \$35.83 per kilogram, with Zn the lowest and Mn the highest. Prices increased between 2021 and 2022, making these costs for nutrients even higher and nearly or more than doubling for most (Table 3.3).

The ratios were not consistent across sites or crops, making them useful for providing a general idea of cost to increase STV, but not an exact dollar value. In situations where the ratio and cost per unit is low, application of excess nutrients may be worth the cost. In establishing perennial crops like alfalfa where establishment is the last chance for fertilizer incorporation for several years, this method may also be beneficial. This works best for nutrients such as P or S where soil concentrations can be increased, and excess nutrients not leached, or luxury consumed. It is important to evaluate starting soil test concentrations and compare them to the goal level to determine if the cost of increase is economical. This is especially the case with nutrients like Zn, where the cost per kg of nutrient increased drastically between 2021 and 2022 going from $4.92 to $41.20 per kilogram Zn. Micronutrients are often not worth the cost to increase the STV by large amounts.

3.4 | CONCLUSIONS

This study compared soil test results and fertilizer recommendations from commercial and public soil testing laboratories located in the Western U.S. There was high variability in reported soil test results from various soil testing labs from the same composite soil samples. Observed differences in soil test results are sometimes due to the accuracy of each lab’s analyses, but they are also largely influenced by different chemical procedures being used to determine nutrient levels. The resulting fertilizer recommendations from these three commercial laboratories and the two universities varied greatly, both for types of nutrients and the rates being recommended. This is likely due to a combination of differences in soil test values (minor influence) and the fertilizer recommendation philosophies (major influence) utilized by each lab. When the five recommendations were applied in field trials, higher fertilizer application rates often resulted in increases in soil nutrient concentrations, but the ratio of the application rate to changes in nutrient levels varied greatly among sites and treatments.

The fertilizer recommendations from lab C increased soil nutrient concentrations for P, K, S, and Zn the highest and most often of all treatments. STV was increased with fertilizer application 56.8% of the time in one year and 75.0% of the time the after two. Labs A and B increased STVs at 43.2 and 25.0 % of sites in the first year, respectively, and 45.8% and in the second year for both. USU's recommendations increased STV at 27.3% of sites in the first year and 20.8% of sites after two years, while UOI's recommendations increased them at 20.5 and 29.2% of sites for each year. The labs that recommended fertilizers more frequently and at higher rates, such as lab C, increased the soil nutrient concentrations the most often. Soil test values in the control plots often decreased due to lack of fertilizer being applied to replace soil nutrients removed by crops. Excessive fertilizer rates are often recommended with the intention of increasing nutrient concentrations within a soil, but high variability in buffering capacities and site-to-site variation need to be considered. When the cost of fertilizers is included, increasing soil nutrient levels by applying high rates of fertilizers is often not financially feasible. It is often more efficient and economical to apply fertilizer to supply the nutrients needed to optimize crop yield for a given year.

The fertilizer recommendations from lab C increased soil nutrient concentrations for P, K, S, and Zn the highest and most often of all treatments. STV was increased with fertilizer application 56.8% of the time in one year and 75.0% of the time the after two. Labs A and B increased STVs at 43.2 and 25.0 % of sites in the first year, respectively, and 45.8% and in the second year for both. USU's recommendations increased STV at 27.3% of sites in the first year and 20.8% of sites after two years, while UOI's recommendations increased them at 20.5 and 29.2% of sites for each year. The labs that recommended fertilizers more frequently and at higher rates increased the soil nutrient concentrations more often.

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Table 3.1 Site properties for twelve sites in Utah and Wyoming in 2021 to 2023 including site, year, location, elevation, soil texture, soil pH, and soil organic matter.

Site	Year(s)	County	Coordinates	Elevation (m)	Soil Texture	pH	Soil OM (%)
1	2021-2022	Beaver	(38.300256, -112.656962)	1818	Manderfield loam (Fine-loamy over sandy or sandy-skeletal, mixed, mesic Calcic Argixerolls)	7.6	3.13
2	2021	Carbon	(39.492229, -110.775926)	1688	Billings silty clay loam (Fine-silty, mixed, calcareous, mesic Typic Torrifluvents)	8.1	2.89
3	2021-2023	Carbon	(39.491011, -110.787813)	1706	Billings silty clay loam (Fine-silty, mixed, calcareous, mesic Typic Torrifluvents)	8.1	2.48
4	2021-2023	Weber	(41.174268, -112.126257)	1292	Syracuse loamy fine sand (Coarse-loamy, mixed, superactive, mesic Oxyaquic Calcixerolls)	7.7	0.92
5	2021	Lincoln	(41.820626, -111.043608)	1900	Bereniceton silt loam (Fine-loamy, mixed, calcareous, frigid Xeric Torriorthents)	8.2	2.59
6	2021	San Juan	(37.601761, -109.465473)	1807	Monticello very fine sandy loam (Fine-silty, mixed, superactive, mesic Typic Argiustolls)	7.8	1.91
7	2021-2023	Sevier	(38.635644, -112.154381)	1642	Escalante gravelly sandy loam (Coarse-loamy, mixed, superactive, mesic Xeric Haplocalcids)	8.0	1.84
8	2021-2023	Iron	(37.874388, -112.860410)	1760	Calcross silty clay loam (Fine-silty, mixed (calcareous), mesic Xeric Torriorthents)	8.0	1.89
9	2021	Beaver	(38.293218, -112.992531)	1551	Rustico silty clay loam (Fine-silty, mixed, superactive, mesic Cumulic Haploxerolls)	7.9	2.46
10	2021-2022	Box Elder	(41.758104, -112.174760)	1343	Kidman loam (Coarse-loamy, mixed, superactive, mesic Calcic Haploxerolls)	7.5	2.97
11	2021-2022	Box Elder	(41.763810, -112.172659)	1338	Parley's loam (Fine-silty, mixed, superactive, mesic Calcic Argixerolls)	8.2	2.18
12	2021	Iron	(38.017778, -112.707795)	1774	Antelope Spring's loam (Fine-loamy, mixed, mesic Xeric Natrargids)	8.1	2.48

