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Demographics, Accuracy, and Impact of Feed Laboratories in the United States

Jerald H. Severe
Utah State University

DEMOGRAPHICS, ACCURACY, AND IMPACT OF FEED LABORATORIES IN THE UNITED STATES

by

Jerald H. Severe

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Approved:

_____	_____
Allen J. Young Major Professor	Thomas D. Bunch Committee Member
_____	_____
Kerry Rood Committee Member	Dale Zobell Committee Member
_____	_____
Earl Creech Committee Member	D. Richard Cutler, Ph.D. Interim Vice Provost for Graduate Studies

UTAH STATE UNIVERSITY
Logan, Utah

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ABSTRACT

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by

Jerald H. Severe, Doctor of Philosophy

Utah State University, 2020

Major Professor: Allen Young, Ph.D.
Department: Animal, Dairy, and Veterinary

Feed analysis is an important tool in the livestock industry and research into feed laboratory demographics, utilization, accuracy, and impact is limited.

Study 1 used internet searches to collect feed laboratory demographic data. One hundred and forty-four laboratories were identified that perform feed analysis in the United States. The majority of laboratories were commercial entities (76%) and most used wet chemistry (≥ 80%) and about half used NIR (≥ 52%).

In study 2, businesses affiliated with to a national forage trade association were surveyed. Of the respondents, 72% used 45 different feed laboratories; one laboratory accounted for 22% of responses. University professionals in 39 states (63% response) listed 10 laboratories which they use or recommend to others; three laboratories were utilized 74% of the time.

Study 3, laboratory performance data from 12 commercial laboratories was collected by using a blind test. Laboratories analyzed three hay types: 1 grass and 2 types of alfalfa. Duplicate samples from the same lot were submitted to 12 laboratories, 3 times each, and analyzed for DM%, CP%, ADF%, NDF%, Ca and P. Results between and

within laboratories showed significant variation, particularly NDF% and DM% (primarily due to humidity in some states).

Study 4 was conducted to determine differences in weight gain and carcass characteristics of crossbred steers. Laboratory values for the grass hay from Study 3 that were above or below one SD from the overall mean (63.9 %; SD = 3.43) were used to construct rations that were High (TDN>69%) or Low (<60%). The overall DMI was 3.26% and 3.30% for the High and Low ration, respectively, which exceeded the expected intake. Gains exceeded target weights by 27 kg (High) and 19 kg (Low). The ADG were 1.68 and 1.53 kg for High and Low rations, respectively. In-house grass hay CP and TDN analysis exceeded the values upon which both rations were based. As a result, both rations were likely over supplemented, which increased feed costs.

In total, these studies provide evidence that there are large variations between and within laboratories analyzing the same sample and these variations can have production and economic consequences.

(178 pages)

PUBLIC ABSTRACT

DEMOGRAPHICS, ACCURACY, AND IMPACT OF FEED LABORATORIES IN THE UNITED STATES

Jerald H. Severe

Feed analysis is very important to modern society. In the United States feed analysis is used to optimize production of food animals. Feed analysis is also used as a tool to place value on crops. As important as feed analysis is to society, little research has been done that describes which feed laboratories are the most popular and why people use them. It has been thought by some patrons that different results from the same feed sample are obtained by different laboratories. Is this true? If so, what is the effect on those that use feed laboratories to produce animals, like beef cattle?

Four studies were the used to answer the questions described above and to learn more about the feed laboratory industry. Study 1 was used find out more about the population of feed laboratories in the United States. Study 2 conducted surveys to discover more about which laboratories are popular and why people use certain feed laboratories. Study 3 was used to find out if all feed laboratories produce results which agree, even when the same feed sample is tested by different laboratories and when the laboratories do not know that they are being compared to each other. Study 4 was used to show how, when different analyses of the same feed are produced, it impacts animal production.

In total, these studies provide evidence that there may be large variations between and within laboratories analyzing the same sample and these variations can have production and economic consequences.

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Jerry Severe

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LIST OF ABBREVIATIONS

AC = analysis cost

ACTP = total of annual wet chemical and near infrared reflectance analysis certifications

ADF = acid detergent fiber

ADG = average daily gain

ARS = Agricultural Research Service

AWS = arid Western State

BCS=body condition score

BWN = both wet chemistry and near infrared reflectance

CE = commercial entities

CF = crude fiber

CP = crude protein

CPYG = calculated percent yield grade

DDGS = dry distillers' grain with solubles

DDM = digestible dry matter

DM = dry matter

DMI = dry matter intake

ENIR = exclusively near infrared reflectance

EWC = exclusively wet chemistry

GAP = Gulf and Atlantic plains

GS = General Service laboratories

IMF=percent intramuscular fat

IMG = immature mixed grass

LC = laboratory certification

LDM = laboratory determined dry matter

LG = dry matter loss or dry matter gained

LI = laboratory identified

LR = laboratory reputation

LW= live weight

ME = metabolizable energy

MR = ranking multiple industries

MUR = multiple industries without ranking

NDF = neutral detergent fiber

NEG = net energy gain

NEL = net energy of lactation

NEM = net energy maintenance

NFTA = National Forge Testing Association

NIR = near infrared reflectance

NIST = National Institute of Standards SRM and Technology

OSD = in-house laboratory standard deviation results included

PBLA = pre-bloom alfalfa

PBDA = pre-bud alfalfa

PDM = pre-submission partial dry matter

RCREC = University of Florida feed energy calculator

REA/CWT = ribeye area per 100 pounds

REA = ribeye area

RFID = radio frequency identification

RFV = relative feed value

RG = regulatory laboratories

RIBFT = rib fat thickness

RMPFT = rump fat thickness

RS = research laboratories

SDA = state departments of agriculture

SRM = Standard Reference Material

TDN = total digestible nutrients

TMR = total mixed ration

WC = wet chemical

CHAPTER 1

INTRODUCTION

Before 1970, feed analysis was practiced by commercial feed manufacturers, government regulatory agencies, universities and a few private laboratories. Longland and Byrd (2006) stated that universities originally established forage laboratories to support the Dairy Herd Improvement Association. By 1975 most extension dairy producers in the United States were actively promoting and/or providing forage testing to stakeholders (Coppock, 1976, Coppock et al., 1981). Eventually, as a result of extension educational efforts, livestock producers became more aware of the importance of balanced rations for improving profitability and therefore the use of forage analysis has continually increased.

Today there are large numbers of analytical laboratories that provide feed analysis for producers in the United States. The scope of feed components that laboratories test is wide-ranging. For example, laboratories that specialize in soil analysis often provide crude protein and mineral analysis on feeds because minimal change is needed in methodology or instrumentation from those used for soils. In contrast, there are laboratories that are more specialized in feed analysis. These laboratories test for crude protein (CP), minerals, and fiber components such as acid detergent fiber (ADF), neutral detergent fiber (NDF), and crude fiber (CF). Many feed laboratories also test for fat, starch, sugar, lignin, amino acids and other feed components.

Feed analysis directly from laboratories has become a necessity for progressive livestock producers. As the science of animal nutrition has advanced, the array of feed components for which laboratories test have increased, as have the methods used to

quantify feed components. Patrons of feed analysis have also increased and are more diverse due to development of broader applications for feed analysis. Some of the more recent applications of feed analysis include:

- Establishment of crop values for trade in domestic and export markets (Guerrero, 2001, Ward, 2004).
- Variety selection of crops and valuation by crop breeders (Mueller-Harvey, 2004).
- Qualifying producers for reception of emergency relief funds from government agencies (Shields and Chite, 2010).
- Environmental studies and mitigation (Beauchemin et al., 2007, Roberts et al., 2007)
- Wildlife and range studies (Memmott et al., 2011, Petersen et al., 2014)

It is clear that feed analysis is a useful tool for the agriculture economy and society. However, few peer review studies have been conducted comparing the accuracy between United States feed laboratories or the impact of laboratory inaccuracy on animal production. This dissertation documents studies conducted which compared analytical results of forage samples which were blindly submitted to United States feed laboratories and the impact of laboratory inaccuracy on animal production. Before a comparative study of feed laboratory results and impact on animal production could be carried out, preliminary studies to identify laboratory locations, characteristics, and utilization in United States was required.

Feed Laboratory Demographics

Numerous extension publications provide valuable information for producers concerning feed analysis, proper sampling techniques, and lists of laboratories that

perform feed analysis. However, there is limited consolidated demographic information available which describes the feed analysis industry in the United States such as:
How many laboratories perform feed analysis?

- What is the geographic distribution of feed laboratories in the United States?
- Are there factors that affect feed laboratories distribution in the United States?
- How many laboratories offer feed analysis to the public?
- Are feed laboratories distinct enough to be classified?
- What types of organizations operate feed laboratories?
- To what extent are major systems of analytical methods, wet chemical (WC), near infrared reflectance (NIR), in vitro (IV), or in situ (IS), utilized by laboratories?
- How many feed laboratories participate in analytic proficiency programs?
- How many private commercial feed laboratories are used in peer reviewed research?

There has been a need for identification and categorization of United States feed laboratories. In addition, collection and analysis information about United States feed laboratories and the feed analysis industry dynamics is required. Such information will lead to greater understanding of the feed analysis industry and will provide a baseline for comparing and measuring the progress and direction of the industry in the future. Chapter 2 of this dissertation provides a current description of United States feed laboratory populations that have never been characterized.

Feed Laboratory Utilization

Forage laboratories have become common in the United States, are easily accessible, and provide relatively inexpensive forage analysis to animal and crop producers. The use

of forage analysis has advanced, becoming an essential component of modern animal production (Ampong-Nyarko and Murray, 2011) and increasingly important to the forage industry for crop valuation and trade activities.

As important as feed analysis is, utilization of forage analysis by agricultural enterprises have been viewed as limited (Corah et al., 2010). It has also been suggested that many patrons of forage laboratories have reservations about the validity of forage analyses (Undersander et al., 2005).

In order for extension professionals to effectively transfer and eventually have information and technologies applied by agricultural end-users, identifying factors which hinder the complete educational process must be identified. Factors hindering acceptance of the practice of forage analysis may be related to human behavior or experience. Other factors may be connected to stages of end-user knowledge (Barao, 1992) of forage analysis. Chapter 2 of this dissertation examines commercial feed laboratory use throughout the United States. Current preferences of laboratory patrons such as specific laboratory selection, systems of analysis, and laboratory performance were examined through surveys of businesses belonging to an international forage trade association. In addition, feed laboratory importance and impact to forage businesses was documented.

Feed Laboratory Accuracy and Precision

Accurate and precise nutritional analysis facilitates more efficient use of animal production resources and provides sound information whereby other end users can make valid inferences and determinations. Commercial and many extension oriented governmental laboratories perform analyses for individuals and organizations that seek to know the nutritional composition of feeds. These laboratories have become commonplace

and are integral parts of both plant and animal agriculture. There is evidence that inaccuracy and imprecision among feed laboratories in the United States maybe a problem; according to peer review (Hristov et al., 2010) and trade (Holin, 2008, McCabe, 2008) literature.

To more thoroughly investigate claims of significate variation of feed analyses between laboratories; a blind ring test was carried out and is described in Chapter 5. This ring test was needed to determine the magnitude of feed analysis variation between and within US feed laboratories that actually provide significant analytic services to agricultural producers. The research approach of this study used experimental methods and materials that minimize participating laboratory bias, and which simulate actual feeds, materials, and methods used widely by producers in preparation for feed analysis.

Impact of Inaccurate Feed Analysis

Evidence of accuracy and precision problems among U.S. feed laboratories has been documented in trade and professional publications and by the study described in Chapter 5. Inaccurate feed analysis performed by commercial laboratories in the United States is costing both feed and livestock producers in terms of over or under priced feed, and in lost production and wasted resources.

Inaccuracies discovered between commercial feed laboratories justify research focused on the impact of variation of feed analysis on livestock production. Research described in Chapter 6 identified elements of feed management affected by variability and inaccuracy in forage analysis. This research also showed how feed costs are affected by variability and inaccuracy in forage analysis.

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CHAPTER 2

REVIEW OF LITERATURE

History and Significance of Feed Analysis

In recent years, feed analysis has become an important tool in many academic disciplines other than livestock nutrition. In the field of range science, feed analysis has been used to access the quality of forages consumed by wildlife (Alldredge et al., 2002). Feed analysis is also used as a tool in crop science to assist in cultivar selection in plant breeding programs (Coors et al., 1986). In the environmental quality field, feed analysis is used to mitigate livestock pollution issues (Fox et al., 2006). In toxicology, feed analysis is used to identify and quantify feed born poisons, like aflatoxin (Decastelli et al., 2007).

In contemporary agribusiness, nutritional information obtained from feed analysis is used to market feed products domestically and internationally (Hopper et al., 2004). Feed analysis is crucial in establishing quality assurance in manufactured feeds (Adesogan, 2002). The monetary value of feedstuffs can be established through valid feed analysis (Mertens, 2000). Feed analysis aids in preventing detrimental or unwanted feed components from reaching consumers (Aganga et al., 2011). Accurate feed analysis performed by commercial laboratories can provide unbiased, independent, third-party verification of feed quality from which sellers and purchasers of animal feeds can negotiate transaction terms.

Presently, feed analysis is used by various governmental organizations on feed analysis for differing reasons. The United States Fish and Wildlife Service utilize feed analysis to set contract parameters for minimum feed quality standards, for pelleted

alfalfa, that is supplied to the National Elk Refuge for its elk feeding program. Several state wildlife agencies also use feed analysis in ways similar to those of the national elk refuge. Feed analysis is also used to enforce and monitor compliance to contract terms. Farm Service has also utilized feed analysis in qualifying farmers and livestock producers for disaster relief.

As previously explained, feed analysis has widespread use among diverse groups. As time passes, feed analysis will continue to increase in importance for society. As land and food resources become more limited, more efficient use of resources will be required (Pelletier and Tyedmers, 2010). Efficient use of feed resources can only come from proper feed management and efficient feed management is made possible chiefly by accurate and reliable feed analysis.

As valuable as feed analysis is to contemporary society, papers outlining the history and origins of feed analysis specifically are limited. Therefore, a brief chronologic account of significant individuals, theories, and technological advancements, which have led to the development of contemporary feed analysis, will be discussed. Apart from providing background on feed analysis in general and insight into the historical use of qualitative analyses of feeds, this review will primarily focus on the history of feed analyses that quantify carbohydrate, lipid and nitrogen components. The history of dietary mineral analysis will not be discussed.

Brief History of Nutrition Science

Historically, feed analysis has developed concurrently with theoretical and technological advancements in the sciences of chemistry and nutrition. Over time progress in chemistry and the nutrition sciences have continuously led to change in

theories, practices, instrumentation, and terminology associated with feed analysis. Modern investigators who have been educated with results of over 200 years of nutritional and chemical discovery may find it hard to understand scientific rational and terminology from the 18th century or earlier. Therefore, an effort is made in this paper to provide a background in relation to histories of chemistry and nutrition sciences and terminology.

Francois Magendie (1783-1855) described nutrition, in his day, as a subject resulting from conjecture, and ingenious hypothesis used to satisfy imaginations. Often knowledge of nutrition was not arrived at through sound scientific experimentation (Carpenter, 2003). Incorrect ideas about nutrition hampered progress in the science. It wasn't until the "chemical revolution" at the end of the 18th century and discovery of true elements that the science of nutrition began to advance significantly. During much of the 18th century and into the beginning of the 19th century, it was thought that three classes of materials existed in nature: mineral, vegetable, and animal. Animal nutrition was considered to be a process by which animals transformed vegetable matter into animal matter (Goodman, 1971). Dry distillation was used for nearly 200 years (1615-1794) to analyze organic matter. Early on, organic matter analyzed through dry distillation, was separated into weighed fractions characterized as gaseous, phlegma (watery matter), oil, or carbon residue. Later organic matter as characterized as carbonic oxide, carbonic acid, watery fraction, emphyrematic oil, acidic fraction, carbureted hydrogen fraction, and charcoal. Even later, volatile alkalies, ammonia, and nitrogen were used by researchers to describe organic matter (Nierenstein, 1934).

In 1785, Claude Berthollet found that ammonia was given off when animal tissues decomposed, establishing that animal tissues contained nitrogen. Other scientists of the period also verified that nitrogen was in animal tissues and it was generally believed that nitrogen was not in plants. Constituents such as sugar, starch or fats were thought to be unique to plants. (Carpenter, 2003). Consequently, in error, nitrogen was considered unique to animal matter. This information was erroneously used as a system to classify organic materials under two broad categories, animal or vegetable substances. Materials classified as animal substances contained nitrogen, while materials thought to have no nitrogen were regarded as vegetable substances. However, in 1789, Antoine François Fourcroy found nitrogen containing substances in the plant family, Brassicaceae (Rosenfeld, 2003). Therefore, in cases where plants contained nitrogen, the plants were considered animal substance with vegetable parts (Goodman, 1971).

Although it had been determined that nitrogen was a characteristic of animal substances, the absolute source for nitrogen in was unknown; whether from an animal's diet or from the atmosphere. In 1816, François Magendie preformed simple nutritional experiments using dogs to determine if animals assimilated atmospheric nitrogen. Magendie fed dogs diets containing exclusively carbohydrates and lipids. After several weeks, with inadequate nitrogen in their diets, all dogs in Magendie's experiments died. Magendie's experiments demonstrated that animals derive nitrogen exclusively from diet and not from the atmosphere. He also discovered that animal diets can be incomplete and diets devoid of nitrogen cannot sustain life indefinitely (Carpenter, 2003). Jean Baptiste Boussingault in 1836 through his own experimentation confirmed Magendie's findings. Boussinggault also proposed that the nitrogen needed by animals could be obtained from

plants. In consideration of Magendie's work and his own, Boussingault suggested indexing and assessing plant foods based on nitrogen content. He also stated that other organic and inorganic substances may also be needed for animal nutrition. Magendie is credited as the first to separate food nutrients into three components, protein, fat, and carbohydrate (Lusk, 1928, Johnson, 2007).

Liebig hypothesized, in 1842, that fat and carbohydrates underwent oxidation in animals (Johnson, 2007). He also generalized and that "albumen" (protein) from plants is the "starting-point" or foundation for diverse animal parts and tissues (Rosenfeld, 2003). In the same year George Budd recognized medical disorders resulting from nutrient deficiency. Although, it may be asserted that through his work with scurvy in 1746, James Lind discovered the link between health and proper nutrition. However, Lind did not recognize citrus juice (vitamin C) as a deficient nutrient. Rather, at the time, citrus juice was recognized as a cure or preventative for environmental conditions that lead to scurvy (Carpenter, 2003). Therefore, the link between disease and nutrition was not adequately established by Lind. Recognition of the importance of proper nutrition for optimum animal and human health stimulated a need to qualify and quantify food by more precise and accurate methods of evaluation; characteristic of chemical of analysis.

Definition of Feed Analysis

Analysis was defined by Fenning (1775) "to dissolve, or break in pieces; a separation or solution of a compound body into parts of which it consists." Analysis was defined by Noah Webster in 1828 as "The separation of a compound body into its constituent parts" (Webster, 1828). The definition of analysis has changed little since 1775, in its primary sense, "a separation of a whole into its component parts" (Analysis, 2015). Taking into

consideration the historical and present-day definition of analysis, feed analysis can be defined as the separation of a forage or feedstuff into components.

Categories of Feed Analysis

There are several categories of components by which feeds are commonly analyzed: anatomical, sensorial, structural, and chemical components. Anatomical components can include such plant parts as: seeds, blossoms, stems, or leaves. Sensorial components comprise feed characteristics such as: smell, texture, taste, and color. Structural components include feed characteristics like particle size, chop length, leaf shatter, or fines. The chemical analyses of feeds are, typically, performed to establish ratios or percentages of broad chemical groups found in feeds such as: water, carbohydrates, lipids, minerals, and protein. However, currently some animal nutrition professionals emphasize that to optimize animal performance chemical analysis of feeds should not only be carried out to quantify broad nutrient groups, but for specific amino acids such as lysine (Pretz, 2013) and even specific sugars (Sniffen and Tucker, 2011).

Feed analysis using nominal or ordinal scales is probably most common when evaluating sensory components of feeds like smell, texture, taste, and color. Qualitative analysis, though not as precise as quantitative measures, will probably always be necessary as long as such feed characteristics as appearance, smell, and texture of feeds are important to livestock producers for rapid, inexpensive, establishment of feed quality.

Currently anatomical, sensory, and structural feed components can be quantified using various technologies (Cheli, 2008). For example, odor and flavor of feeds can be measured and digitized using technology such as electronic nose analysis (Rapisarda et al., 2012). Physical components commonly evaluated using qualitative measures, can also

be assessed using quantitative measures: particle size (Garcia, 2009), grain content (Mc Geough et al., 2010), leaf or stem content (Mowat et al., 1965), or stem shear force (Liu et al., 2009).

Present-day analyses of chemical feed components are almost exclusively quantified using methods which express measurements in continuous numerical values, which is the case where feed component determinations are established using gravimetric, volumetric, or spectroscopic methods.

Early History of Feed Analysis

This section will present a brief historical summary of feed analysis from its beginnings to about 1860. Other authors have written more extensive histories of feed analysis which cover details of methods development and individuals involved. Flinn (1991) published "Feed Analysis 1860-1990: How much has really changed" and Midkiff (1984) "A century of analytical excellence: The history of feed analysis, as chronicled in the development of AOAC official methods, 1884 to 1984".

Although many systems or methods of feed analysis change with advancements in sciences, use of animals to evaluate feed quality have been constant throughout history. Assaying animal performance has likely been practiced with differing logic, determination, and methodology since prey animals were first domesticated over 8500 years ago (Wahlqvist, 1992) for food and fiber production. Paradoxically, even with extraordinary advancements in contemporary feed analysis, animal response remains the best measure of feed quality.

Much of what was understood about mechanisms of animal nutrition up to the late 18th century was based on speculation and creative thinking. The philosophy of matter

was metaphysical (Pérez-Bustamante, 1997). Studies of substances were largely qualitative where chemicals were defined by sensory characteristics and comparisons (Macquer and Keir, 1777). Therefore, it follows that methods for analysis of feeds were like those in chemistry, were qualitative. Feed characteristics, before the late 18th century, were described by sensory and comparison methods.

Weisbjerg et al. (2010), suggests that feedstuffs have been recognized as having different feeding values for centuries. Tyler (1975) corroborates Wiesbjerg's assertion by referencing examples of feed evaluation using hay or straw standards as early as 1725. However, it is probably more correct to state that animal feeds have been analyzed or ranked by livestock producers by relative nutritional values of feeds (equivalents) since 2500 BC (Ryle and Ørskov, 1990). Examples of analyzing feed quality in terms of color, smell, favor, texture, and animal responses are abundant in ancient literature. Although, not as precise and perhaps objective in accessing nutrient content in feeds using modern chemical or spectroscopic methods, sensory assessment has been shown in modern times to be strongly correlated to nutrient composition in feeds (Rohweder et al., 1978).

Dickson (1788) describes production techniques and concepts related to feed quality from translated Roman texts from about the second century BC to fifth century AD. Translations summarized in Dickson's "The husbandry of the ancients" provides insight into beneficial Roman forage production practices that were, apparently, valued by 18th century producers. Interestingly, Roman feed management and evaluation practices outlined in Dickson's work correspond with many contemporary feed management and evaluation concepts. Although Roman wording describing feed quality is different from modern language.

Roman producers recognized relative nutritional values of different feeds (Bradley, 1725, Dickson, 1788). Roman authors state that “medica” (alfalfa) and other legumes are characteristically superior for rapid fattening and greater milk production in sheep and cattle compared to other fodders. They also recognized the basic significance of dry matter content in feeds “If you shall give it (alfalfa) dry…give it more sparingly, because it has more strength”. Columella suggests that because of the “strength” of dry alfalfa, it can be “infused” with water and mixed with short straw for feeding.

The correlation of crop maturity and feed quality was also understood by Roman producers. They suggest “by cutting grass early …the hay is much better quality and that medica should be cut when “it begins to flower”. Recognizing that contemporary researchers continue to suggest that the optimum time to harvest alfalfa is at the physiological stage of one-tenth bloom (Sharma, 2014) lends credence to Roman knowledge of alfalfa quality.

Although unaware of dynamics rumen microbial populations, Roman producers were aware of the necessity of adaptation of cattle in relation to feeding alfalfa (Bradley, 1725). When changing cattle from another feed to alfalfa, Roman writers suggest “at first, this new kind of forage must be given sparingly for it makes cattle swell” (Dickson, 1788). Roman agriculturalists such as Columella clearly recognized the value of adjusting rations (daily intakes) according to animal performance and that adjustments in quantity of feed were dependent on characteristics of specific plants (Dickson, 1788).

Efforts of 18th century writers to translate Roman text in order discover and document practices of forage selection, cultivation, evaluation make it clear that Roman systems were valued by 18th century producers. It may be assumed that knowledge of

feed quality as well as animal health, growth, and production changed so little since Roman times that 18th century British producers still sought information from ancient sources. This assumption is verified by Dickson who, on occasion recommends that Roman practices are “worthy of our imitation”.

In 1725 straw units were used to evaluate of feeds by relative comparison in Bavaria. A straw standard was used for comparison since straw was the most abundant fodder in the region (Tyler, 1975). Although Albrecht Thaer (1752 -1828) is often credited in literature as one of the first to create a system for feed evaluation (Van Soest, 1994). Tyler (1975) provides many examples from others of late 18th century who evaluated feed using equivalents. Thaer (1816), describes a system for evaluating feeds based on a hay standard. And apparently, data used for Thaer’s evaluation system was taken from John Middleton (Van Soest, 1994). However, from what is documented from Roman authors it is likely that feed evaluation using equivalents date back much earlier than the late 18th century. Columella (4 AD – 70 AD) ranked feeds, “The best for Fodder, are the Medica (alfalfa), Fenugreek, and Tares, and the next to those are Vetches, the Orobus or Ervum (bitter vetch), and the Farrago, which is green Barly” (Bradley, 1725).

Chemical Analysis of Feeds

Use of chemical analysis to evaluate feeds likely emerged at the turn of the 18th century. In Grundsätze der rationellen Landwirthschaft (1809–1812), Thaer, on at least three occasions, described the use of chemical analysis to establish feed quality. In Thaer’s English translation of “The principles of practical agriculture” (Thaer, 1856), Thaer explains that data used to create his hay-based feed evaluation system came from chemical analysis (albumen) and animal feeding studies carried out by Heinich Einhof

(1777-1808). Thaer was uncertain as to specific methods Einhof used to determine qualities of feeds (Thaer, 1856).

Summarizing the chronology of developments in chemistry which lead to food or feed analysis is challenging, especially prior the late 18th century. Archaic philosophies concerning the true nature of matter and antiquated terminology can encumber comprehension of earlier science by modern investigators. Additionally, the meandering nature of scientific discovery and slow transitions toward new philosophies and away from old make construction of a purely sequential outline of discoveries and people leading to use of chemical feed analysis impractical. Therefore, in this section a general outline of development chemical feed analysis will be presented.

Before Dalton (1766 –1844) developed modern atomic theory, there had been numerous philosophies concerning the composition of matter throughout the world, largely based on metaphysics (May, 2010). However, it was through the work of many leaders in science, such as Antoine Lavoisier and John Dalton (Holmes, 1971), that facilitated a transitioning away from old ideas concerning the nature of matter to modern.

Efforts in early chemical analysis produced separations of matter relative to technology and knowledge available. From about 400 BC to 1500 AD “composition of bodies”, or elements in modern terms, were categorized into four broad categories Earth, Air, Water, and Fire. Conception of this four-element theory attributed to Empedocles, 490-430 BC (Colombani, 2011). Connectedly, analysis of matter anciently was limited to sensory analysis, hence conception of four tangible elements, Earth, Air, Water, and Fire.

Paracelsus (1493-1541) separated matter into more refined categories of Mercury (volatile components), Sulfur (oily components), and Salt (solid residues) (Manz, 2001,

Colombani, 2011). These three elements correspond closely to products obtained from distillation analysis. Colombani (2011) suggests that during later part of the 17th century the four-element system of Empedocles and three element system of Paracelsus were "sometimes mixed" creating a five-element system, Earth, Water, Mercury, Sulfur, and Salt. These elements were thought of as the end results of chemical analyses or substances that could not be broken down further (Colombani, 2011).

According to Colombani (2011) from about 1750 to 1787 was a period in which chemical substances, to an extent, became defined by steps of analysis or separation toward ultimate substance or element. Proximate substances (i.e. oils and fats) resulted from analyses which gave products that could be "decomposed" further to ultimate substance or elements. Ultimate, primitive, or remote substances (elements), as they were referred to, resulted from final analyses which gave products that could not be broken down further by methods of the day.

Categorizing substances by degree of analyses was antecedent to concepts of proximate and ultimate analyses. Proximate analyses describe procedures which separate substances into broad categories such as moisture, protein, fiber, fats, ash, and oil. These categories are often preceded by the adjective crude. Conversely, ultimate analysis describes procedures which lead to determination of specific elements such as: nitrogen (N), calcium (Ca), phosphorus (P), potassium (K) or sulphur (S).

Fourcroy's (1755-1809) statement: "The goal of chemistry is to know the intimate (inmost) nature of bodies (chemical composition)" (Gough, 1988) aids in understanding reasons for major transitions and goals of chemistry in the late 18th century. A clear objective of chemistry was to ultimately discover fundamental substances. Therefore, a

trend of chemistry to labor towards discovery of “principes” or substances that could not be decompose further (Colombani, 2011) lead to transitioning away from old philosophies as real elements were discovered.

In late the 18th century modern theories of chemical composition began to be recognized, transitioning chemistry away from old philosophies of matter. Colombani (2011) indicates that by 1787 definitions of matter such as Earth, Water, Mercury, Sulfur, and Salt had been dropped and replaced by 55 “simple substances”. Just over half of the 55 were true elements. Other items such as acids, light, and caloric were included in the list of 55 elements. Items included in the list 55, not considered elements today, were likely included because technology did not exist to “decompose” the substances further.

Many writers identify the late 18th century as the beginning of the “chemical revolution”. During this period, because of great scientists like Lavoisier, Berthollet, Fourcroy, and without question others, the science of chemistry established a sure-footing based on sound theory, experimentation, and improved methods of analysis; all of which aided in developments and progress in the science of nutrition and consequently feed or food analysis.

Albrecht Thaer and Heinich Einhof used chemical methods to evaluated feeds as early as 1809 (Van Soest, 1964). The so called Weede Method of analysis was the first comprehensive or formal chemical system of feed analysis was initially developed by Heinich Einhof (Van Soest and McQueen, 1973). Through the Weede method feeds can be separated into five constituents: water, ash, fat, protein, and carbohydrates (Flinn, 1991). Interestingly, even with the advancement of science and technology, nutritional analyses of feeds have changed little in almost 150 years (Flinn, 1991). Primary methods

upon which contemporary feed analyses are based still comprise gravimetrics, extractions, and distillations.

Gravimetry. According to Beck (1994) "gravimetry is the determination of an element (or substance) through measurement of the weight of an insoluble product". Gravimetric analysis was developed throughout the 18th century. Combustion and distillation methods were commonly used to isolate chemical substances and gravimetric analysis was used to quantify isolated fractions (Nierenstein, 1934). Before the 20th century nearly all chemical analyses were done by gravimetry.

Although titrimetric and spectroscopic determinations are widely used in current feed analysis, gravimetric are still among the foremost methods used in feed analyses. Gravimetric methods are valid standalone analyses having no need for reference material on which to compare results (Beck, 1994). Dry matter, crude fiber, acid detergent fiber, and neutral detergent fiber determinations all employ gravimetric procedures.

Distillation. Although not used directly to quantify nutrients in animal feeds, distillation methods lead to the discovery of nitrogen in animal matter and apparent absence or relatively minute quantities of nitrogen in vegetable matter. Distillation is also a crucial phase in separating free ammonia during protein determination using Kjeldahl analysis. Therefore, distillation is relevant to the history of feed analysis.

The technology of distillation has been used to separate substances for millennia. Fundamentally, distillation is carried out when a volatile substance is vaporized, collected, condensed, and recollected into another vessel (Nelson, 1975). Distillation methods exploit characteristic boiling points of substances for separation from chemical mixtures.

Use of distillation methods for fractionation of animal and plant substances was driven, in part, by economic applications for distillates. It was also thought that distillates derived from animal and vegetable substances would lead to advances in medicine and understanding animal nutrition. In addition, it was believed in the 18th century, that distillates from organisms could be used in biological classification for distinguishing animal from vegetable matter (Goodman, 1971). These applications for distillation methodology lead to copious documentation of distillation of practically every creature available as demonstrated by work of Neumann and Lewis (1773).

Distillation methods were used from about 1615 to 1794 (Nierenstein, 1934) to fractionate organic substances. Fractions collected from distillation procedures were referred to as either aqueous, gaseous, phlgma (mucus, (Scarborough, 2005)), oil, or carbon residue. Distillates were even quantified as weighted fractions, when possible (Nierenstein, 1934). Early in the 18th century, volatile alkali and acidic fractions were collected through distillation and later, in error attributed, to either animal or plant substances, respectively.

As a side note, often when scientific science discoveries or observations are made, and their significance is not recognized or understood at the time. For example, Brandit made the first discovery of a chemical element, phosphorus, in 1669. But phosphorus was not recognized as a chemical element until Lavoisier in about 1789 (Pérez-Bustamante, 1997). Similarly, determination of nutritional composition of feed through chemical analysis was not practiced probably any earlier than the end of the 18th century. However, through distillation methods, as early as the late 17th or start of the 18th century it was found the young plants “gave more volatile alkali (ammonia) and less

acids than did mature ones" (Holmes, 1971). It was nearly 100 years later when it was recognized that sources of volatile alkali (ammonia) come from decomposition of nitrogenous compounds (crude protein) in plant material and that dietary nitrogen was needed to sustain life. Today it is generally recognized, through chemical analysis, that less mature forages have characteristically higher crude protein and are more nutrient dense than more mature forages. But these realizations only came about with advancements in chemical and nutritional knowledge that facilitated true correlations between maturity of forages and nutrient density.

Extractions. Before 1800 it was recognized that combustion and dry-distillation were destructive methods of isolating chemical substances. Extraction methods of chemical analysis are more benign facilitating collection of substances unchanged (Fruton, 1976). Extraction through the use of solvent became a more preferred method for isolation of chemical substances.

According to Van Soest (1994) as early 1800 there was an agreement that plants have an indigestible woody fiber component. Evidently feed quality was thought to be negative correlated to woody fiber content. This led to the emergence of fiber determination through extraction. Extraction or leaching of digestible plant components was seen as a method of woody fiber determination. Extraction methods facilitated nutritional feed quality evaluation.

Einhof (Van Soest, 1994) made crude fiber determination of feeds through a series of extractions. Ether, alcohol, water, dilute acid and dilute alkali are all solvents used by Einhof to isolate the crude fiber component in feeds.

Balancing Rations. In traditional animal nutrition, several basic concepts have directed the focus of the science. These basic concepts are animals have nutrient requirements for maintenance, growth, and reproduction (Provenza, 1991; Guide, 2002). Also, that animal nutrient requirements can be satisfied through their consumption and assimilation of balanced diets or rations (Mitchell and Hamilton, 1935; Guide, 2002). And finally, that data disclosing nutrient composition in animal feeds is needed to facilitate formulation of economically balanced animal diets or rations (Fitts and Jamison, 1927); Guide, 2002). Valid feed analysis establishes nutrient composition in feedstuffs. In considering these concepts it becomes clear that feed analysis plays a foundational role in traditional animal nutrition.

Accuracy and Precision. Although feed analysis is a field that undergoes frequent change, there are two unchanging universal objectives that guide all responsible individuals who perform feed analysis or who value feed analysis as a resource. Those objectives are accuracy and precision. Accuracy is a primary objective of feed analysis. Accuracy is used to describe how well an analytical value or measurement from a sample represents the true value from a population (Weiss and St-Pierre, 2007). Precision is how closely a group of measurements taken from a specific analyte agree. Evidence of accuracy and precision problems among U.S. feed laboratories has been documented in trade and professional publications. Inaccurate feed analysis confounds the true objectives of the science, costing rather than benefiting end-users.

SUMMARY

Feed analysis has become an integral part of traditional animal nutrition. It has become so, because feed is the major cost of modern animal production systems (Bryden, 2012). And, reliable data on nutrient composition in feedstuffs is needed to economically balance animal rations (Adesogan, 2002). Therefore, feed analysis has emerged as a valuable tool for animal nutritionists, owners, caregivers, and producers. Feed analysis facilitates balancing of animal rations efficiently and economically.