Table 3.2 Management characteristics for twelve on-farm trial sites in 2021-2023 including crop grown, yield goals, stand age (if applicable), previous crops, N fertilizer applied through fertigation, and irrigation type.

Site	Crop Grown 2021-2023	Yield Goal	Stand Age	2019 Crop	2020 Crop	N Fertilizer Applied	Irrigation Type
		Mg ha^{-1}				kg ha^{-1}	
1	Small Grains	9	n/a	Unknown	Small Grains	10	Pivot
2	Small Grains	6	n/a	Corn	Oats	0	Pivot
3	Small Grains	6	n/a	Alfalfa	Alfalfa	0	Wheel line
4	Alfalfa	17	3	Alfalfa	Alfalfa	0	Flood
5	Alfalfa	10	3	Alfalfa	Alfalfa	0	Pivot
6	Alfalfa	13	1	Fallow	Fallow	0	Wheel line
7	Alfalfa	13	4	Alfalfa	Alfalfa	0	Pivot
8	Alfalfa	13	2	Alfalfa	Alfalfa	0	Wheel line
9	Silage Corn	63	n/a	Alfalfa	Corn	22	Pivot
10	Grain Corn	20	n/a	Corn	Corn	45	Pivot
11	Grain Corn	20	n/a	Wheat	Wheat	45	Pivot
12	Silage Corn	72	n/a	Alfalfa	Alfalfa	11	Pivot

Table 3.3 Fertilizer sources used in recommendation studies in 2021-2023 including nutrient, fertilizer source, analysis of fertilizer, additional S, and cost per kg and Mg per unit of nutrient for each year of study

Nutrient	Source	Fertilizer Analysis	Additional Sulfur	2021 Cost	2022 Cost	2023 Cost
		% of target nutrient	% S	\$ kg^{-1} of Nutrient	\$ kg^{-1} of Nutrient	\$ kg^{-1} of Nutrient
Nitrogen (N)	Ammonium Nitrate	34%		1.62	2.89	2.89
Phosphorus (P)	Triple Super Phosphate	45%		2.16	4.15	3.55
Potassium (K)	Potash	60%		1.35	1.35	1.26
Sulfur (S)	Elemental Sulfur	90%		0.48	0.48	0.63
Sulfur-sulfate (SO_4^{2-})	2021 Gypsum	64%	12%	0.13		
Zinc (Zn)	Zinc Sulfate	36%		4.92		
Manganese (Mn)	Manganese	8%	6%	35.83		
Boron (B)	Boron	14%		14.96		
Copper (Cu)	Copper Sulfate	25%		20.85		
Sulfur-sulfate (SO_4^{2-})	22-23 Gypsum	97%	17.5%		0.14	0.14
Zinc (Zn)	Chelated Zinc	9%			41.20	41.20
Manganese (Mn)	Manganese	5%			66.36	66.36
Boron (B)	Boron	10%			32.07	32.07
Copper (Cu)	Copper	8%			42.76	42.76

Table 3.4 Site properties for nine sites in Utah and Wyoming in 2021 to 2023 including site, year, location, elevation, soil texture, soil pH, and soil organic matter.

Site	Year(s)	County	Coordinates	Elevation (m)	Soil Texture	pH	Soil OM%
13	2021	Sevier	(38.808800, -111.940587)	1716	Xeric Haplogypsids-Sigurd association (Loamy-skeletal, carbonatic, mesic Xeric Torrifluvents)	8.0	2.85
14	2021	Weber	(41.229860, -112.094538)	1289	Warm spring fine sandy loam (Fine-loamy, mixed, active, mesic Oxyaquic Calcixerolls)	8.1	1.66
15	2021	Box Elder	(41.430395, -112.055623)	1290	Logan silty clay loam (Fine-silty, mixed, superactive, mesic Typic Calciaquolls)	7.9	3.02
16	2021	Beaver	(38.301958, -112.658025)	1814	Manderfield loam (Fine-loamy over sandy or sandy-skeletal, mixed, mesic Calcic Argixerolls)	7.1	2.52
17	2021	San Juan	(37.559897, -109.495637)	1747	Monticello very fine sandy loam (Fine-silty, mixed, superactive, mesic Typic Argiustolls)	7.5	1.41
18	2021	Uintah	(40.419550, -109.823075)	1676	Paradox loam (Fine-loamy, mixed, superactive, calcareous, mesic Ustic Torriorthents)	7.9	1.40
19	2021	Iron	(37.880835, -112.873661)	1749	Calcross silty clay loam (Fine-silty, mixed (calcareous), mesic Xeric Torriorthents)	8.0	2.12
20	2021	Box Elder	(41.800090, -112.161698)	1338	Fine-silty, mixed, superactive, mesic Calcic Argixerolls	7.8	3.71
21	2021	Emery	(39.465472, -110.748420)	1676	Killpack clay loam (Fine-silty, mixed, active, mesic Typic Haplocambids)	8.1	2.83