Currently, feed analysis is practically standard practice for many animal production systems. It plays an important role in facilitating and promoting animal health and has brought about historically unprecedented advances in livestock production and efficiency through ration balancing, especially in developed nations. However, the use of feed analysis has evolved beyond a tool limited to traditional animal nutrition. Feed analysis impacts many facets of society and is likely to continue to evolve and have even greater positive impacts on society than are now enjoyed.

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CHAPTER 3

DEMOGRAPHICS OF UNITED STATES FEED LABORATORIES

ABSTRACT

Feed analysis provided by qualified laboratories has become essential to progressive livestock producers and important to other end users in the United States. A study was conducted to characterize and identify U.S. feed laboratories. Data were compiled from public internet sources and by direct communications with management of analytic laboratories. A total of 144 laboratories able to perform feed analysis were identified. Administrative bodies sponsoring feed laboratories operations included: commercial entities, state departments of agriculture, universities, and USDA-ARS. Proportions of feed laboratories supported by these administrative bodies are 76%, 17%, 5% and 2%, respectively. Feed laboratory establishment has a strong positive correlation to areas with greater livestock and crop populations in the U.S. In all areas of the U.S., private commercial entities sponsor a majority of feed laboratories, except for feed laboratories in Gulf and Atlantic plains where more feed laboratories are sponsored by universities (63%). Most feed laboratories (91%), do not have limited operational focus (clientele). However, 5 and 4 percent of laboratories limit operational focus to research or regulation, respectively. Of 144 feed laboratories identified in this study, ≥ 80% use wet chemistry and ≥ 52% use NIR to analyze feeds. Laboratories that perform in vitro and in situ analysis account for 13% and 8% of all laboratories, respectively. Multiple feed analysis systems are used by 42% of all laboratories identified. From 2010 to 2014 mean participation in National Forge Testing Association (NFTA) certification was 67% out of the 144 laboratories identified in this study. Mean grades given to laboratories for 2010 to

2014 was 3.45; out of a maximum of 4 (an A rating). Use of commercial feed laboratories in research published in refereed journals increased from 2004 to 2014, with three laboratories accounting for 85% of publication acknowledgments. As of December 2014, 92% of feed laboratories identified had internet exposure through websites, 3% used social media (Facebook) exclusively, and online directories were used exclusively by 5% of identified laboratories. The United States feed laboratory population is dynamic. Data collected describes conditions of United States feed laboratories in terms of number, distribution, sponsorship, organization, analytic systems, certification, and advertisement methods.

INTRODUCTION

The idea that animal diets require essential feed components for health and productivity has been recognized for hundreds of years. Analytic methods for evaluating nutritional qualities of feed, developed in conjunction with studies in animal nutrition, have been practiced for almost 200 years (Van Soest, 1964).

Livestock have nutritional requirements for maintaining good health or for achieving desired levels of performance and production. When livestock are provided with a ration that fulfills daily nutrient requirements the ration is described as being a “balanced ration”. The concept of ration balancing has been taught to livestock producers since about 1865 (Stone, 1898). Through balanced rations animal health, performance, or production can be optimized. However, before producers are able to balance animal rations, the nutritional composition of feeds intended for consumption by livestock must be established.

Knowing the nutrient composition of specific feeds became increasingly important to animal producers as university agricultural experiment station and extension professionals encouraged balanced rations for livestock. When the concept of balanced rations was new, laboratories performing feed analysis were not readily available and communication was limited. Consequently, livestock producers received information on feed composition in the form of tables created by agricultural experiment stations (Armsby, 1880; Stone, 1898) from feed analysis performed on feeds typically used by livestock producers. Similar tables are still in use today, although generally considered less accurate than actual laboratory measurements for determining feed composition.

In general, before 1970, feed analysis was practiced by commercial feed manufacturers, government regulatory agencies, universities and a few private laboratories. Longland and Byrd (2006) stated that universities originally established forage laboratories to support the Dairy Herd Improvement Association. By 1975 most extension dairy producers in the United States were actively promoting and/or providing forage testing to stakeholders (Coppock, 1976, Coppock et al., 1981). Eventually, as a result of extension educational efforts livestock producers became more aware of the importance of balanced rations for improving profitability and therefore the use of forage analysis has continually increased.

Today there are a greater number of analytical laboratories that provide feed analysis for producers in the United States. The scope of feed components that laboratories test is wide-ranging. For example, laboratories that specialize in soil analysis often provide crude protein (CP) and mineral analysis on feeds because minimal change is needed in methodology or instrumentation from those used for soils. In contrast, there are

laboratories that are more specialized in feed analysis. These laboratories not only test for CP and minerals, but for fiber components such as acid detergent fiber (ADF), neutral detergent fiber (NDF), and crude fiber (CF). Many feed laboratories also test for fat, starch, sugar, lignin, amino acids and other feed components.

Feed analysis directly from laboratories has become a necessity for progressive livestock producers. As the science of animal nutrition has advanced, the array of feed components for which laboratories test have increased, as have the methods used to quantify feed components. Patrons of feed analysis have also increased and are more diverse due to development of broader applications for feed analysis. Some of the more recent applications of feed analysis include:

- Establishment of crop values for trade in domestic and export markets (Guerrero, 2001, Ward, 2004).
- Variety selection of crops and valuation by crop breeders (Mueller-Harvey, 2004).
- Qualifying producers for reception of emergency relief funds from government agencies (Shields and Chite, 2010).
- Environmental studies and mitigation (Beauchemin et al., 2007, Roberts et al., 2007).
- Wildlife and range studies (Memmott et al., 2011, Petersen et al., 2014).

It is clear that feed analysis is a useful tool for the agriculture economy and society. Numerous extension publications provide valuable information for producers concerning feed analysis, proper sampling techniques, and lists of laboratories that perform feed analysis. However, there is limited consolidated demographic information available which describes the feed analysis industry in the United States such as:

- How many laboratories perform feed analysis?
- What is the geographic distribution of feed laboratories in the United States?
- Are there factors that affect feed laboratories distribution in the United States?
- How many laboratories offer feed analysis to the public?
- Are feed laboratories distinct enough to be classified?
- What types of organizations operate feed laboratories?
- To what extent are major systems of analytical methods, wet chemical (WC), near infrared reflectance (NIR), in vitro (IV), or in situ (IS), utilized by laboratories?
- How many feed laboratories participate in analytic proficiency programs?
- How many private commercial feed laboratories are used in peer reviewed research?

The objective of this study was to identify and categorize feed laboratories in the United States. In addition, this study endeavors to collect and analyze information about United States feed laboratories that will lead to greater understanding of the feed analysis industry and will provide a baseline for comparing the dynamics, progress and direction of this industry in the future.

MATERIALS AND METHODS

The degree to which laboratories perform analysis on animal feeds can vary greatly. Therefore, minimum criteria were established in this study to identify an analytical laboratory as a feed laboratory. A laboratory that performed analyses resulting in the determination of crude protein (CP), acid detergent fiber (ADF), neutral detergent fiber (NDF), or crude fiber (CF) was considered a feed laboratory. The phase "wet chemistry" was used to denote analytical methods that chemically measure feed components as opposed to using NIR methods.

Analytical laboratories that perform feed analysis are often referred to by different titles such as forage, animal nutrition, or agricultural laboratories. In this study all laboratories were refer to as feed laboratories. The phrase "commercial entity" was used in this study to denote all profit seeking organizations that operate feed laboratories that are not affiliated with government and/or university organizations.

To meet the objectives of this study, data was compiled from the following internet public sources:

- Trade association directories
- Laboratory certification organizations membership roles
- State extension publications
- USDA and State departments of agriculture websites
- Laboratory advertisements and websites
- University websites

Feed laboratory information that was not available via internet search or inconclusive from sources listed previously was obtained by email correspondence or direct telephone

interviews with laboratory management. Information collected concerning United States feed laboratories included:

- Location (city, state, and zip code)
- Current participation in National Forage Testing Association (NFTA) certification program
- Laboratory affiliation (i.e. United States government, state departments of agriculture, university, and commercial)
- Primary patronage
- Major analytical services
- Acknowledgment in peer review literature
- Website access

The feed laboratory population identified during this study was unique in that all laboratories had exposure through information sources previously listed; in varying degrees. We acknowledge there are feed laboratories in the United States not accounted for in this study; however, such feed laboratories probably have limited publicity or are outside the criteria previously stated defining feed laboratories.

Geographic distribution of U.S. feed laboratories was determined by compiling U.S. postal zip codes for each identified laboratory. Microsoft MapPoint 2010 (Microsoft, Redmond, Washington) was used to plot the U.S. zip codes on a United States map. Information concerning laboratory participation in the National Forage Testing Association (NFTA) certification program was obtained from their website (NFTA, 2014).

To identify factors that may contribute to establishment of feed laboratories, reasonable relationships between the number of feed laboratories found in each state and other agronomic variables, such as dairy cow numbers or crop yields, were collected for each state and analyzed using correlation analysis. Agricultural statistics used for correlation analysis between state feed laboratory numbers and other agronomic variables for each state was obtained from the 2012 USDA Census of Agriculture (NASS, 2014).

Google Scholar, an online search engine, was used to determine how many, and to what extent, private commercial laboratories are used by researchers for peer reviewed studies. This was accomplished by finding peer reviewed publications which credited private commercial feed laboratories for feed analyses performed as part of studies being documented. Google Scholar searches were performed in three steps. First, a general search was carried out on the title of each lab identified in the study to determine which laboratories occur in scholarly literature. Second, using Google Scholar's advanced search option, peer reviewed publications were found by placing the phrase "sent to" followed by a lab title in the "with the exact phrase" search box with the terms CP, ADF, and NDF in the "with all of the words" search box. Third, the second step was repeated, but the words "sent to" were replaced with the words "analyzed by". Google Scholar searches were performed for private commercial feed laboratories exclusively. Feed laboratories unadvertised or publicized with universities, or state and federal governments were not searched. Searches were performed for every private commercial feed laboratory identified in this study. To broaden the "exact phase" search on feed laboratory names, abbreviations such as Inc., Corp, Ltd, or LLC were omitted from feed laboratory titles. Titles of feed laboratories found in peer reviewed articles were recorded

as well as year and number of different articles in which they occurred. If feed laboratory participation in any peer reviewed study was unclear from citations provided by Google Scholar, full digital transcripts of studies were reviewed to verify laboratory participation. Search results such as dissertations, thesis's, reports, citations for professional meetings, or extension publications were not counted.

All compiled data was recorded in an Excel spreadsheet and analyzed using Excel database commands. SigmaPlot 12 (Systat Software Inc., San Jose, CA, USA) was also used to perform statistical analysis and graphics.

RESULTS AND DISCUSSION

A total of 173 laboratories were initially identified in the United States that perform feed analysis. However, after investigating the status of all 173 laboratories the total number of feed laboratories, as of August 2014, was revised to 144. The difference between the initial feed laboratory total and the revised number was largely due to outdated laboratory directories or lists which had not been maintained or updated. Through examination of internet sources and by direct correspondence with past and present laboratory management, it was found that common business events such as: mergers, acquisitions, bankruptcies, or change in organizational focus were responsible for a change in number of feed laboratories. In addition, some universities and state departments of agriculture discontinued providing public feed laboratory services, which added to lower laboratory numbers than initially tallied.

Figure 1 shows feed laboratory distribution, location, and type of organizational support for laboratories identified. Visual inspection of the U.S. feed laboratory

distribution map suggested that U.S. feed laboratories are broadly, but not evenly distributed. Feed laboratory locations appear to be established in areas of the U.S. where dairy, beef, forage or grain crops are robust.

Correlation analysis showed a positive relationship ($P<0.05$) between feed laboratory numbers identified in each state and dairy cow numbers (Figure 2). Other factors such as corn silage/green chop and alfalfa hay production in each state also have positive relationships to feed laboratories with coefficients of correlation of 0.73, and 0.71, respectively (Table 1). It is reasonable that dairy cow numbers, corn silage/green chop production and alfalfa hay production are related to the establishment of feed laboratories. Cows and feed are essential components of the dairy industry. The crops noted are particularly popular and widely used in milk production. So, it follows that feed laboratories are established in areas where milk production is substantial and where modern feed management is practiced. Modern feed management is problematic without feed analysis. In addition, there were positive coefficients of correlation with the beef ad feedlot industries (Table 1).

Feed Laboratory Classifications

Results were analyzed and it was determined that feed laboratories could be grouped by any or all of 4 broad classifications: sponsorship, operational focus, analysis system(s), or by network role. Sponsorship refers to the type of organization associated with a feed laboratory. Operational focus describes laboratories by primary purpose or mission. Feed laboratories can specialize in exclusively one system of feed analysis or many analysis systems; therefore, laboratories can be classified by the systems used.

Recently, laboratory networks have developed, and member laboratories have distinct roles in feed analysis.

Information sources indicated that there are several types of administrative bodies throughout the United States which currently sponsor feed laboratories operations. Administrative bodies are defined as non-profit or for-profit organizations which support feed laboratories. General categories of administrative bodies identified in this study were: commercial entities (76%), universities (17%), state departments of agriculture (5%), and USDA Agricultural Research Service (2%) (Table 2). The phrase commercial entities (CE) was used to describe a large group of diverse privately held organizations which include large multinational corporations, small businesses and cooperatives. Peer reviewed publications describing and providing breakdown of feed laboratory sponsorship in the United States is limited. However, Coppock (1976) reported that universities, private businesses and cooperatives, and state departments of agriculture sponsored 49%, 42%, and 9% of feed laboratories in the U.S. and Canada (n = 45 laboratories). Coppock et al. (1981) updated his earlier work describing feed laboratory sponsorship with very similar results. Although number of universities and state departments of agriculture sponsoring feed laboratories remain somewhat similar today compared to 1976, current data indicates a drastic increase in laboratory sponsorship by private businesses and cooperatives in the last 33 years.

A feed laboratory distribution map was created based on three areas with distinct patterns of feed laboratory distribution, density, and sponsorship: a Pacific Coast-Intermountain (PCIM) area, an interior plains-Appalachia (IPA) area and a Gulf and Atlantic plains (GAP) area (Figure 1). The PCIM and IPA areas are similar in that a

majority of feed laboratories are sponsored by commercial entities followed by universities, state departments of agriculture, and the ARS (Table 2). In contrast, university feed laboratories dominate the GAP area followed by commercial entities and a state department of agriculture laboratory. No USDA/ARS feed laboratories were identified in the GAP area.

Initially, it may seem apparent that limited establishment of commercial feed laboratories in the GAP area is due to such factors as fewer dairy cows, crop types, or forage acreages when compared to PCIM and IPA. However, these factors cannot totally explain absence of commercial feed laboratories in GAP, since several GAP states have dairy cow populations that are comparable or even greater than states in PCIM and IPA areas. Similarly, absence of commercial feed laboratories in GAP cannot be attributed to lack of forage acreage in comparison to PCIM and IPA, since many GAP states dedicate as much or greater acreage to forage crop production than states in PCIM or IPA areas (NASS, 2014).

A possible explanation for comparatively limited numbers of commercial feed laboratories in the GAP area may be that universities and extension networks have established strong relationships with agricultural producers in GAP states. By providing consistent, quality service to agricultural producers in GAP states, university feed laboratories and extension networks may have cultivated devoted client bases that have come to rely on these organizations for analysis of feeds. Strong university-extension relationships with producers in the GAP may have eliminated a need for establishment of commercial feed laboratories. It’s possible that university laboratories in other areas of the United States have discontinued feed analysis services because of commercial feed

laboratory dominance. Commercial laboratories with apparently quick, reliable, affordable, and accurate feed analysis services have essentially fulfilled a need once met by universities, thus putting some university laboratories out of the feed analysis business.

Finding that laboratories establish distinct roles made it possible to classify feed laboratories into three broad categories based on laboratory clientele: general service, research, and regulatory. Percentages of feed laboratories placed in these three categories were 91%, 5%, and 4%, respectively (Table 3). General Service laboratories (GS) do not limit clientele or focus. Research laboratories do not perform feed analysis for the public but operate solely for research purposes. Regulatory laboratories perform feed analysis to maintain quality control of manufactured feeds or monitor the accuracy of feed labeling.

General Service feed laboratories, as a rule, do not limit clientele; however, they can limit or broaden clientele base on analytical services offered. This is also true for research and regulatory feed laboratories. In this survey, 9% of feed laboratories in the United States perform feed analysis for exclusively regulatory or research purposes. These laboratories strictly limit the scope of feed laboratory use in terms of clientele. Regulatory Laboratories (RG) and research laboratories (RS) are not limited to governmental and university sponsorship but are also established among privately held businesses and corporations. The majority of U.S. feed laboratories do not limit clientele and provide analytical services for clients with research, regulation, and commercial objectives.

Systems of Feed Analysis

Analytic methods, techniques and procedures used by feed laboratories can be wide ranging. To help in describing and accounting for analytic processes used by laboratories, all processes were categorized into four general systems of analysis: wet chemistry (WC), near-infrared reflectance analysis (NIR), in vitro, (IV), and in situ (IS). A summary of analytic systems used by laboratories according to operational focus is shown in Table 4. Feed laboratories may use more than one system of feed analysis; therefore, totals of feed analysis systems are greater than the total number of feed laboratories identified in the United States. Almost all laboratories (82%) use WC, while 52.8% use NIR. Interestingly, few state departments of agriculture used NIR and no IV or IS.

Most feed laboratories in the United States perform feed analyses independent or without formal relationships with other laboratories. However, 25% of feed laboratories studied were part of laboratory networks. Feed laboratory networks have different designs. A common design among network laboratories is a system consisting of "satellite" laboratories. Satellite laboratories may play various roles in a feed analysis network. Satellite laboratories may have limited analytical capacity such as a single NIR unit. In this case samples requiring more rigorous or specialized testing are collected by the satellite lab and fed onto a primary lab. In some cases, satellite laboratories by design are specialized and performed analyses that supported the network, such as IA and IS analyses which require specialized facilities. In these cases, samples are received into a central laboratory then distributed to laboratories in the network with the facilities and expertise to carry out the desired analysis.