Table 3.5 Management characteristics for nineteen on-farm trial sites in 2021-2023 including crop grown, yield goals, stand age (if applicable), previous crops, and irrigation type

Site	Crop Grown 2021-2023	Yield Goal	Stand Age	2019 Crop	2020 Crop	Irrigation Type
		Mg ha^{-1}	yr			
13	Small Grains	9	n/a	Unknown	Unknown	Pivot
14	Alfalfa	17	1	Unknown	Alfalfa	Flood
15	Alfalfa	16	4	Alfalfa	Alfalfa	Pivot
16	Alfalfa	11	5	Alfalfa	Alfalfa	Pivot
17	Alfalfa	13	3	Alfalfa	Alfalfa	Wheel line
18	Corn	67	n/a	Corn	Corn	Flood
19	Corn	67	n/a	Alfalfa	Alfalfa	Pivot
20	Corn	17	n/a	Wheat	Wheat	Pivot
21	Corn	56	n/a	Alfalfa	Corn	Pivot

Table 3.6 Soil analytical methods and extractants used by three commercial soil testing laboratories for the following parameters: pH, Organic Matter (OM), Electrical Conductivity (EC), N, P, K, SO_4^{2-}, Zn, Fe, Mn, Cu, and B. Method numbers reference Soil, Plant, and Water Reference Methods For the Western Region 4th Edition (Gavlak et al., 2013).

	Lab A		Lab B		Lab C	
Parameter	**Method Number**	**Methods**	**Method Number**	**Methods**	**Method Number**	**Methods**
pH	S-2.20	1:1 (soil:water)	S-2.20	1:1 (soil:water)	S-2.10	1:2 (soil:water)
OM	S-9.20 adjusted	Loss on Ignition adjusted to Walkley Black	S-9.10	Walkley Black	S-9.20	Loss on Ignition
EC	S-2.30 adjusted	1:1 (soil:water) adjusted to saturated paste	S-2.20	1:1 (soil:water)	not provided	methods not provided
N	S-3.10	KCl Extraction / Cadmium Reduction	S-3.10	KCl Extraction / Cadmium Reduction	S-3.10	KCl Extraction / Cadmium Reduction
P	modified S-4.60	Olsen modified by AA-NH_4F Kewlona extraction	S-4.10	Olsen-Sodium Bicarbonate	S-4.10	Olsen-Sodium Bicarbonate
K	S-5.10 adjusted	AA 1:10 extraction adjusted to bicarbonate	S-5.10	Ammonium Acetate / ICP	S-5.10	Ammonium Acetate / ICP
SO_4^{2-}	S-4.60	AA-NH_4F Kewlona extraction	S-6.11	DTPA / Sorbitol / ICP	S-5.10	Ammonium Acetate / ICP
Zn	S-6.10	DTPA Extraction	S-6.11	DTPA / Sorbitol / ICP	S-6.10	DTPA Extraction
Fe	S-6.10	DTPA Extraction	S-6.11	DTPA / Sorbitol / ICP	S-6.10	DTPA Extraction
Mn	S-6.10	DTPA Extraction	S-6.11	DTPA / Sorbitol / ICP	S-6.10	DTPA Extraction
Cu	S-6.10	DTPA Extraction	S-6.11	DTPA / Sorbitol / ICP	S-6.10	DTPA Extraction

B	S-4.60	AA-NH4F Kewlona extraction	S-6.11	DTPA / Sorbitol / ICP	S-6.10	DTPA / Sorbitol / ICP

Abbreviations: DTPA, diethylenetriaminepentaacetic acid; ICP, Inductive Coupled Plasma

Table 3.7 Number of sites for each treatment fitting within each of the four categories defining types of fertilizer addition and soil test changes throughout the duration of the study. Eleven sites were evaluated after one year and six sites after two years.

Nutrient	Treatment	2021-2022				2021-2023			
		1	**2**	**3**	**4**	**1**	**2**	**3**	**4**
P	Lab A	9	0	1	1	4	0	0	2
	Lab B	8	1	1	1	4	0	2	0
	Lab C	6	2	1	2	4	0	0	2
	USU	6	0	2	3	2	0	1	3
	UOI	6	0	2	3	5	0	0	1
	Control	0	11	0	0	0	6	0	0
K	Lab A	1	6	0	4	1	2	0	3
	Lab B	1	7	0	3	3	2	0	1
	Lab C	2	5	0	4	4	0	0	2
	USU	1	9	0	1	1	3	0	2
	UOI	1	8	0	2	1	3	0	2
	Control	0	11	0	0	0	6	0	0
S	Lab A	6	0	1	4	2	0	1	3
	Lab B	0	4	0	7	1	0	1	4
	Lab C	11	0	0	0	5	0	0	1
	USU	2	5	3	1	0	2	3	3
	UOI	1	6	2	2	0	2	1	3
	Control	0	11	0	0	0	6	0	0
Zn	Lab A	3	5	0	3	4	2	0	0
	Lab B	2	7	0	2	3	3	0	0
	Lab C	6	4	0	1	5	0	0	1
	USU	3	7	0	1	2	4	0	0
	UOI	1	9	0	1	1	5	0	0
	Control	0	11	0	0	0	6	0	0