While surveying laboratory personnel and management concerning analytical methods offered, the term “Partner” was frequently used. Partner was used to describe a relationship between a laboratory in need and an accommodating laboratory. An accommodating laboratory provides expertise, facilities, equipment, data, or software to its dependent partner that has limited services or analytic capacities. Laboratories that only perform NIR analysis are good examples of partner arrangements. NIR units require appropriate calibration based on reliable WC for optimum performance. Through partnering with WC laboratories, laboratories that exclusively use NIR analysis systems have access to data needed to maintain valid calibrations. In a sense, participation in National Forage Testing Association (NFTA) certification is a form of partnering by independent NIR laboratories. The NFTA certification process requires that participating laboratories test several different forage standards multiple times annually. NFTA feedback concerning precision and accuracy aids independent laboratories in evaluating performance. NFTA certification is especially valuable to exclusively NIR laboratories since they lack WC systems to check NIR performance in-house.

National Forage Testing Association Participation

The NFTA certifies laboratories in the use of WC and/or NIR for analysis of forages. The NFTA certification process measures feed laboratory accuracy and precision in analysis of DM, CP, ADF, and NDF. Laboratories seeking certification are required to analyze several dry forage standard unknowns: alfalfa, alfalfa-grass mix, corn silage, and grass. Laboratories receive scores that reflect accuracy and precision achieved in analysis of each type of standard forage type.

Among the 144 feed laboratories identified in this study, 86 (60%) have participated in NFTA certification a least once for WC, NIR or both systems from 2010-2014; while 42 (29%) of the 144 feed laboratories identified have participated in certification every year from 2010-2014 for either wet chemical, NIR, or both systems. Despite inconsistent NFTA participation by specific laboratories, number of laboratories participating from year to year was relatively constant. Mean participation in NFTA certification from 2005 to 2014 was 69 (SD = 3).

The degree to which WC and NIR systems are used by US feed laboratories has been conjectured. Figure 3 shows NFTA certification participation for laboratories classified as entirely wet chemistry (EWC), entirely NIR (ENIR), and both WC and NIR (BWN) from 2005 to 2014.

Certifications for ENIR showed an increase in certifications and percentage beginning about 2012 (Figure 3). At the same time (2012), NFTA certification for EWC systems showed a strong trend of decreasing certifications. This probably indicates a movement away from wet chemical systems or adoption of NIR systems by previously EWC laboratories.

The decrease of NFTA certification by EWC laboratories is likely due to EWC laboratories acquiring NIR technology, discontinuation of WC by BWC laboratories or new laboratories opting to commence with NIR systems rather than more expensive wet chemical. Another explanation for fewer annual WC verses NIR certifications could be that advantages of NIR systems compel feed laboratories to invest time and effort in NIR certifications rather than WC systems (Stuth et al., 2003). Interviews with some feed laboratory management expressed the idea that NIR systems have become the primary

system for forage analysis, while WC systems were still operated and serve as support and verification for NIR systems.

Standard WC methods and procedures have been well defined by both NFTA and AOAC. Perhaps a need to certify such established methods is judged as redundant to some laboratories. Whereas, NIR systems are secondary forms of analysis that inherently require calibration with a primary analytical method. Consequently, NFTA certification compliments NIR operations by providing a regular, valid, independent assessment of NIR systems for accuracy and precision. Certification services such as those provided by the NFTA are very advantageous to users, by facilitating system assessment without investment in costly WC systems.

Increased use and popularity of NIR systems among some feed laboratories may have reduced demand or incentive for WC certifications. Coppock et al. (1981) stated "Infrared reflectance offers great potential advancement in forage and feed analysis; if these capabilities are realized, they far exceed today's methodology by wet chemistry". Certification data showing a raise in NIR and decrease in WC certifications indicates that he may be correct in his prediction of NIR future capabilities.

Feed Laboratory Proficiency

Annual NFTA proficiency scores earned by feed laboratories are valuable to producers, traders, researchers, and others, when selecting a feed laboratory to conduct analyses for feed components.

Feed laboratories that earn NFTA certification are given proficiency ratings on an A, B, C, D, or F grade scale or 4, 3, 2, 1 on a numerical basis. Laboratories that receive proficiency ratings lower than a C or 2 are not awarded certification. Certification grades

are based on accuracy and reproducibility of laboratory analysis of reference samples for DM, CP, NDF, and ADF (NFTA, 2015). Performance scores for each forage type are used to calculate an overall certification grade for a certifying laboratory. NFTA certification grades are calculated as follows:

- Grades for each of the certification unknown (DM, CP, ADF, NDF) are assigned a number value (A=4, B=3, C=2, D or F =1)
- Numerical grades are then averaged
- Grades are assigned as A > 3.4, 3.4 ≤ B > 2.4, 2.4 ≤ C > 1.4, ≤ 1.4 is failing

Based on NFTA data for 2010 to 2014, the mean certification grade for 86 identified laboratories participating during the period was 3.46 (SD = 0.52) (Table 5). This mean was calculated using the 452 certifications grades awarded from 2010 to 2014 and included grades from all NIR and WC certifications. Annual certification grades earned by laboratories were made public beginning in 2010 and in subsequent years. However, laboratories were allow to opt out of grade publication for the 2010 certification year. Consequntly, there are more laboratory certifications than grades for 2010.

The wet chemistry system accounted for 50.4% (n = 228) of certifications; while NIR systems accounted for the rest (n = 224). Mean certification grades for WC and NIR systems were 3.46 (SD = 0.52) and 3.38 (SD = 0.57), respectively. These statistics indicate that the achieved grade for the two systems were similar and may be related to the increased use of NIR for laboratories.

From 2010 to 2014, 46.5% of laboratory certification for WC systems received mean grades of 3.4 or greater (A's), while 52.6% received B grades, and 0.9% received C grades. In comparison, mean grades for laboratories certifying NIR systems during 2010

to 2014 were: 42.9%, A grades; 52.7%, B grades; and 4.5%, C grades. Both systems received similar grades; NIR received a higher percentage of C grades. The similarity in accuracy and proficiency is probably a reason for the increase in NIR usage.

Patterns of EWC Laboratory Proficiency

When identified US feed laboratories are categorized by analytical system used to evaluate feeds, it was determined that EWC feed laboratories are the largest group within the 144 laboratories identified. EWC laboratories consist of 44.4% (n = 64) of identified feed laboratories (Table 6). Another 33% of laboratories had both WC and NIR. The dominance of WC systems among US feed laboratories is likely due to WC methods being historically recognized and accepted as being valid. Also, WC systems consist of the only feed analysis methods approved of by the AOAC, except for feed moisture for which NIR is approved.

From 2010 to 2014, out of 64 EWC laboratories, an average of 34.4% (n = 22) laboratories participated in NFTA certification. The BWN group had 50% certification and the ENIR had 70% certification (Table 6). Based on usage by the ENIR group, we speculate that the higher certification for the BWN group is due to the NIR portion. It's interesting that the "gold" standard group only had a third that participated in the NFTA system.

Laboratories that use ENIR systems currently represent 28 (20%) of all feed laboratories (144) identified in this study. Since NIR methods are not AOAC approved for analysis of feed components, except for moisture, NFTA certification is more important to NIR users. NFTA is an organization that can be used, by ENIR laboratories, to validate NIR systems. In addition, for ENIR laboratories that do not have WC

instrumentation or are not partnered with a WC laboratory, NFTA certification provides an essential, reliable resource for checking NIR proficiency. Mean certification scores of laboratories using ENIR systems, from 2010 to 2014, increased from 3.25 (B) to 3.54 (A), respectively.

NFTA Participation

Laboratories were found to be affiliated with four organizational types: commercial entities (CE), state departments of agriculture (SDA), universities (UNIV), and the Agricultural Research Service (ARS). From 2010 to 2014, the mean NFTA participation within the organizational types were 53.6% (n = 59 of 110), 29.2% (n = 7 of 24), and 37.5% (n = 3 of 8) for CE, UNIV, and SDA, respectively (Table 7). ARS feed laboratories did not participate during the five-year period. Mean NFTA participation for all organizational types from 2010 to 2014 was based on the average number of laboratories that did participate (n = 68). The averages were: 86% for CE, 10% for UNIV, 4% for SDA, and 0% for ARS.

Laboratories identified in this study were placed into three broad categories of operational focus: General Service (GS), Research (RS), and Regulatory (RG). GS laboratories do not limit clientele or focus. RS laboratories operate for research purposes and do not perform feed analysis for the public. RG laboratories perform feed analysis to maintain quality control of manufactured feeds or monitor the accuracy of feed labeling and do not perform feed analysis for the general public.

Participation in NFTA certification, within categories, were 49.6% (n = 65 of 131) for GS, 14.3% (n = 1 of 7) for RS, and 33.3% (n = 2 of 6), respectively (Table 8). An average of 68 labs identified in this study participated in NFTA certification from 2010 to

2014. Mean NFTA certification, based on the number of labs that participated, was 96.6% for GS; participation by the others was minor. The conclusion from this data is that the vast majority of NFTA participants was by commercial laboratories that service a broad range of clients and needs. The other groups may be important to subpopulations, but are not the mainstream part of the feed industry.

Feed Laboratories and Citations

A broad citation search, using Google Scholar, for each of 144 feed laboratories identified in this study showed that 41.7% were acknowledged in a publication. Restricting the search to only peer-reviewed publications found that 14 feed laboratories were acknowledged in 110 peer reviewed articles. Of these, three laboratories accounted for 85% of publication acknowledgments. Average NFTA testing scores for each of the three labs from 2010 through 2014 were 4.0, 3.4, and 4.0 for wet chemical methods and 3.5, 3.0, and 4.0 for NIR methods.

Number of acknowledgments in peer reviewed papers for commercial feed laboratories ranged from 4 in 2004 to a high of 22 in 2013. Correlation analysis showed a strong positive relationship between numbers of acknowledgments in peer reviewed studies and year ($r = 0.93$).

Feed laboratories and internet exposure

As of December 2014, 92% of feed laboratories identified in this study had internet exposure through websites. Levels of complexity between laboratory websites varied greatly. Of identified feed laboratories, 3% used social media (Facebook) exclusively to

disperse laboratory information. Online directories were used exclusively by 5% of identified labs to provide basic contact and company information.

Though internet technology and express mail services U.S. feed laboratories are able to reach out to clients and potential clients throughout the world. Currently, laboratory websites supply feed sample submission information, laboratory credentials, analytical services, staff qualifications, and even progress of sample analysis in real time. Many laboratory websites also provide educational materials dealing with proper sampling techniques, analytical procedures, explanations and definitions for feed components, and other topics.

CONCLUSIONS

Efficient feed management is more important today than ever before. High cost of grains, forages and increased use of unconventional feeds requires efficient and judicious management of animal feeds. Accurate feed analysis, provided by reliable laboratories, are needed for effective feed management and are also increasingly important to other sciences, industries, and businesses.

This study described the current conditions and characteristics of United States feed laboratories. Our findings are that there are a large number of feed laboratories in the U.S. and the majority can be classified as general service commercial. These labs are located in areas with high populations of dairy, beef and crops. The use of NIR is increasing compared with WC, probably due to the improved accuracy and proficiency of the test as shown by NFTA participation. In laboratory selection, end users should be

aware of feed laboratory NFTA proficiency grading and frequency of laboratory participation in NFTA programs.

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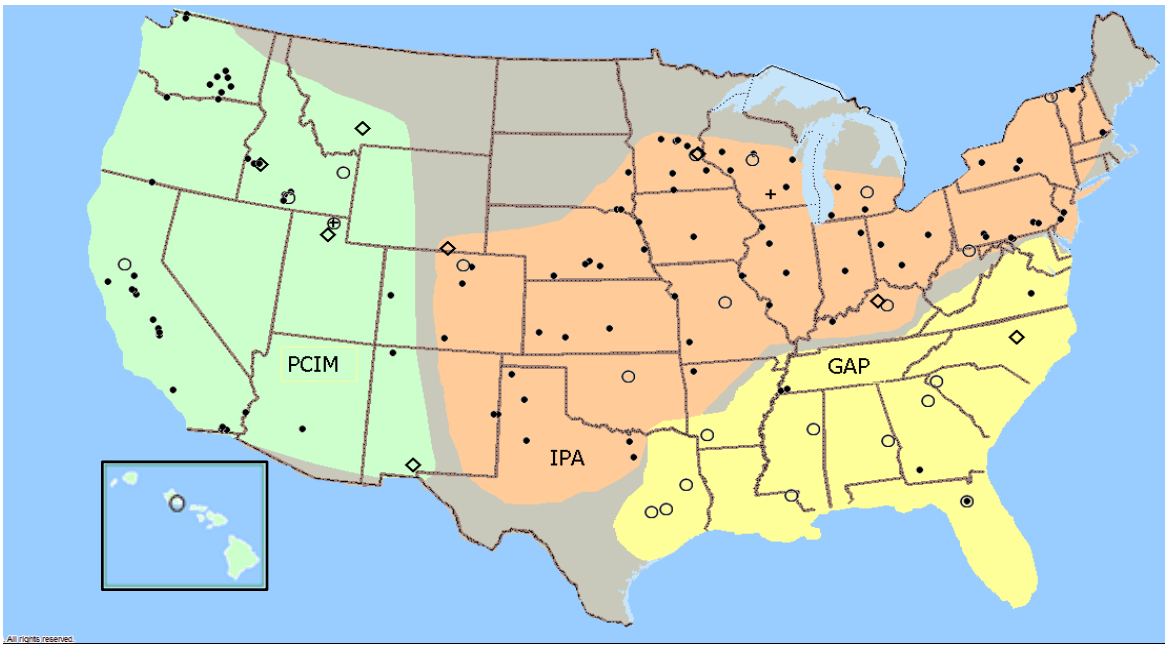

Figure 3.1. Map of location and type of feed laboratories in the United States. Symbols represent each type of administering organization: commercial entity (●), university (○), State Department of Agriculture (◊), USDA/ARS (+). Three groupings were created based on laboratory distribution, density, and sponsorship: Pacific Coast-Intermountain (PCIM) area, interior plains-Appalachia (IPA) area and Gulf and Atlantic plains (GAP) area.

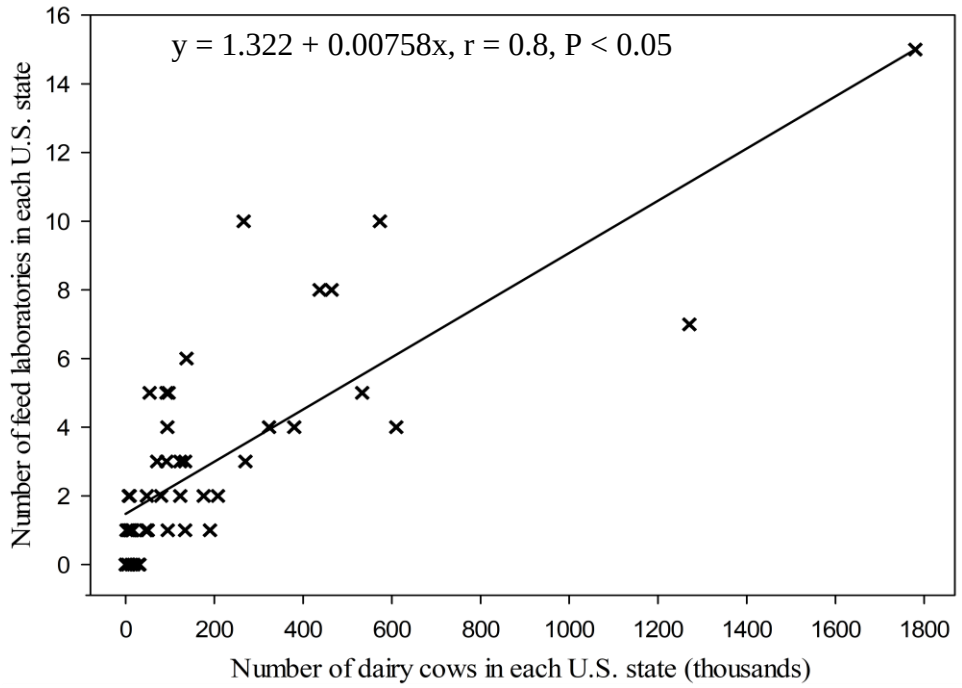

Figure 3.2. Scatter plot showing relationship between dairy cow numbers and number of feed laboratories in each U.S. state.

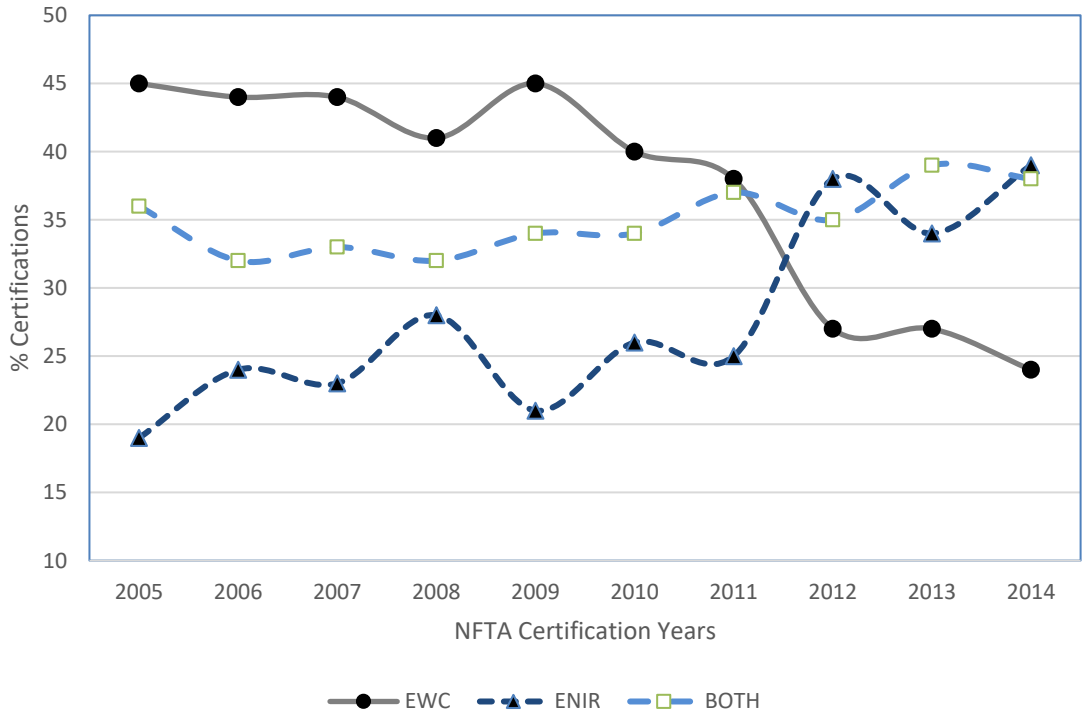

Figure 3.3. Annual feed laboratory participation in the National Forage Testing Association (NFTA) certification by analysis system categories[1].

[1] EWC (●) = exclusively wet chemistry, ENIR (▲) = exclusively near-infrared reflectance analysis, BWN (□) = both wet chemistry and Near-infrared reflectance analysis

Table 3.1. Coefficients of correlation between numbers of feed laboratories identified in each U.S. state and different agricultural variables for each state.

Livestock			Crops			Industry factors		
Variable	CC[2]	P	Variable	CC	P	Variable	CC	P
No. of beef cows	0.27	0.057	Corn silage /green chop	0.73	<0.73	Cattle feedlots	0.35	0.014
Cow calf inventory	0.55	<0.001	Other silages /green chop	0.55	<0.55	No. of dairy farms	0.40	0.004
No. of dairy cows	0.80	<0.001	Alfalfa hay	0.71	<0.71	Total cropland	0.37	0.008
No. of beef /dairy cows	0.56	<0.001	Corn grain	0.21	0.15	Dairy cows per farm	0.53	<0.001

[1]Values used to calculate coefficients of correlation for agricultural variables and laboratories identified in each state were obtained from the USDA 2012 Census of Agriculture (NASS, 2014).
[2] CC= Coefficients of correlation

Table 3.2. Number of feed laboratories identified by operational focus and affiliation[1].

Laboratory[2] Focus	Commercial Entities	University	State Dept. of Ag	USDA/ARS	Total	%
General Service	104	20	7	0	131	91
Research	2	3	0	2	7	5
Regulatory	4	1	1	0	6	4
All Laboratories	110	24	8	2	144	100

[1] Commercial entities are diverse, privately held organizations which include large multinational corporations, small businesses and cooperatives. Universities include institutions of higher learning and associated organizations.
[2] General Service laboratories do not limit clientele or focus. Research laboratories operate for research purposes and do not perform feed analysis for the public. Regulatory laboratories perform feed analysis to maintain quality control of manufactured feeds or monitor the accuracy of feed labeling and do not perform feed analysis for the general public.

Table 3.3. Totals of U.S. feed laboratories by operational focus and geographical region.

	GAP	IPA	PCIM	Total
Commercial	5	68	37	110 (76%)
University	10	9	5	24 (17)
State Dept Ag	1	3	4	8 (6)
ARS	0	1	1	2 (1)
Total	16 (11%)	81 (56)	47 (33)	144 (100%)

[1] Commercial entities are diverse, privately held organizations which include large multinational corporations, small businesses and cooperatives. Universities include institutions of higher learning and associated organizations.
[2] GAP = Gulf and Atlantic plains, IPA = interior plains-Appalachia, and PCIM = Pacific Coast-Intermountain area.

Table 3.4. The number of U.S. feed laboratories grouped by operational focus and affiliation. Percentages shown in brackets are based on operational focus and affiliation.

	System of feed analysis[1]			
Laboratory operational focus[2]	WC	NIR	IV	IS
General service (n=131)	109 (83)	68 (52)	14 (11)	7 (5)
Research (n=7)	4 (57)	4 (57)	4 (57)	3 (43)
Regulatory (n=6)	5 (83)	4 (67)	1 (17)	1 (17)
All laboratories (n=144)	118 (82)	76 (64)	19 (13)	11 (8)
Laboratory affiliation				
Commercial entity (n=110)	88 (80)	60 (54)	12 (11)	8 (7)
University (n=24)	22 (92)	12 (50)	5(21)	2 (8)
St. Dept. of Agric. (n=8)	6 (75)	2 (25)	0 (0)	0 (0)
USDA/ARS (n=2)	2(100)	2 (100)	2 (100)	1 (50)
All laboratories (n=144)	118 (82)	76 (64)	19 (13)	11 (8)

[1] In cases where feed laboratories that provide IV and IS analysis via NIR, NIR was the only feed analysis system counted.
[2] General Service laboratories do not limit clientele or focus. Research laboratories operate for research purposes and do not perform feed analysis for the public. Regulatory laboratories perform feed analysis to maintain quality control of manufactured feeds or monitor the accuracy of feed labeling and do not perform feed analysis for the general public.
[3] Commercial entities are diverse, privately held organizations which include large multinational corporations, small businesses and cooperatives. Universities include institutions of higher learning and associated organizations.

Table 3.5. Number and percentage[1] of identified United States feed laboratories receiving National Forage Testing Association (NFTA) certification from 2010 to 2014, by feed analysis systems.

		2010		2011		2012		2013		2014		5-yr avg	
Lab Systems	LN[2]	No.	%	No.	%	No.	%	No.	%	No.	%	No.	%
WC & NIR[3]	48	23	33	26	37	23	35	24	37	26	36	24	36
WC only	64	28	41	27	38	15	27	19	29	20	27	22	32
NIR only	30	18	26	18	25	25	38	22	34	23	37	21	31
In vitro or in situ	2	0	0	0	0	0	0	0	0	0	0	0	0
Total	144	69	100	71	100	66	100	65	100	73	100	69	100

[1]Annual percentages of NFTA participation were calculated using total of laboratories identified (n = 144) as of 2014.
[2]Number of laboratories identified by study.
[3]Laboratories certifying wet chemistry (WC) and near-infrared (NIR) systems.

Table 3.6. Number of National Forage Testing Association (NFTA) laboratory certifications issued and average grades from 2010 to 2014, by feed analysis system. Rankings from highest to lowest are 4, 3, and 2[a].

	WC[1]			NIR[1]			Total		
Year	N[2]	M[2]	SD	N	M	SD	N	M	SD
2010	45	3.4	0.50	33	3.36	0.55	78[3]	3.4	0.52
2011	53	3.38	0.53	44	3.36	0.53	97	3.4	0.53
2012	41	3.37	0.54	48	3.37	0.57	89	3.37	0.55
2013	43	3.48	0.50	46	3.4	0.61	89	3.43	0.57
2014	46	3.7	0.48	53	3.4	0.60	99	3.5	0.56
5-yr avg	228	3.46	0.52	224	3.38	0.57	452	3.42	0.55

[a]In 2010, publication of NFTA certification grades were optional; therefore, 92 certifications took place; but only 78 certification grades were published. NFTA certification grades are assigned as A > 3.4, 3.4 ≤ B > 2.4, 2.4 ≤ C > 1.4, ≤ 1.4 is failing
[1] WC = wet chemistry systems, NIR= near-infrared reflectance analysis systems, and Total = total certifications
[2] N = number of certifications, M = average grade, SD = standard deviation

Table 3.7. Annual National Forage Testing Association (NFTA) grades for laboratories that used wet chemistry (WC) systems from 2010-2014.

Grade[1]	A		B		C		ACTP[3]	
Year	N[2]	P	N	P	N	P	N	P
2010[4]	19	42	26	58	0	0	78	58
2011	21	40	31	58	1	2	97	58
2012	16	39	24	59	1	2	89	46
2013	20	65	23	35	0	0	89	48
2014	30	65	16	35	0	0	99	46
5-yr total	106	46	120	53	2	1	452	50

[1]Certification grades are on an A, B, C, D, or F scale. Grades lower than a C do not earn certification.
[2]N = number; P = percentage
[3]ACTP = total of annual WC and NIR certifications, percentage of WC certifications.
[4]In 2010, publication of grades was optional; therefore, 8 WC certifications scores were not included.

Table 3.8. Annual National Forage Testing Association (NFTA) grades for laboratories that used near-infrared reflectance analysis (NIR) systems from 2010-2014.

Grade[1]	A		B		C		ACTP[3]	
Year	N[2]	P	N	P	N	P	N	P
2010[4]	13	39	19	58	1	3	78	42
2011	17	39	26	59	1	2	97	45
2012	20	42	26	54	2	4	89	54
2013	21	46	22	48	3	6	89	52
2014	25	47	25	47	3	6	99	54
5-yr total	96	43	118	53	10	4	452	50

[1]Certification grades are on an A, B, C, D, or F scale. Grades lower than a C do not earn certification.
[2]N = number; P = percentage
[3]ACTP = total of annual WC and NIR certifications, percentage of WC certifications.
[4]In 2010, publication of grades was optional; therefore, 8 WC certifications scores were not included.

Table 3.9. Number and percentage of US feed laboratories participating in National Forage Testing Association (NFTA) certification by laboratory affiliation.

	Commercial entities		Universities		State Dept. of Ag		Total	
LI[1,2]	110		24		8		144	
Year	N[2]	P	N	P	N	P	N	P
2010[4]	55	50	7	29	2	25	64	44
2011	58	53	7	29	3	38	68	47
2012	55	50	8	33	2	25	65	45
2013	63	57	6	25	3	38	72	50
2014	64	58	6	25	3	38	73	51
5-yr total	59	54	7	28	3	33	69	48

[1]Number of laboratories identified, by category, at the end of 2014.
[2]There were 2 USDA/ARS laboratories identified, but none were certified in any year.

Table 3.10. Number and percentage of identified United States feed laboratories participating in National Forage Testing Association (NFTA) certification according to laboratory focus.

	General research		Research		Regulatory		Total	
LI[1,2]	131		7		8		144	
Year	N[2]	P	N	P	N	P	N	P
2010[4]	61	47	1	14	2	25	64	44
2011	65	50	1	14	2	25	68	47
2012	60	46	2	29	3	38	65	45
2013	70	53	1	14	2	25	72	50
2014	70	53	1	14	2	25	73	51
5-yr total	65	4.8	1	0.45	2	0.45	68	4.1

[1]Number of laboratories identified, by category, at the end of 2014.

CHAPTER 4

FEED LABORATORIES: A NATIONAL SURVEY OF INDUSTRY UTILIZATION, PREFERENCE, INTERACTION AND IMPACT

ABSTRACT

Feed analysis is important to many livestock industries. Laboratories that preform feed analysis have become common, easily accessible, and provide relatively inexpensive feed testing services in the United States. This study sought to examine preferences of commercial feed laboratory use throughout the United States.

Survey 1 was administered to United States businesses which have membership in an international trade association specializing in feed. Response rate for 308 businesses was 52%. Out of 161 businesses that responded to the survey, 72% indicated they use feed laboratories. About half of businesses that trade exclusively in beef (53%), equine (54%), or retail feeds (40%) do not use feed laboratories. Of businesses that trade exclusively in dairy and export feeds, 100% use feed laboratories. Of businesses that use feed laboratories, 90% use public commercial laboratories. Surveyed businesses used 45 different feed laboratories that currently operate in the U.S; 1 laboratory accounted for 22% of all responses. Qualities sought when selecting a feed laboratory, in order of importance, are certification, reputation, sample turnaround time, and cost of analysis. Of 107 surveyed businesses, 47% preferred NIR analysis, 21% preferred chemical analysis, and 32% had no preference for a specific system of analysis. Sample turnaround time was most frequently chosen by businesses preferring NIR analysis. Accuracy was most frequently chosen by businesses preferring wet chemistry. Fifty-six percent of 115 businesses consider feed analysis to be very important to their business. Most businesses

are confident in the accuracy of feed laboratories used but have moderately weak confidence in laboratory accuracy in general. Dissatisfaction with feed laboratory performance was reported by 50% of businesses. Out 110 businesses, 49% indicated that money was lost from feed analysis issues. Out of 113 respondents, 35% indicated damage or loss to business relationships from feed analysis issues.

Survey 2 was administered to 54 university professionals in 39 states (63% response). Respondents named 10 laboratories which they used or recommended to others. Three laboratories were named 74% of the time. Respondents described accuracy and service as being primary reasons for feed laboratory selection.

Laboratory use is important to most people working with feeds and is diverse due to primary business and needs of the individual.

INTRODUCTION

Feed laboratories provide valuable services to both animal and crop producers. Through accurate and precise forage analysis, laboratories provide information that allows animal producers to efficiently manage feeds to optimize profits, animal health, and production. In addition, forage producers, dealers, and distributors use forage analysis to establish crop value, facilitating marketing and other trade activities (Undersander, 1996).

Extension professionals, for decades, have communicated the importance of forage analysis and encouraged agricultural producers to take advantage of services offered by forage laboratories (Coppock et al., 1981, Chase and Grant, 2013). Initially, forage laboratories were associated with universities for the benefit of the Dairy Herd Improvement Association (Longland and Byrd, 2006). Currently agricultural producers have several options when it comes to acquiring forage analysis. Many universities, state departments of agriculture, and private commercial laboratories offer forage analysis to the public (Longland and Byrd, 2006).

Forage laboratories have become common in the United States, are easily accessible, and provide relatively inexpensive forage analysis to animal and crop producers. The use of forage analysis has advanced, becoming an essential component of modern animal production (Ampong-Nyarko and Murray, 2011) and increasingly important to the forage industry for crop valuation and trade activities.

As important as feed analysis is, utilization of forage analysis by agricultural enterprises have been viewed as limited (Corah et al., 2010). It has also been suggested

that patrons of forage laboratories have reservations about the validity of forage analyses (Undersander et al., 2005).

In order to have information and technologies applied by agricultural end-users, identifying factors which hinder the process must be identified. Factors hindering acceptance of the practice of forage analysis may be related to human behavior or experience. Other factors may be connected to stages of end-user knowledge of forage analysis (Barao, 1992).

The objectives of this study were to examine commercial feed laboratory use throughout the United States. Current preferences of laboratory patrons such as specific laboratory selection, systems of analysis, and laboratory performance were examined. In addition, this study sought to document feed laboratory importance and impact on businesses.

MATERIALS AND METHODS

A survey was created to examine areas of interest concerning feed laboratories with emphasis on business use, understanding, experience, and confidence. Areas of interest were:

- Extent of utilization of forage analysis by different agricultural industries
- Preferences in forage laboratory selection.
- Knowledge of forage laboratory methods.
- Factors influencing laboratory selection.
- Confidence in, and impact of, laboratory performance
- Value placed on forage analysis

Industry Survey

A survey was administered to United States businesses that are part of an international trade association specializing in feed. Trade organization membership was comprised of businesses that specialize in feed production, manufacture, trade, export, and use in 42 states. Trade organization membership, at the time of this study, did not extend into AK, DE, HI, NH, RI, or VT. Surveys were conducted via telephone interviews with businesses from April 2013 through May 2013. Survey's that were unable to be administered via telephone interviews were delivered to businesses by regular mail from June 2013 through August 2013. Undergraduate students from the Brigham Young University-Idaho Department of Animal and Food Science conducted telephone interviews and prepared survey packets for distribution by U.S. Postal Service.

University Professionals Survey

Through an internet search carried out from November 2015 to February 2016, a list was compiled of university professionals in the United States with documented interest in feed quality or animal nutrition. Undergraduate students from the Brigham Young University-Idaho Department of Animal and Food Science administered a survey via email, text messaging, or directly by telephone interviews. The survey consisted of two questions. The questions asked what is the name of the feed laboratory that you primarily use or recommend to others, and, using just one word, what is the primary reason that you use or recommend this laboratory?

Feed laboratories named by those surveyed were identified by numerical codes to protect laboratory privacy. Compiled data were recorded in an Excel spreadsheet and analyzed using Excel database commands. SigmaPlot 12 (Systat Software Inc., San Jose, CA, USA) was also used to perform statistical analysis and graphics.

RESULTS AND DISCUSSION

A total of 145 telephone surveys were attempted that resulted in 33 competed surveys and a response rate of 23%. Researchers experienced a high nonresponse rate due to telephones not being answered. However, surveys that were mailed to 112 non-responding businesses from the telephone survey and another 163 additional businesses, also part of the trade organization, produced a response rate of 57%. Surveys were completed by businesses from 36 states. Responses were not received by businesses in MA, ME, MO, NJ, NM, or WV. Using telephone and mail methods, a total of 161 (52%) responses were received out of 308 businesses surveyed.

Businesses and Industries of Trade

The first question asked, "In which livestock industries do you or your company primarily trade?" They were given the following options: dairy, equine, beef, sheep, export, retail, or other industry. Respondents were allowed to list single or multiple industries, but were asked to rank their options (1^{st}, 2^{nd}, etc.) based on level of business. Out of 161 surveyed businesses, 151 indicated working with specific feed industries. Surveyed businesses answered Question 1 in four ways: by checking a single industry (n = 68), checking multiple industries without ranking (n = 19), ranking multiple industries (n = 64), and by not answering the question (n = 10).

Several businesses wrote in three industries not printed on the survey form: grower, rabbits, and poultry. Industries written in were included in the "Other" category. Results for industry and feed laboratory use are shown in Table 1. It is important take into consideration that businesses have accepted practices in their particular area of business

that have been established by market demands. Performing feed analysis may or may not be required practice in some segments of the feed industry.

Seventy-four percent of the businesses indicated that they used analytical laboratories for feed analysis (Table 1). This includes all responses, across all industries. However, using survey results from single industry businesses that use feed laboratories is more instructive in gauging feed laboratory use by specific feed industries. Single industry businesses that use feed laboratories represent 72% of businesses.

The distribution of use by single industry businesses are not equal. Those businesses that deal in dairy or export use a laboratory essentially 100% of the time. We conclude that feed laboratories or analysis are essential to these industries. There was a strong positive correlation ($r=0.8$) between state dairy cow numbers and number of feed laboratories in each U.S. state, indicating the strong influence of the dairy industry on feed laboratories.

Our results show that 100% of businesses that work with the export market use feed laboratories. We found unusually large numbers of feed laboratories are established in locations where forage exports are considerable and where the large number of labs cannot be explained by state dairy cow numbers alone. Businesses from six western states represent most trade in exported of feeds. Other states from which businesses claimed involvement in feed export were: SD, NE, NC, and NY. Since trade is driven by demands of markets, it is safe to assert that dairies and feed importers want to know the nutritional composition of feeds to be consumed.