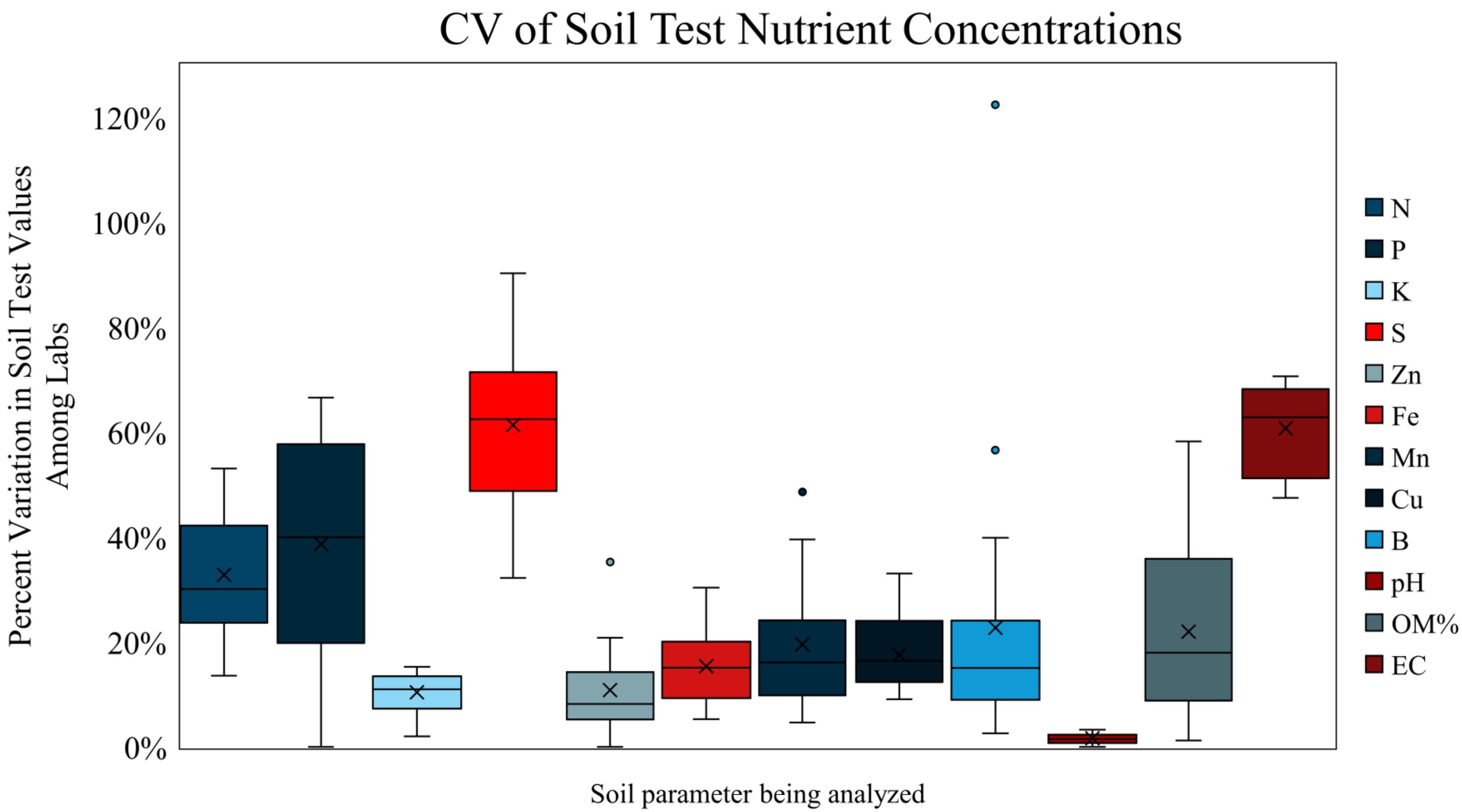

Figure 3.1 Calculated CVs for reported soil test results for soil samples from twenty-one sites sent to three commercial soil testing laboratories for analysis.