Among businesses that trade solely in equine, beef, or retail feeds, 65% or less indicated use feed laboratories use (Table 1). Since trade is driven by demands of

markets, ultimately it is the purchaser of feeds that determine if feed analysis is wanted or not. Lack of greater feed laboratory use among feed retailers may be explained by packaged or manufactured feeds already having nutritional labeling as required by law. But this does not explain lack of feed laboratory use in equine and beef industries. Survey results indicate that more education is needed in equine and beef industries regarding benefits of proper feed management to animal health, production, and performance. Greater use of, and education about, feed management in equine and beef industries should lead to greater feed laboratory use and consequently increased efficiency, performance, and profits in these industries.

A question was asked about whether they used analytical laboratories to determine forage quality? Out of 46 businesses claiming no feed laboratories use, 30 indicated single industries of trade in the feed industry (Table 1). Seven businesses choose multiple industries of trade but did not rank their choices. Four surveyed businesses claimed no feed laboratory use and did not identify their industries of trade. Analysis of the data showed that the beef and equine industries primarily listed no feed laboratory use (Table 1; 59% of all negative responses).

Lack of feed laboratory use in some feed industries can be rationalized. Feed retailers not using laboratories may be explained by nutritional information being provided by suppliers and manufactures or both, through labeling of manufactured feeds. But, feed laboratories not being used by businesses primarily trading in equine and beef industries, indicates lack of consumer demand for nutritional information.

Many authors encourage feed analysis among equine owners (Longland and Byrd, 2006, Johnson et al., 2010, Saastamoinen and Hellämäki, 2012). However, low feed

laboratory uses by businesses specializing in the equine industry is an indication that more education is needed among equine owners concerning balanced equine nutrition. Lack of feed laboratory use by businesses that trade primarily in the beef industry is further indication of need for more nutritional education emphasizing benefits of feed analysis and balanced rations to increase animal performance and producer profits.

Feed Laboratory Preference

One of the questions asked, "What is the name of the forage laboratory that you would primarily use?" with a follow-up of what would be your second choice? There were 144 feed laboratories identified in the United States and assigned numeric codes to each. Surveyed businesses reported use of 52 different feed laboratories. However, 7 laboratories named no longer perform feed analysis. Therefore, trade member laboratory use data was compiled for 45 feed laboratories that are currently in operation. Figure 2 shows number and frequency of feed laboratories used by trade organization members. One feed laboratory had 22% of all responses (Figure 2). The summation of the next 4 laboratories doesn't equal the use by that one laboratory.

Disproportionate, frequent use of this one laboratory seems like an unusual bias among businesses, considering the large number of highly competent feed laboratories available in the United States. However, this kind of bias is not unprecedented. Out of 14 commercial feed laboratories in this study, not operated by universities or state departments of agriculture, and acknowledged in 110 peer review papers from 2004 to 2013, 3 commercial feed laboratories represented 85% of all acknowledgments. Therefore, feed laboratory bias or preference is not limited to trade organization member included in this study.

While it is not apparent why businesses don't use laboratories, several questions asked why they did use a laboratory and was important in that decision. Businesses were asked to rank what qualities were important to them based on the following options: a) if a laboratory was certified; b) laboratory reputation; c) sample turnaround time; d) cost; or d) other. The results are shown in Table 2 and out of 128 first choices, response percentages were 46% (n = 59), 35% (n = 45), 11% (n = 14), 5% (n = 7), and 2% (n = 3), respectively.

Survey data shows that when choosing a feed laboratory, certification is a primary consideration for most businesses followed by laboratory reputation. Importance of certification in feed laboratory selection was also confirmed because 94% (n = 152) of responses named laboratories that have participated in NFTA certification at least once from 2010 to 2014. Six out of 45 laboratories had not participated in NFTA certification but use of these laboratories is minimal among trade organization members. Survey results showed that certification is major factor considered in choosing laboratories to perform feed analyses.

Feed laboratory reputation is also a major factor contributing to feed laboratory selection by businesses (Table 2). However, no survey questions were created to investigate intricacies of laboratory reputation and laboratory selection. Groups such as the trade organization chosen for this study often trade in close circles where reputation and trust are dominate in trade activities. It is possible that aspects of laboratory reputation such as organization member opinions, experiences, habits, and perhaps business strategies play greater roles in feed laboratory selection than can be determined

by this study. Further research is required into connections between feed laboratory preference verses laboratory reputation.

Feed Laboratory Use and Trader Proximity

Of 112 feed businesses that responded to a question of whether location was important, 49% (n = 55) indicated use of feed laboratories in home states and the rest (n = 57) indicated feed laboratory use in other states. However, it should be noted that 45% (n = 26) of businesses used feed laboratories outside home states, used labs in conjoining states. In addition, of 31 feed laboratories used outside trade organization member home states, 10 were separated by a single state from member home states. So, when out of state feed laboratories were preferred by trade organization members, 63% (n = 36) choose regional feed laboratories.

Trade organization member rankings of feed laboratory qualities are logical and reflect priorities of feed trade. An accurate description of feed or forage characteristics is essential to successful trade. In trade situations were nutritional composition is required, as it is in the dairy industry, accurate analysis of feed components from proficient laboratories is necessary. Laboratory certification is a primary means for businesses to establish feed laboratory proficiency.

Over time as businesses utilize a specific laboratory and analyses provided are not unreasonably inconsistent with animal performance, customer expectations, or analyses of other feed laboratories, businesses become confident in a feed laboratories performance; and a laboratory's reputation is established. Trading feed is time sensitive and competitive and feed transactions often cannot be finalized or even initiated until reliable descriptions of feed composition are provided to purchasers. Consequently,

sample turnaround time becomes important to businesses. However, they ranked it as their clear third choice (Table 2). It is not known why it didn't rank higher.

Cost of feed analysis was not considered as important to trade organization members, when choosing a feed laboratory (Table 2). Considering the significate risks associated with inaccurate feed analysis trade such as loss of animal health and production, under or overvalued feed relative to quality, nonpayment, or litigation, businesses appropriately ranked cost of analysis as least important of all feed laboratory qualities.

Survey of University Professionals

Similar to the survey responses from Table 2, 54 university professionals from 39 US states were identified and surveyed. The response rate was 63% (n = 34) from 24 states. They were asked two questions. The first question was, "What is the name of the feed laboratory that you primarily use or recommend to others?" Respondents named 10 different laboratories and the most prevalent laboratory listed by the businesses was also named 50% of the time for this group.

The second question asked them to use just one word to describe the primary reason that they recommended the laboratory they named in question 1. The answers were open-ended, and the responses suggest that laboratory proficiency and service are equally important to university professionals in laboratory selection and recommendation (Table 3). Certification was not named by any respondents; however. 41% described proficiency, through terms named, as a reason for laboratory selection or recommendation. If university professionals are unfamiliar with certification, which verifies feed laboratory accuracy and precision, how is feed laboratory proficiency

established? Informal comparison of commercial laboratory results with predetermined feed analysis or with actual animal performance may be used to establish proficiency.

According to another 41% of respondents feed laboratory selection is based on service. Laboratory service must be established through experience or trial and error; since there is no organization which officially measures, reports, or rates feed laboratory service. Selection or recommending feed laboratories based on service is logically guided by the assumption that accuracy and precision between United States feed is equal or not significantly different. However, NFTA certification records and peer reviewed papers (Hristov et al., 2010) establish that all feed laboratories are not equal.

Preference for Chemical or NIR Analysis.

A survey question asked businesses that when selecting a laboratory, which they prefer, chemical analysis, NIR analysis, or no preference? Of 107 businesses that responded to this question, 47% preferred NIR analysis, 21% preferred chemical analysis, and 32% had no preference for a specific system of analysis. Since, 32% of trade organization member responses were no preference, it may be an indication that some businesses recognize no differences between chemical and NIR systems of analysis. Large percentage of "no preference" responses may also be viewed as progress in acceptance of NIR technology as equal to chemical systems or lack of knowledge concerning feed analysis systems or both among trade organization members.

When responses to preferences for either chemical analysis or NIR analysis were grouped with corresponding choices to the question of "Why do you prefer the analysis selected in the previous question", factors guiding choice between feed analysis systems are evident. As shown in Figure 3, trade organization member responses confirm the

appeal of NIR analysis advantages of rapid analysis (turnaround time) and low cost. Out of 62 survey responses asserting why NIR analysis was preferred, 40% (n = 25) chose turnaround time, whereas cost and accuracy were both selected by 29% (n = 18) each. Accuracy is not generally a characteristic uniquely attributed to NIR in relation to feed analysis. However, businesses seemed to consider NIR accuracy as appealing as the low cost of NIR.

Eighty-four percent (n = 21) of businesses that preferred wet chemical systems for feed analysis indicated that accuracy was a foremost reason and 12% (n = 3) indicated turnaround time. These data suggest that more that 30% of trade organization members, that have a feed analysis preference, consider wet chemical systems to be more accurate than NIR systems. The idea or perception that wet chemistry systems are more accurate in matters of feed analysis is not without basis. NFTA certification data compiled from 2010 to 2014 for United States based feed laboratories showed that the average percent of wet chemistry certification, by grade, were 54% (n = 114), 51% (n = 113), and 8% (n = 1) for A, B, and C certifications, respectively. Average percent of NIR certification, by grade, were 46% (n = 98), 49% (n = 109), and 5% (n = 11) for A, B, and C certifications, respectively. Slightly weaker NFTA certification performance of NIR systems as compared to wet chemical systems from 2010 to 2014 may support preferences that some businesses have for wet chemical systems.

Dissatisfaction with feed laboratory performance logically influences laboratory selection and use. One question asked those surveyed “Have you ever been dissatisfied with the performance of a forage laboratory?” Of the 113 responses, 51% (n = 58) indicated dissatisfaction with laboratory performance. Another question asked why they

were dissatisfaction with feed laboratories. Of 61 responses, 75% (n = 46) indicated that accuracy was the reason for dissatisfaction (Figure 3); three businesses indicated more than one reason.

Businesses were asked, “How important was forage analysis to their business?” Most businesses (n=64, 56%) indicated that feed analysis was very important to their business (Table 4). The median (Mdn) response to question 9 was 5 (very important) with an interquartile range (IQR) of just 1. This small IQR is an indication of strong consensus among businesses as to the importance of feed analysis. Also, combining the responses of important and very important together totaled 76% (n = 87), and confirmed the importance of feed analysis to their businesses. Eleven percent (n 16) responded that feed analysis, in varying degrees, was not important to their business. Trade organization members, in order to conduct business, must have a means of representing feeds being bought and sold. If feed analysis was not important, how was feed quality represented for trade purposes among such businesses? There are a few possible explanations for how feed quality is represented by businesses without laboratory analysis: nutritional information was provided by other second or third parties, sensory analysis (smell, touch, taste, color) was used instead laboratory analysis or reference table (NRC) values were used to determine nutritional quality of feeds being traded.

Additional questions were asked to aid in measuring trade organization member confidence in feed laboratories. One question asked, “how confident are you in the accuracy of the forage laboratory that you use?” Seventy-six percent of businesses (n = 84) were fairly to very confident in the accuracy of their feed laboratory (Mdn = 4, IQR = 1). This consensus was understandable, since trade organization member current use of

any particular feed laboratory would, logically, be based on a positive level of confidence. In contrast, the consensus of confidence in labs used by individual businesses was not seen as much in the question that asked, "How confident are you in the accuracy of forage laboratories in general?" Of 111 responses, neutral (n=31) and fairly confident (n = 39) were the two highest values (i.e. response answers 3 and 4 out of 5) and received almost two-thirds of the responses. The responses were more centrist, with responses indicating that confidence in feed laboratories in general was moderate or perhaps vacillated.

Although the importance of feed analysis to businesses was confirmed by the survey, a specific impact of feed analysis on business was not addressed. A question was asked, "How important have forage analyses been in generating profits for your company?" The median response was 4 (fairly important) with an IRQ of 2 indicating moderate consensus among businesses as to whether or not feed analysis is important in generating profits. Out of 108 responses, 59% chose options 4 and 5, indicating that feed analysis was important in generating profits for 60% of trade organization member businesses that responded (Table 4). Twenty-four percent of businesses said that feed analysis was not important in generating profits for their businesses (Table 4).

Some Negative Impacts of Feed Analysis

Survey respondent opinions regarding feed laboratory performance came from direct or indirect experiences or both. Several survey questions attempted to assess some specific circumstances in which businesses may have been negatively impacted by feed analysis issues.

Businesses were asked if they had ever been dissatisfied with the performance of a forage laboratory? Responses were evenly split between yes (50%; n = 56) and no (50%; n = 55). Reponses also showed that 75% and 18% of businesses thought that laboratory accuracy and turnaround time, respectively, were causes of dissatisfaction. Businesses were also given an opportunity to identify other possible reasons for dissatisfaction with feed laboratories. Cost was the least identified reason for dissatisfaction (5%). Association of laboratory accuracy and turnaround time with impacts on business is clearly plausible. Lengthy sample turnaround times can delay feed transactions and possibly cause loss of feed sales to competition. Inaccurate laboratory analysis can potentially cause greater direct loses and can impact businesses in more ways than any other factor associated with laboratory performance.

A final question was if you or your business had ever lost money because of feed analyses issues?" Fifty percent (n = 55) said yes to this question. When asked to estimate the total losses in dollars, 44% (n =24) said thousands of dollars. The next highest responses were either hundreds of dollars (n = 12; 22%) or tens of thousands of dollars (n = 12; 22%). Surprisingly, 13% said hundreds of thousands of dollars.

Responses indicating monetary losses due to feed analysis issues are important. Monetary losses experienced by some businesses may be a factor influencing lab use. This question could have been more instructive if a follow up question determining business size in terms of gross sales, net profits, or tonnage sold, etc. was asked. This additional information would have allowed relative measurements of effects of feed analysis issues on business.

Trade relationships are valuable and assigning actual monetary value to lost or damaged trade can be complicated. A question was asked if their business relationships had ever been damaged or lost due to feed analyses issues?" Thirty-five percent (n = 40) answered yes to having damaged or lost business relationships.

In circumstances where nutritional information is required, successful trade of feeds is based on accurate representation of nutritional qualities of products. When negotiating transactions involving feed, businesses present laboratory analysis regarding feed components of their commodity to potential buyers. Feed analysis that is not reasonably accurate can damage trade relationships by undermining trader reputations and buyers trust, because feed traded appeared to be misrepresented.

CONCLUSIONS

Feed analysis provided by proficient analytical laboratories is an essential tool for businesses working in dairy and export feed industries. Survey data suggest that greater education is needed to promote benefits of modern feed management and feed analysis to optimize profits, animal health, and production in beef and equine industries.

Feed customers, dealers, exporters, manufactures and other businesses surveyed, provided valuable information regarding utilization of feed laboratories in the United States. Data suggest that among these members feed laboratory utilization is disproportionate directed to a single feed laboratory, although many other laboratories are used by organization members.

Accuracy is the primary quality organization members looked for in feed laboratory selection, followed by reputation, turnaround time and lastly, cost. NIR has emerged as a

system of analysis most businesses use. NIR laboratories apparently have the qualities businesses look for when selecting a feed laboratory. Accuracy is essentially the only reason that wet chemistry labs are preferred over NIR labs.

Feed analysis provided by laboratories is an important business component for most businesses for completing transactions and generating profits. Effects of feed laboratory performance on industry can extend beyond analyses produced. Laboratory performance can bolster or undermine end user confidence in feed analysis and hamper feed management practices meant to benefit producers. Feed analysis can be the basis for lost or damaged trade relationships and loss of revenue. Considering the vital roles and profound impacts that feed analysis has on industry, it is incumbent that laboratory management and technicians appreciate the impact and important work of performing feed analysis.

This study focused on just one community or organization of feed businesses. Other, more specific, studies are needed concerning feed laboratory utilization among groups such as dairy, beef, equine, and crop producers as well as professionals like feed consultants to determine if patterns, practices, preferences, and views documented in this study are shared between industries.

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Table 4.1. Response to question of whether or not their business used a forage testing laboratory by the primary industry that they worked with. Business were allowed to answer with a single or multiple answer. Multiple responses were summed for each industry. Total surveys with a response were n = 117 for yes and n = 46 for no.

	Single		Multiple		Total		Single
	Yes	No	Yes	No	Yes	No	Yes (%)
Beef	19	13	12	3	31	16	59
Dairy	37	1	13	2	50	3	97
Equine	26	14	15	5	41	19	65
Export	14	0	2	0	16	0	100
Retail	2	2	11	5	13	7	50
Sheep	0	0	18	1	18	1	95
Other	3	5	6	1	9	6	38
Multiple	14	7	0	0	14	7	67
Undisclosed	2	4	0	0	2	4	33
Total	117	46	59	16	176	62	72

Table 4.2. Survey rankings in answer to the question of what was important in selecting a feed testing laboratory.

	Rank[1]				
Quality	1	2	3	4	Total
Certification	59	18	10	10	97
Reputation	45	30	14	7	96
Turnaround time	14	32	39	17	102
Analysis cost	7	16	26	43	92
Other	3	1	0	2	6

[1]1 = highest rank; 4 = lowest rank

Table 4.3. Word response frequency of university professionals who were asked to use just one word to define what was the primary reason they used or recommended the laboratory they primarily used. Responses were organized within 4 motivation categories; there were 34 responses.

Proficiency		Service		Emotion		Cost	
Response	N	Response	N	Response	N	Response	N
Quality	6	Reliable	4	Familiarity	3	Price	1
Accuracy	4	Service	3	Confidence	1		
Consistency	3	Convenience	2	Reputation	1		
Experience	1	Location	2	Trust	1		
		Comprehensive	1				
		Speed	1				
Total	14		13		6		1

Table 4.4. Survey rankings in response to questions related to importance and confidence in forage testing laboratories.