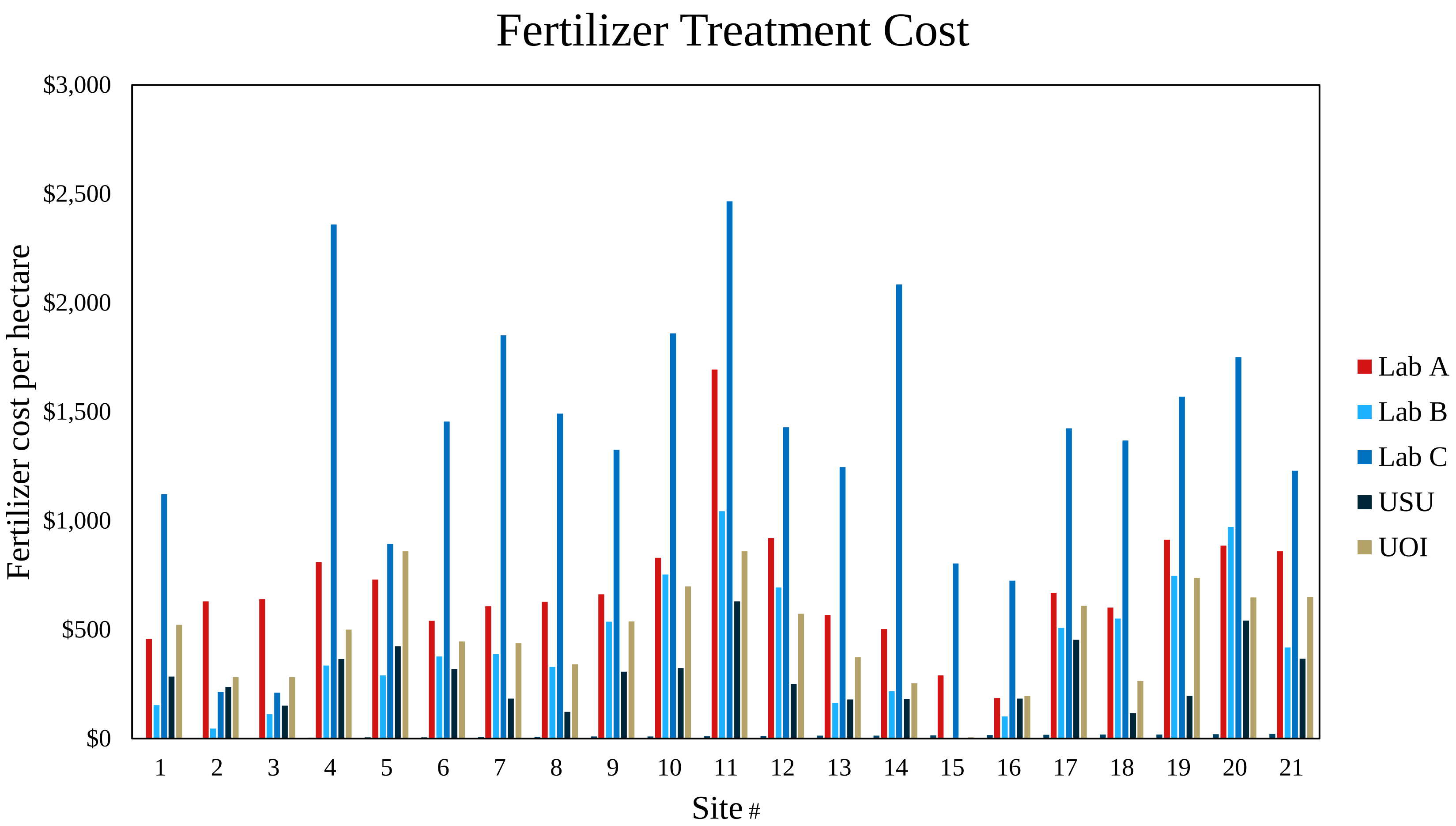

Figure 3.2 Treatment cost per hectare in 2021 for fertilizer recommendations from three commercial laboratories and two universities from twenty-one sites.