	Ranking scale					Total
Survey question	1	2	3	4	5	responses
How important is forage analysis to your business? (Q. 9)	10	6	12	23	64	115
How confident are you in the accuracy of forage laboratories in general? (Q. 11)	8	16	31	39	17	111
How confident are you in the accuracy of the forage laboratory that you use? (Q. 10)	5	6	16	43	41	111
How important have forage analyses been in generating profits for your company? (Q. 13)	17	9	18	30	34	108

1 = not important/confident; 2 = slightly important/confident; 3 = neutral; 4 = fairly important/confident; 5 = very important/confident

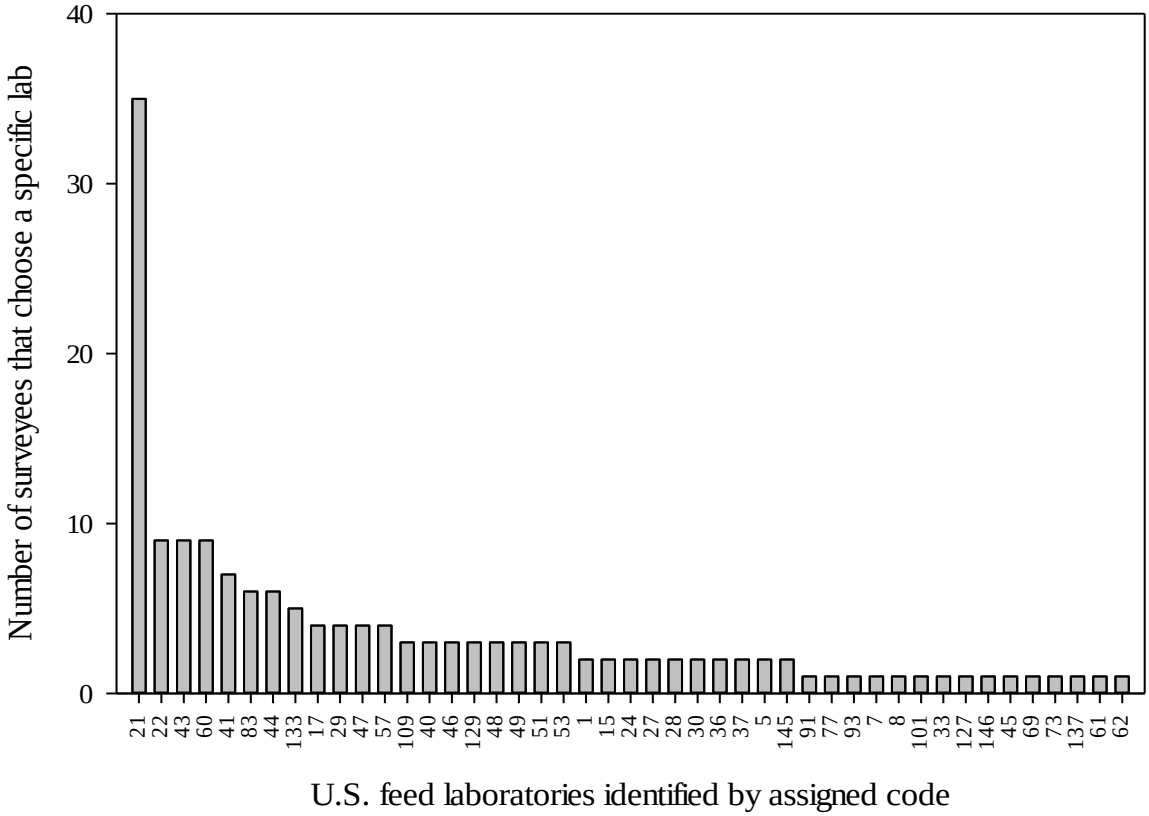

Figure 4.1. Results of primary and secondary choice response to the questions that asked the name of the forage laboratory they used. Results are coded for privacy reasons.

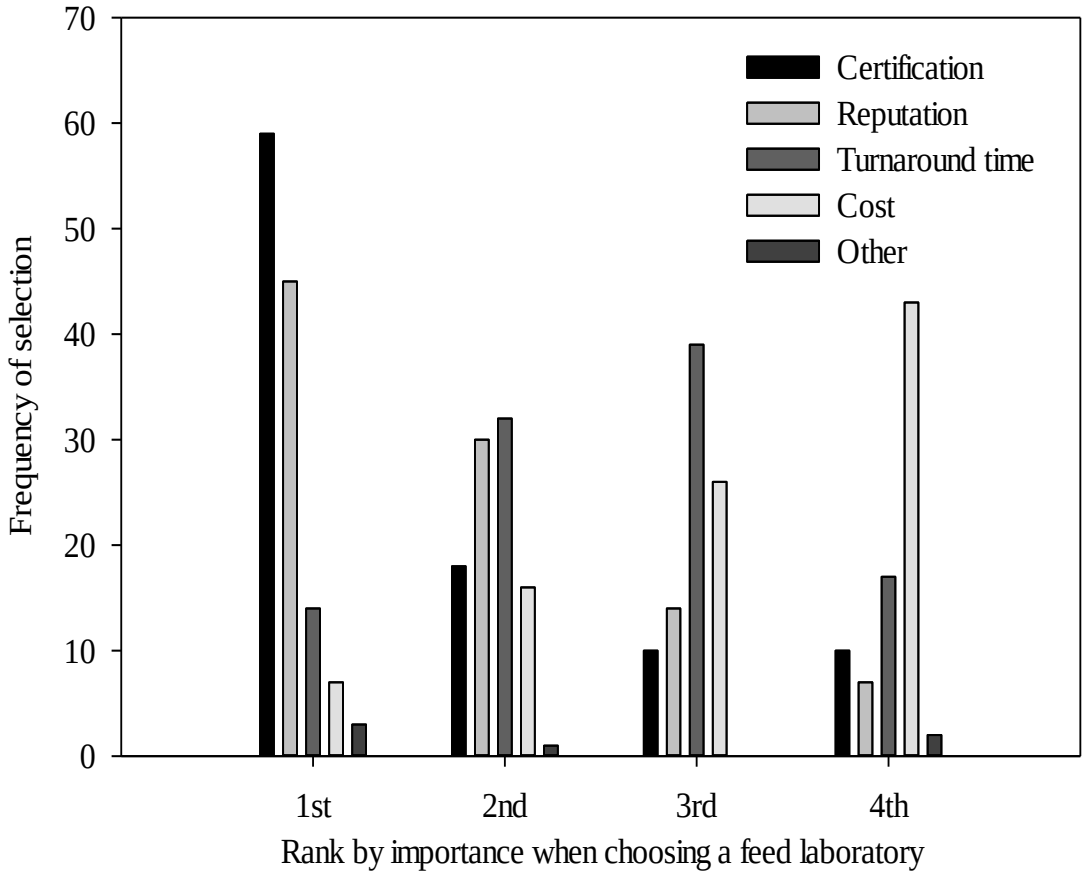

Figure 4.2. Responses to the question that asked which qualities were most important to their business for choosing a forage laboratory. Five options were given, and respondents were asked to rank them from 1 to 5 (high to low).

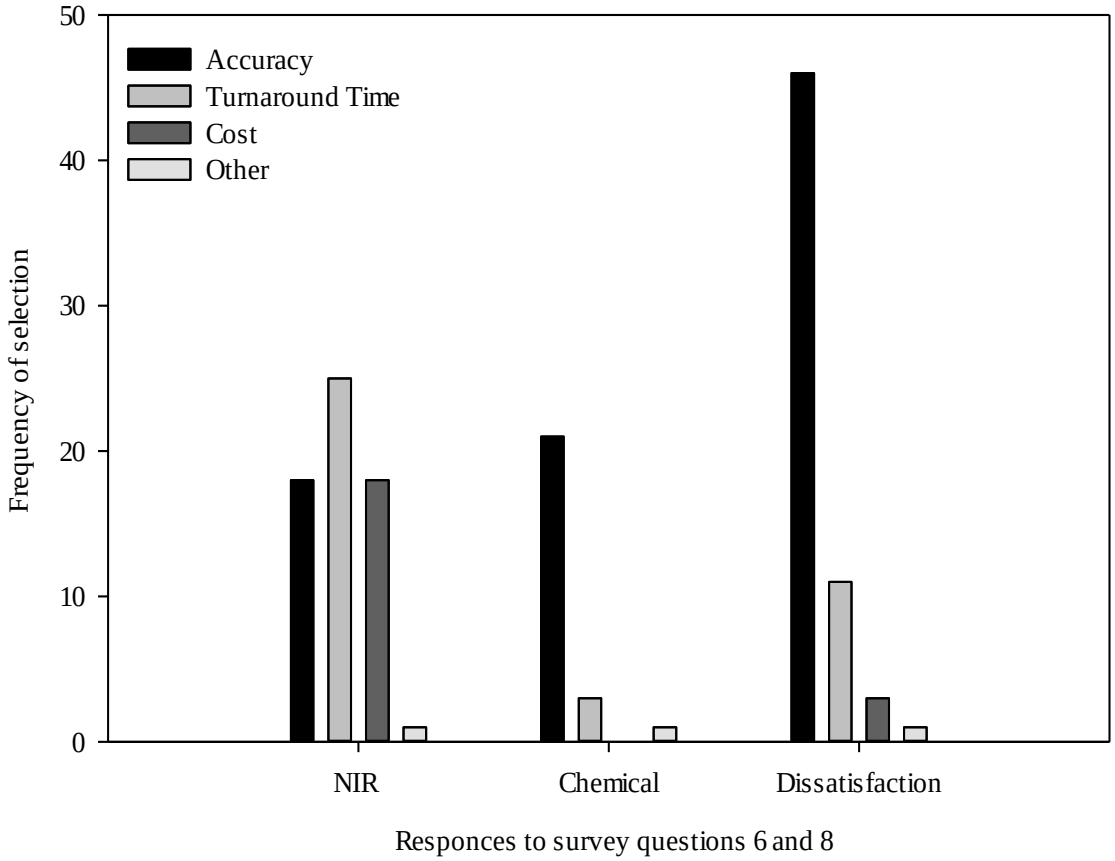

Figure 4.3. Survey results from a combination of questions which asked why a business preferred to use chemical or NIR for feed analysis, what was most important to them in why they chose a forage laboratory and reasons for dissatisfaction with a laboratory. Accuracy, turnaround time, cost and other were options given on the survey. No business identified cost as a reason for preferring chemical feed analysis.

CHAPTER 5

ACCURACY AND PRECISION OF COMMERCIAL FORAGE ANALYSIS: A BLIND COMPARISON OF 12 UNITED STATES LABORATORIES

ABSTRACT

Nutritional analysis of feedstuffs is the foundation of progressive feed management. Feed analysis provides producers with nutritional information needed to optimize animal health and production. Peer review and popular literature indicate widespread concern with the accuracy between US feed laboratories. Objectives of this study were to determine variation of feed analysis between US feed laboratories using a blind ring test. Selected laboratories were paid to perform DM, CP, ADF, NDF, Ca and P analyses. Three hay types: immature mixed grass, pre-bloom alfalfa, and pre-bud alfalfa were submitted to each of 12 laboratories, 3 times in duplicate. Minimum, maximum, mean, and standard deviation results for relative feed value for immature mixed grass, pre-bloom alfalfa, and pre-bud alfalfa were: 87, 161, 118, 13.6; 101, 176, 141, 13.9; and 158, 290, 237, 31.7; respectively. CP results were: 8, 15, 10.8, 1.3; 21, 29, 24, 1.9; and 23, 29, 25, 2.5; respectively. ADF results were 26, 42, 32, 3.2; 27, 40, 33, 2.1; and 18, 29, 22, 2.5; respectively. NDF results were 40, 60, 51, 4.3; 35, 54, 42, 3.5 and 22, 40, 29, 3.8; respectively. Out of 216 samples submitted to commercial laboratories, 7 (3%) results had obvious clerical errors and were corrected before statistical analyses. Before laboratory submissions, partial DM was determined for all samples. Differences between laboratory determined DM (LDM) and pre-submission partial DM (PDM) were calculated for each sample. For 216 submissions 49% produced negative differences

when PDM was subtracted from LDM, indicating that samples increased moisture content after mailing. LDM-PDM differences from western state laboratories were compared to LDM-PDM differences from eastern state laboratories using mixed model data analysis. LDM-PDM differences from western state laboratories were highly significant ($P < .0001$) compared to eastern state laboratories. Feed samples contaminated by ambient humidity is likely a major cause of differences in forage analysis between US commercial laboratories. Ambient humidity is characteristic to US regions, seasons of the year, immediate weather patterns, or laboratory environments. Moisture contamination should be avoided to avert variation of feed analysis between laboratories.

INTRODUCTION

Nutritional analysis of feedstuffs is the foundation of feed management for contemporary animal production systems. Feed analysis provides producers with nutritional information required to optimize animal health and production (Mueller-Harvey, 2004). Nutritional analysis also provides feed manufactures, crop producers, researchers, and governments with valuable information needed to meet management or program objectives. Accurate and precise nutritional analysis facilitates efficient use of animal production resources and provides end-users with information required to make valid judgements and implement improvement.

Commercial and many governmental laboratories perform analyses for individuals and organizations that seek to know the nutritional composition of feeds. These laboratories have become commonplace and are integral parts of both plant and animal agriculture. As important as feed laboratories are, there is evidence that inaccuracy and imprecision among feed laboratories in the United States maybe a problem (Holin, 2008, Hristov et al., 2010; McCabe, 2008)

Hristov et al. (2010), showed significant variability in feed analysis between "participating" laboratories. However, Hristov's study may have not shown the full magnitude of inter and intra laboratory variation that producers actually experience for several reasons. Laboratories had a choice of involvement and were aware of participation in a scientific study. Laboratories were also selected from a group of National Forage Testing Association (NFTA) laboratories. Laboratory knowledge of participation may have influenced attention given to feed samples. Also, it is not clear whether laboratories included in Hristov's study actually represent those frequently used

by US producers. Of 144 US laboratories capable of feed analysis only 29% have participated in NFTA certification every year from 2010-2014. Hristov's study focused on variability of analysis for 2 TMRs and the associated individual components. He clearly identifies analysis variability between feed laboratories, but many important questions were unanswered.

McCabe (2008) and Holin (2008) authored popular publications that reported noteworthy variation in feed analysis between laboratories. To avoid laboratory bias, comparison studies reported in these popular publications were carried out using blind procedures. However, original peer-reviewed research upon which articles in popular publications were based could not be identified through literature searches. Further research is needed to validate claims of significate variation of feed analyses between laboratories.

The objective of this study was to use a blind ring test to determine the magnitude of feed analysis variation between and within US feed laboratories.

MATERIALS AND METHODS

Feed Laboratory Selection

Feed laboratories used in the blind ring test were selected from laboratories identified as most frequently used by United States members of a feed trade organization. In order to include feed laboratories from as many regions of the United States as possible, laboratory geographic location was considered in selection as well as reputation, services offered, and cost. If multiple, frequently used, laboratories were located in the same region only one was chosen for the study. The U.S. Census Bureau identifies 9 divisions of the United States: Pacific, Mountain, West North Central, West South Central, East North Central, East South Central, Middle Atlantic, South Atlantic, and New England (NASS, 2015). One to three laboratories were selected for each region. Of these laboratories, 4 were operated by universities and 8 by commercial entities; all 12 perform feed analyses for the public. Near infrared analysis was used by 4 laboratories and wet chemical methods were used by 8. A non-public in-house laboratory was included in the ring test and was operated by the author. Feed laboratory names were not disclosed but were identified only by numerical codes.

Submission Sample Selection

Pre-bloom alfalfa (PBLA), pre-bud (PBDA) alfalfa (Medigo sativa), and immature mixed grass (IMG) hay were used as forage types for submission to laboratories. All three hay types were obtained from southeastern Idaho growers. Alfalfa samples were collected from 4 bales of each type. A larger quality of IMG hay (18 bales) was probed to collect forage materials and to facilitate future feeding studies.

The alfalfa hay types were harvested from the same field and were the same cultivar. Both alfalfa hays were free of grass and weeds. The IMG hay contained several grass species: orchard grass (Dactylis glomerata), smooth brome (Bromus biebersteinii), Kentucky bluegrass (Poa annua), and tall fescue (Festuca arundinacea).

Submission Sample Preparation

Approximately 50 kg of hay was collected from each hay type. Sample material was collected by randomly probing all bales of each hay with a drill type hay probe (Best Harvest 61 cm) with a 1.6 cm core diameter (Putnam, 2003) and a bag attachment. Ziploc bags were filled to an average weight of 450 grams for a total of about 12.5 kg from each bale of both alfalfa hay types. About 2.7 kg of hay was collected from each of 18 grass hay bales. All hay bales were probed as recommended by Undersander et al. (2005). All were label sequentially and stored indoors at ambient temperatures.

Bags within each hay type were randomized using Microsoft Excel 2010 (Microsoft Corporation, NY, USA). Each of the three forage types were mixed by emptying 30 randomized bags (13.5 kg) into a Wakomi (0.29 m^3) three-point tumble type mixer, powered by a John Deere 3020 tractor. During mixing, the Wakomi mixer was set to rotate at 22 rpm. The initial 13.5 kg load of forage was placed in the mixer was allowed to blend for 10 minutes. A 198 cm sampling pole with a 10.2 x 11.4 cm cylindrical cup attached at one end was used to remove hay samples from the mixer. Mixed hay was collected into empty, pre-weighed, numbered, Ziploc bags. To collect a sample from the mixer, the end of the sampling pole with the open lined cup was inserted into the center of the rotating mixer and withdrawn when the bag was full. After 25 bags of forage were removed from the mixer, the mixer was stopped, and an additional five randomized bags

of hay were emptied into the mixer. After being filled, each bag was sealed and weighed. This procedure was repeated for each hay type until each type was mixed and transferred into bags. About 400 samples were collected for each hay type. All bags of hay were placed in boxes and stored at -20 C.

Blind Sample Selection and Submission for Laboratory Analysis

A randomized list of numbered SZ bags was created for each forage type using Microsoft Excel 2010 (Microsoft Corporation, NY, USA). In consecutive order, each hay sample was assigned to the feed laboratories in numerical order as coded. After being assigned to feed laboratories, hay samples, with bags open, were placed on aluminum pans and dried in a Shel Lab (model FX28-2) forced air oven for 72 hours at 55 ºC. After drying, samples were allowed to air-equilibrate for 8 hours at 22 ºC; then were resealed and weighed. This process of analyte assignment was repeated each time analytes were prepared for submission to selected feed laboratories.

Each hay type was submitted to each of 13 laboratories, 3 times, in duplicate, for a total of 6 replications. One of the 13 laboratories constituted the in-house laboratory. Samples were sent to all laboratories along with standard submission forms, provided to the public by each respective laboratory. Analyses required of all laboratories included: dry matter (DM), crude protein (CP), acid detergent fiber (ADF), neutral detergent fiber (NDF), calcium (Ca), and phosphorus (P). Laboratories were provided with any pertinent information requested on submission forms concerning sample characteristics such as forage type, time of harvest, or origin, etc. Samples were mailed to feed laboratories via Priority Mail from Dec 27, 2013 to July 3, 2014 at irregular intervals (roughly monthly). All submissions were made in the name of an actual, but anonymous, corporation that

specializes in feed distribution throughout the United States. All payments to laboratories for analysis performed were made through the anonymous corporation.