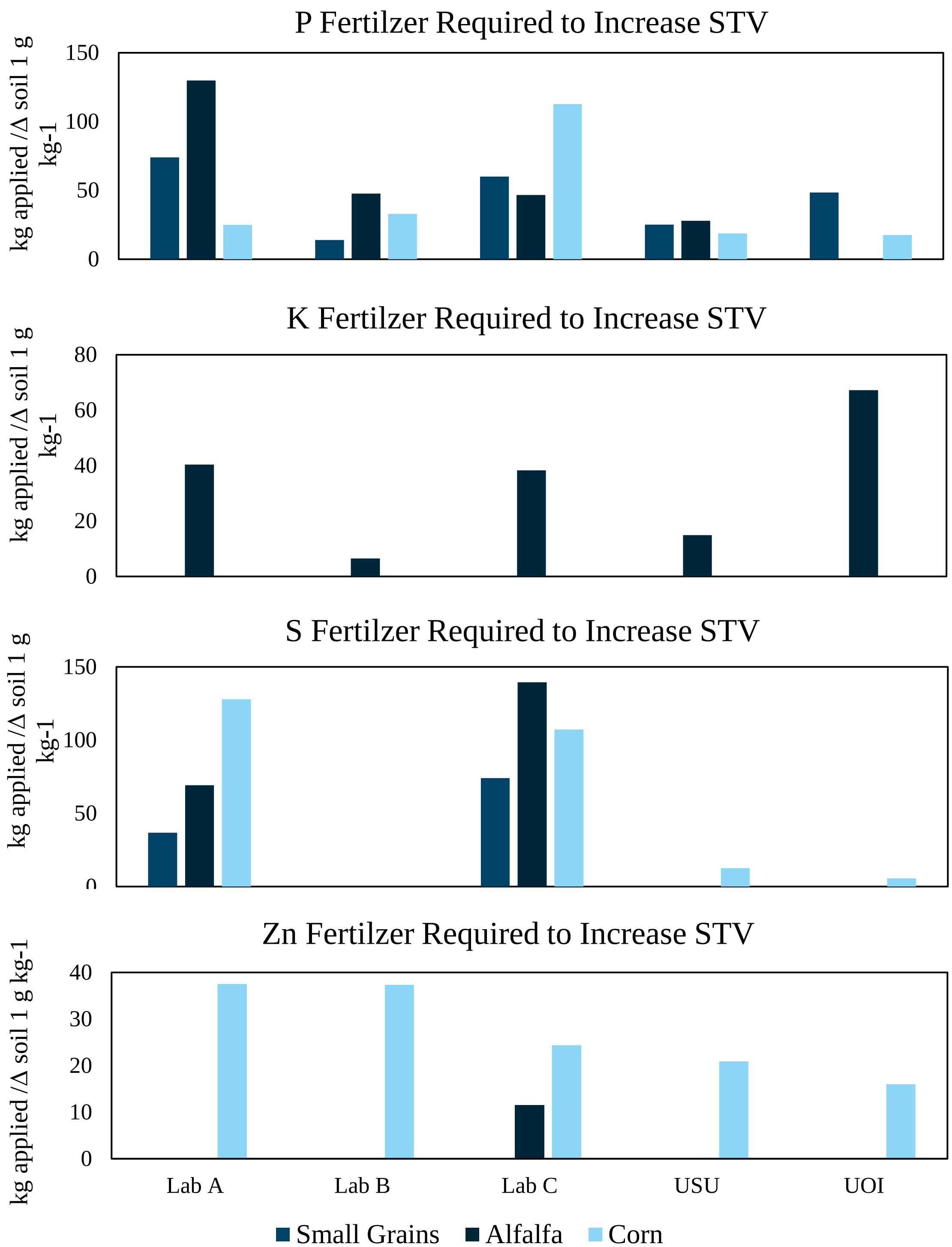

Figure 3.3 Ratio of nutrient applied to change in soil test results after one year for each treatment and averaged for each crop. The following nutrients were evaluated after one year of fertilizer recommendations from five labs being applied: P, K, S, and Zn.

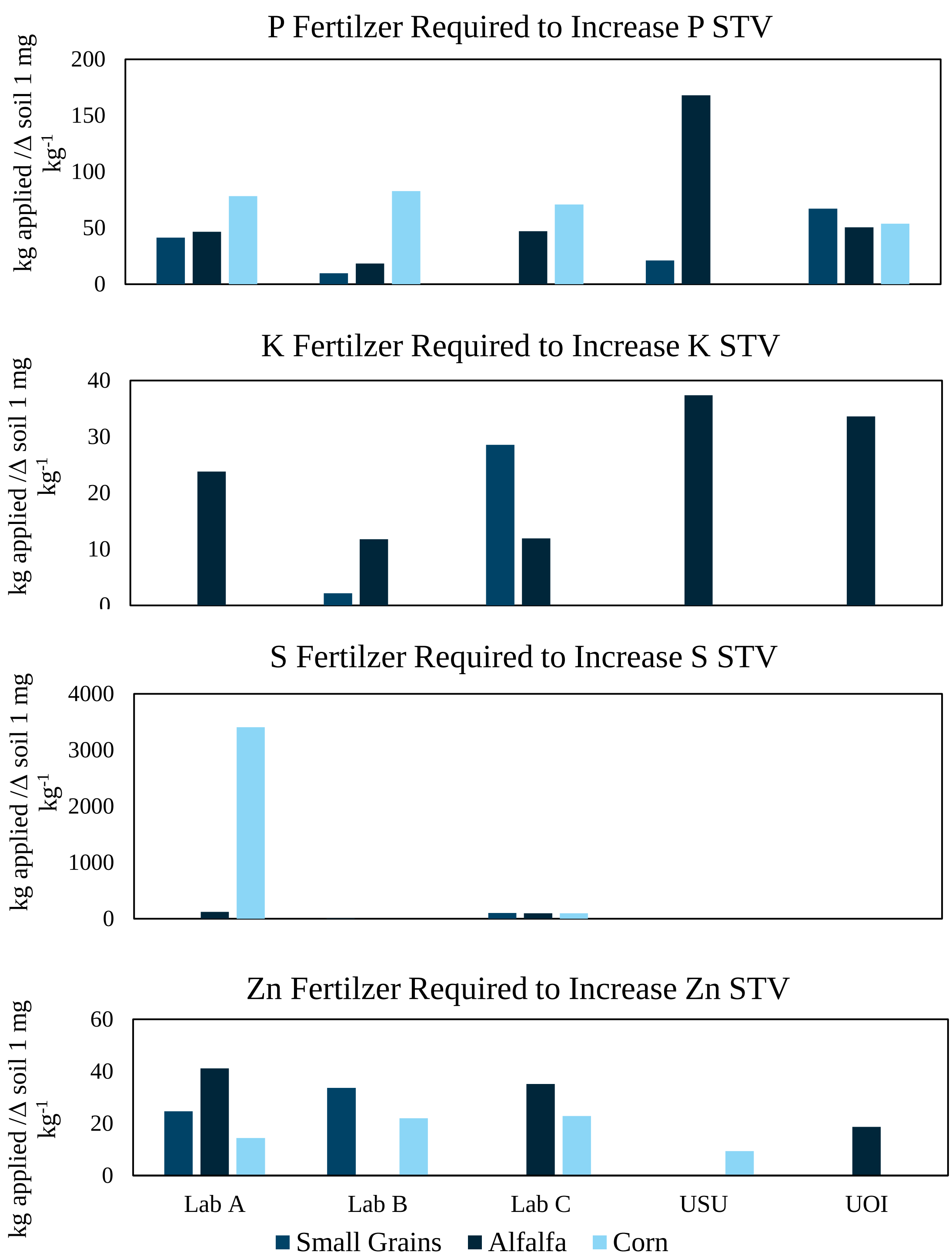

Figure 3.4 Ratio of nutrient applied to change in soil test results after two years for each treatment and averaged for each crop. The following nutrients were evaluated after two years of fertilizer recommendations from five labs being applied: P, K, S, and Zn.

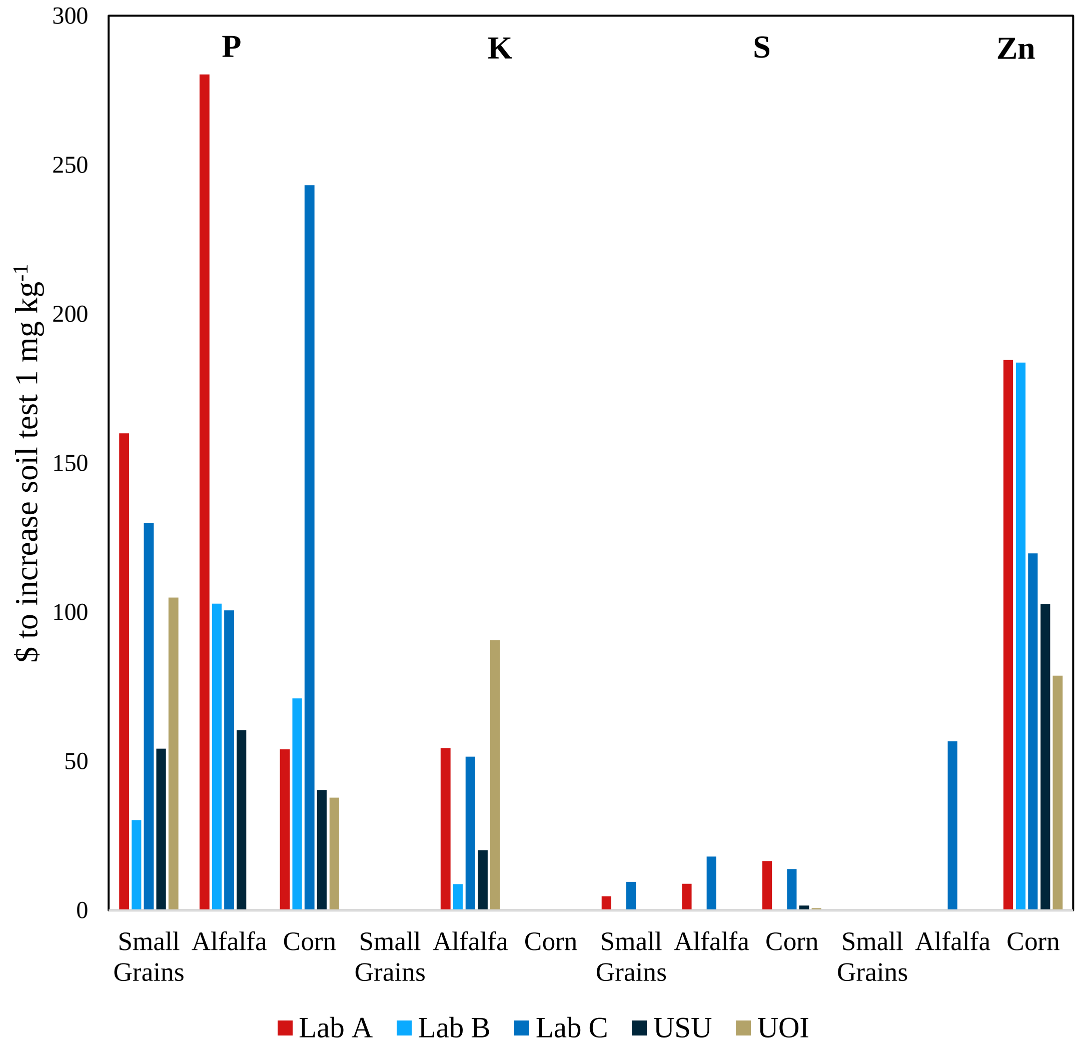

Figure 3.5 Cost of ratio of nutrient applied to change in soil test results after one year for each treatment and averaged for each crop. The following nutrient costs were evaluated after one year of fertilizer recommendations from five labs being applied: P, K, S, and Zn.

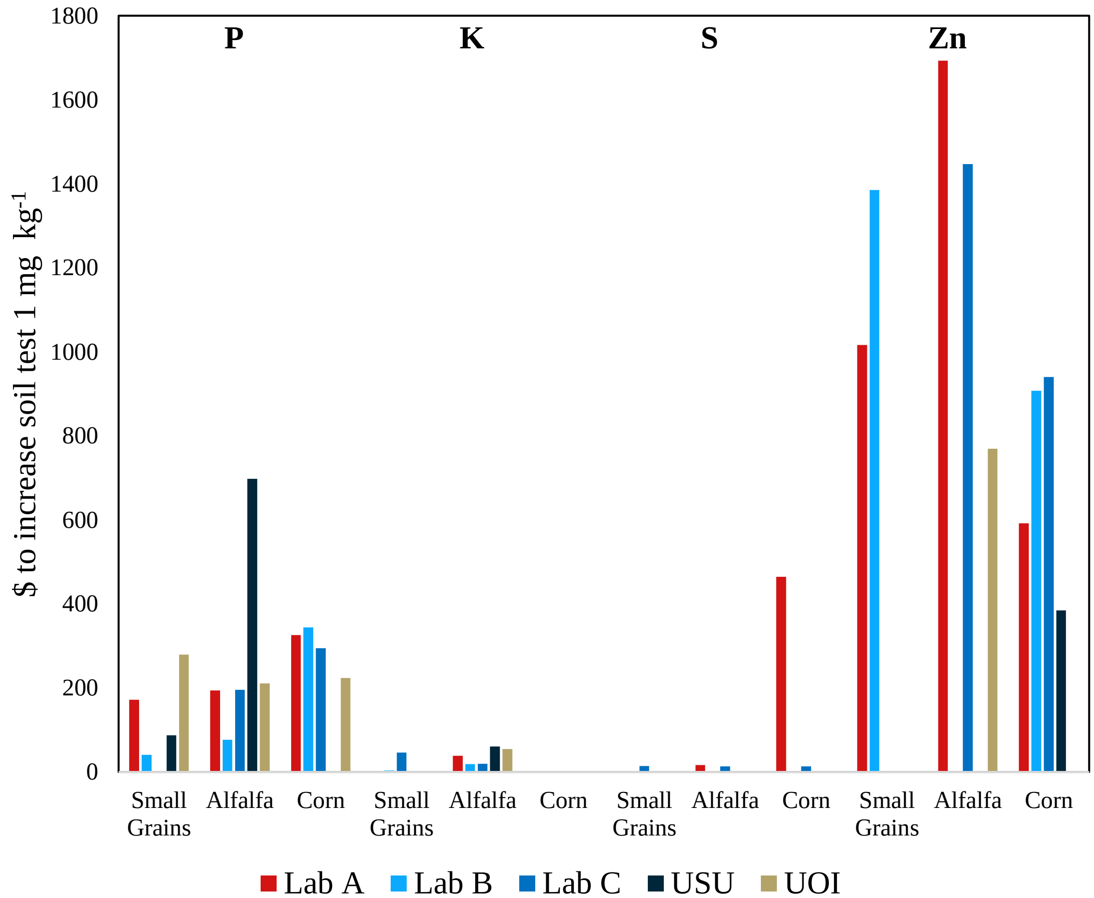

Figure 3.6 Cost of ratio of nutrient applied to change in soil test results after two years for each treatment and averaged for each crop. The following nutrient costs were evaluated after two years of fertilizer recommendations from five labs being applied: P, K, S, and Zn.

CHAPTER IV

COMPARISON OF PRIVATE AND PUBLIC LAB FERTILIZER RECOMMENDATION IMPACTS ON FIELD CROP PRODUCTION AND SOIL TEST RESULTS: CONCLUSION

This study compared soil test results and fertilizer recommendations from commercial and public soil testing laboratories located in the Western U.S. There was high variability in reported soil test results from various soil testing labs for identical samples being analyzed. Observed differences in soil test results are sometimes due to the accuracy of each lab's analyses, but they are also largely influenced by different chemical procedures being used to determine nutrient levels. The resulting fertilizer recommendations from these three commercial laboratories and the two universities varied greatly, both for types of nutrients and the rates being recommended. This is likely due to a combination of differences in soil test values and the fertilizer recommendation philosophies utilized by each lab. These recommended nutrients and rates, yield, forage quality, and cost were evaluated for each of the five fertilizer treatments and nonfertilized control. Large variation in reported soil test results, fertilizer recommendations, and treatment costs were observed, with few impacts on the resulting yield or forage quality.

Silage corn was not impacted by fertilizer treatments at any site in either year, but fertilizer recommendations and cost differed greatly. Yield was increased by treatments at small grain forage sites, as were several of the quality factors, but treatment impacts were not consistent and rarely would be economical. Fertilizer treatments increased yield at one alfalfa site, but no impacts were observed at any of the other four. Forage quality was occasionally influenced by treatments, but these differences rarely caused the alfalfa to change quality designation categories. Furthermore, the nonfertilized control at the responsive alfalfa site produced among the highest returns indicating little need for fertilizer at this site.

Higher fertilizer application rates often resulted in increases in soil nutrient concentrations, but the ratio of the application rate to changes in nutrient levels varied among sites and treatments. Soil test values in the control plots often decreased due to lack of fertilizer being applied to replace soil nutrients taken up by growing crops. Excessive fertilizer rates are often recommended with the intention of increasing nutrient concentrations within a soil, but it is not possible to predict exactly how much the soil test values will be increased by.

The cost of fertilizer recommendations varied greatly among treatments and sites, but the resulting similar crop responses indicate that the higher rates are rarely justified. The fertilization philosophy and recommendation calculation methods likely had the largest impact on the fertilizer recommendations from each laboratory. Recommendations from the Universities were often more conservative than the commercial laboratories, but crop response to these fertilizer treatments was similar. These treatments were often the most economical, with yields being increased similarly with much lower inputs. However, commercial laboratories do not always recommend excessive fertilizer applications, commercial lab B recommended similar rates to USU and UOI in many cases.

Fertilizer is a large input cost for many agricultural operations and can greatly influence resulting profits. Comparison studies like this provide transparency for the possible fertilizer recommendation sources used by growers. While the nonfertilized control yielded similarly, this does not indicate that fertilizers are not necessary. This just indicates that more-efficient fertilizer rates can optimize crop production while minimizing costs and negative environmental impacts.