In-house Laboratory

Brigham Young University - Idaho forage laboratory, Rexburg Idaho and Brigham Young University - Environmental Analytical Laboratory, Provo Utah were designated as the in-house laboratory and analyzed all forage samples assigned to the in-house laboratory. Sample preparation, dry matter determinations, ADF, and NDF analyses were all carried out at BYU-Idaho. Nitrogen, calcium, and phosphorus determinations were performed at BYU-Provo. Samples assigned to in-house laboratory were ground using a Wiley mill (model 4) equipped with a 1-mm screen. Samples were placed in bags and stored in locking airtight containers at about 16 ºC in a dark room until analysis.

Dry matter. Dry matter analyses were carried out on all samples by oven drying using a VWR gravity convection oven (model 406). Samples were dried at 100ºC for 24 hours according to the total dry matter-cool weigh method described by Undersander et al. (1993).

Crude protein. Forage nitrogen content was determined by combustion method using a CN Determinator (TruSpec Micro, LECO, St. Joseph, MI, USA). Furnace temperature was 950 ºC. Encapsulated in each tin foil cup was 0.1 g of forage analyte. National Institute of Standards and Technology (NIST), Standard Reference Material (SRM) 1547 (Peach Leaves) standard was run before and after each batch of approximately 30 samples. Forage nitrogen content was converted to crude protein using nitrogen-to-protein conversion factor of 6.25.

Acid and neutral detergent fiber. Forage samples were analyzed for ADF and NDF components using a Ankom 200 Fiber Analyzer following Ankom Technology method 5 (Ankom, 2016a) and 6 (Ankom, 2106b) , respectively.

Ca and P determination. Forage samples were digested by nitric acid – hydrogen peroxide microwave digestion (Ethos EZ, Milestone, Shelton, CT, USA) using EPA method 3052. Calcium and phosphorus were determined by ICP-OES analysis (iCAP 7400, Thermo Electron, Madison, WI, USA).

Calculated Values. Relative feed value (RFV) was determined for all forage types analyzed. RFV is derived from a standard equation and is the same equation used by all feed laboratories. Total digestible nutrients (TDN) and net energy of lactation (NEL) equations can differ between feed laboratories. TDN, NEL, ME, NEM, and NEG values were calculated using Pennsylvania State equations for grasses and legumes (Undersander, 1993). TDN and NEL values, for grass and alfalfa, were calculated using Pennsylvania State equations for grasses and legumes (Undersander, 1993). Pennsylvania State equations for ME, NEM, and NEG values were used for calculation of both grass and legume energy values (Undersander, 2016). Equations used were as follows:

- RFV = DDM × DMI / 1.29 (DDM = digestible dry matter and DMI = dry matter intake)(ADF and NDF values)
- TDN = 4.898 + 89.796*NEL
- ME = 0.01642*TDN
- NEL = 1.0876 - 0.0127*ADF (Grass)
- NEL = 1.044 - 0.0119*ADF (Alfalfa)
- $NEM = -0.508 + 1.37*ME - 0.3042*ME^2 + 0.051*ME^3$

- NEG = -0.7484 + 1.42*ME - 0.3836*ME^2 + 0.0593*ME^3

Analytical Determinations and Statistical Analysis

All laboratories analyzed all forage samples for the following: crude protein (CP), ADF, and NDF analyses. Results from the laboratory analyses were used to calculate feed characteristics such as TDN and RFV. All compiled data was recorded in an Excel spreadsheet and analyzed using Excel database commands.

Mixed model statistical analysis was performed for each hay type. Commercial laboratories were designated treatments. Different hay types were specified as blocks. Differences between means were made using Tukeys multiple means comparison test with $P<0.05$ used to determine significance. SigmaPlot 12 (Systat Software Inc., San Jose, CA, USA) was also used to perform statistical analysis and graphics.

RESULTS AND DISCUSSION

Laboratories provided results on an as received and dry matter bases; except for one laboratory which reported all results on a 100% DM basis. Out of 216 forage samples submitted to commercial feed laboratories 3% (n = 7) sample results had obvious clerical errors; clerical errors were observed in 2 of the 12 commercial laboratories tested. Clerical errors may have been avoided had analyses been reviewed by personnel with knowledge of typical component values for the forage types analyzed. Clerical errors were corrected by involved laboratories and amended values were included into appropriate data sets. All laboratories provided TDN values. One laboratory did not provide RFV or any net energy values. In addition, one other laboratory provided net energy of gain (NEG) and net energy of maintenance (NEM), but not NEL values.

All laboratories provided calculated feed values such as: RFV and TDN. Most laboratories provided NEL, NEG, and NEM. However, one laboratory did not provide any net energy values and a second laboratory provided NEG and NEM, but not NEL values in feed analysis reports. Both laboratories, that did not include NEG, NEM, or NEL in feed reports, were operated in states with marginal dairy populations.

Mixed model statistical analysis showed significant differences exist for DM results between laboratories for each forage type. Significant differences were not found between laboratories for CP for any forage type. Significant differences for ADF and NDF analyses were found between laboratories for IMG hay. There were no significant differences for ADF, NDF, or RFV between laboratories for PBLA hay. For PBDA hay, there were significant differences between laboratories for NDF and RFV.

Impact of inter-laboratory differences on end-users may best be shown using RFV. Relative feed values were calculated for or by all laboratories using the same standard equation and are based on forage ADF and NDF values. RFV is currently the most widely use feed index upon which quality of feeds are evaluated and consequently traded. Therefore, comparison of RFV is likely the best method to show the impact of inter-laboratory variation of feed analyses on end-users.

RFV Estimates

Mean and standard deviation of RFV% for the in-house laboratory (Tables 1 and 3) and 12 laboratories (Tables 2 and 4) are listed for each hay type. Scatter plots of individual laboratory values, by hay type, are shown in Figures 1-3. Overall inter-laboratory range of RFV was 87 to 161, 101 to 176, and 158 to 290, for IMG, PBLA, and PBDA, respectively. Ranges for RFV by the in-house laboratory were 128 to 138, 152 to 166, and 244 to 288 for IMG, PBLA, and PBDA, respectively. Coefficients of variation for RFV determined by commercial laboratories versus in-house laboratory for IMG, PBLA, and PBDA were 9.1 v 2.9, 10.0 v 2.9, and 13.8 v 5, respectively.

Hay quality is often evaluated by livestock producers, crop producers, and traders using RFV ranges (Rudstrom, 2004). Currently hay quality is correlated to specific ranges of RFV. Using RFV estimate, hays can be grouped into USDA marketing categories: Supreme, Premium, Good, Fair, or Utility. These categories correspond to RFV ranges of > 185, 170-185, 150-170, 130-150, or < 130, respectively (Putnam and Undersander, 2006; Lehmkuhler, 2012; USDA, 2016). In USDA market reports and in other publications, RFV ranges often correspond to ranges in hay pricing. Systems which correlate RFV of hays to hay characteristics, and pricing facilitate trade and fair exchange

of hay quality information. However, when feed laboratories produce imprecise or inaccurate forage analyses, hay RFV can be misrepresented. Hays may be assigned to the wrong RFV category or to multiple RFV categories. Errant feed analysis can confound systems for communicating hay quality and value and can damage and trade relationships.

Laboratory RFV estimates for each hay type (n = 72) were grouped within marketing categories. Estimates categorized grass (82%), second cutting alfalfa (51%), and fourth cutting alfalfa (84%) as Utility, Good, and Supreme, respectively.

Although laboratories provide RFV's for grass hays, USDA hay market reports actually use a protein scale as a guideline to categorize grass hay as Premium, Good, Fair, or Utility. This marketing scale based on percent CP corresponds to > 13, 9 to 13, 5 to 9, and < 5, respectively. Therefore, using the protein scale and CP values, it was shown that 10%, 85%, 6%, and 0% of IMG hay samples were categorized as Premium, Good, Fair, and Utility, respectively.

Most laboratory RFV estimates (51%, n = 37) for PBLA were categorized as good quality with 4%, 26%, and 19% of laboratory RFV estimates categorizing the same hay as Supreme, Premium, Fair, and Utility, respectively. Laboratory estimates for PBDA were categorized as Supreme (88%) of the time. All other laboratory RFV estimates categorized this hay as Premium. Although 88% of PBDA samples submitted were in the same RFV range, the supreme category is open-ended (> 185) with 105 RFV points difference between the minimum and maximum RFV estimate of 290. In comparison within the closed ended Good category there is only a 20-point range. Greater variation

was observed in RFV estimates provided by laboratories for the PBDA (158-290), than for IMG (87 to 161) or PBLA (101 to 176).

Hay marketing categories alone are not precise enough to establish monetary value or feed quality to benefit both forage and livestock producers. Accurate and precise descriptions of forage nutrient composition must be established so that forage producers are fairly compensated for crops and livestock producers are supplied with forage that satisfies expectations and management needs.

Coppock (1997) suggested an RFV based pricing system for hay. The practical application of an RFV based pricing system was also described by Undersander (2000). When trading hay, Coppock (1997) purposed that buyers and sellers establish a standard RFV for a given hay type. Then traders assign a standard value for each RFV point. If the RFV for the hay traded is above or below the standard RFV, pricing can be adjusted by adding or subtracting value for each point. This strategy allows traders to more specifically buy or sell hay based on quality. Assigning monetary values to hays based on RFV points aids forage and livestock producers in establishing fair market values for feeds; especially when forage is placed in opened ended market categories of Supreme or Utility.

Importance and impact of feed analysis on trade is more acute when hays are valued based on RFV points. For trade purposes, it is impractical with inherit variation of forage composition and laboratory analyses to expect absolute precision in determination for a forage RFV. Established marketing categories may serve as reasonable guidelines for ranges of tolerance for RFV variation. Closed ended marketing categories for Premium, Good, and Fair have RFV ranges of 170-185, 150-170, and 130-150 or 15, 20, and 20

points. Undersander (2000), hypothetically, used a 20-point RFV tolerance to demonstrate a method for forage contracting.

Inter laboratory ranges for RFV observed in this study for IMG, PBLA, and PBDA were 270%, 275%, and 560%, respectively; greater than a 20 RFV point tolerance for RFV variation. Intra laboratory ranges for RFV were consistently closer to a 20 RFV point tolerance than inter laboratory ranges. RFV estimates within a 20 RFV point tolerance for IMG, PBLA, and PBDA were produced by 93%, 50%, and 21% of laboratories, respectively. Narrow ranges of RFV estimates, produced within individual laboratories, supports the assertion that traders should mutually agree upon analysis by the same laboratory to facilitate forage transactions.

When RFV ranges were analyzed, it was shown for IMG, PBLA, and PBDA that 0%, 21%, and 71% of laboratories produced RFV ranges with point spreads greater than 30 points within each forage type.

Dry Matter Determination

In general, water is the most unstable nutrient component contained in feeds. Water content in feeds can originate from growth processes that formed feed material. Since feeds are hygroscopic, water content in feeds may also come from the environment. Removal or subtraction of water content from feed allows DM content to be established for accurate ration balancing and facilitates grinding for further laboratory analysis.

Mean and standard deviation of DM% for the in-house laboratory (Tables 1 and 3) and 12 laboratories (Tables 2 and 4) are listed for each hay type.

Scatter plots of individual laboratory values, by hay type, are shown in Figures 4-6. Overall inter-laboratory range of DM was 91 to 100, 90 to 100, and 86 to 100, for IMG,

PBLA, and PBDA, respectively. DM determinations by in-house laboratory were 95 to 97, 94 to 96, and 95 to 97 for IMG, PBLA, and PBDA, respectively. Coefficients of variation for DM determined by commercial laboratories versus in-house laboratory for IMG, PBLA, and PBDA were 2.1 v 0.69, 2.7 v 0.72, and 3.3 v 0.84, respectively.

Prior to sending blind samples to each targeted laboratory, partial dry matter (PDM) was determined via forced air oven at 55ºC for 72 hours for each feed submission. Laboratories using accepted oven DM methods, destructive analytical processes, should produces DM results greater than initial PDM, since water or DM loss is expected from forage samples oven dried at temperatures equal to or greater than 100ºC. Laboratories using NIR systems, non-destructive processes, should produce DM results equal to initial PDM determination, since NIR systems analysis determine DM on samples unchanged without oven drying, except for grinding processes.

There were no significant differences ($P< 0.05$) between the PDM and the in-house PDM for the three hay types. Forty-five percent (n = 105) of samples had negative differences when laboratory DM% was subtracted from pre-submission PDM. Negative differences between LDM and pre-submission PDM indicated that samples gained water content after submission to laboratories. Conversely, positive differences are expected between PDM and standard oven DM% determinations, since water or DM loss is expected from forage samples oven-dried at temperatures greater than 55ºC.

LDM-PDM differences produced by arid western state (AWS) laboratories (CA, ID, UT, and WA) were compared to LDM-PDM differences produced by moist eastern state (MES) laboratories (LA, MA, NE, NY, SC, TN, and WI). Eastern laboratories were significantly higher ($P < .0001$) indicating that samples had absorbed water.

Mean CP percent analyses from AWS laboratories were compared to MES laboratories and found to be significantly lower (P = 0.005); 19.6% (n=108) compared to 20.1% (n=144). Greater CP results produced by MES laboratories are to be expected due to lower DM% values. Since CP determinations are adjusted to an DM basis, lower DM determinations produced by MES laboratories would result in larger CP values. In addition, ADF and NDF determinations from MES laboratories would similarly have larger values than AWS laboratories. Understandably, greater ADF, NDF or both components generated by MES laboratories would depress calculated values such as RFV, TDN, and NEL.

Characteristically high relative humidity in laboratory locations outside the AWS is the most likely reason for DM% being less than pre-submission DM%. Inaccurate oven dry matter determinations where samples are dried at temperatures higher than prescribed could also be a reason; although less likely. One laboratory from the southern US was an NIR laboratory that produced the greatest average differences between pre- and post-submission DM of -3.09 percentage points (n = 18); values ranged from 1.5 to -9.0 with a SD of 3.52. NIR forage analyses does not necessarily require drying of low moisture forage prior to analysis, however NIR analyses methods do require grinding of samples to particle sizes > 1mm. Grinding of samples increases forage particle surface area. In high humidity environments, simply grinding samples would significantly change original DM content of samples originating in dryer climates.

CP, ADF, and NDF determinations

By design, representative and distinctly different forages were selected for use in the blind ring test. Differences in CP, ADF, and NDF analyses between forages were

expected. There were differences in terms of precision between laboratories. Mean and standard deviation of CP% for the in-house laboratory (Tables 1 and 3) and 12 laboratories (Tables 2 and 4) are listed for each hay type. Scatter plots of individual laboratory values, by hay type, are shown in Figures 7-9. Overall inter-laboratory range of CP% was 8 to 15, 21 to 29, and 23 to 29, for IMG, PBLA, and PBDA, respectively. Determination of CP% by the in-house laboratory were 12 to 13, 23 to 24, and 26 to 27 for IMG, PBLA, and PBDA, respectively. Coefficients of variation for CP% determined by commercial laboratories versus in-house laboratory for IMG, PBLA, and PBDA were 10.9 v 4.2, 6.8 v 0.62, and 5.4 v 1.1, respectively.

Mean and standard deviation of ADF% for the in-house laboratory (Tables 1 and 3) and 12 laboratories (Tables 2 and 4) are listed for each hay type. Scatter plots of individual laboratory values, by hay type, are shown in Figures 10-12. Overall inter-laboratory range of ADF% was 26 to 42, 27 to 40, and 18 to 29, for IMG, PBLA, and PBDA, respectively. Determinations of ADF% by the in-house laboratory were 27.8 to 29.4, 29.4 to 33.1, and 19 to 21.6 for IMG, PBLA, and PBDA, respectively. Coefficients of variation for ADF% determined by commercial laboratories versus in-house laboratory for IMG, PBLA, and PBDA were 6.1 v 2.4, 6.4 v 1.9, and 11.9 v 5.1, respectively.

Mean and standard deviation of NDF% for the in-house laboratory (Tables 1 and 3) and 12 laboratories (Tables 2 and 4) are listed for each hay type. Scatter plots of individual laboratory values, by hay type, are shown in Figures 13-15. Overall inter-laboratory range of NDF% was 26 to 42, 27 to 40, and 18 to 29, for IMG, PBLA, and PBDA, respectively. Determinations of NDF% by the in-house laboratory were 45.4 to 48.1, 37 to 39.7, and 24.6 to 27.5 for IMG, PBLA, and PBDA, respectively. Coefficients

of variation for NDF% determined by commercial laboratories versus in-house laboratory for IMG, PBLA, and PBDA were 7.2 v 2.2, 8.6 v 2.3, and 13.5 v 4.2, respectively.

RFV is a product of ADF% and NDF% values, variations between laboratories can translate into large differences in RFV. Large variation in feed components, especially in RFV, would pose significant negative economic and production impact on forage users and producers in real-life situations. Design of this blind study confirm impacts of feed analysis. Had errant hay analyses been used in actual trade or production, adverse effects would have been experienced whether through under or overpriced feed or through under or over feeding.

Organizations which certify feed laboratory performance exist because inter-laboratory variation exist. However, there should be concern when inter-laboratory variation is not acknowledged as significant or when laboratory proficiency data is not considered in laboratory selection. A characteristic of this blind study was that all samples were submitted to commercial laboratories in the name of an actual company involved in forage trade. Participating laboratories had no knowledge that samples were unordinary. Samples analyzed were considered typical and received no special treatment or consideration. Therefore, analyses produced were being provided or released so that an end-user in society could make desired decisions. However, from a real-world perspective every errant hay analysis represented what could turn out to be real-world negative effects.

In-house laboratory analysis of all hay types was performed for nutrient analyses and compared with all other 12 laboratories. Means comparisons are shown for DM% (Table 5), CP (Table 6), ADF% (Table 7), NDF% (Table 8), RFV% (Table 9), NEL (Table 10)

and TDN% (Table 11). Significant differences were found between the in-house lab and some of the 12 laboratories for some hay types and some nutrients; especially DM%, NEL and TDN%. Even though many laboratories weren't different than the in-house laboratory, the range of means for an analysis that should have shown no differences suggests that there are problems in feed analysis.

The in-house analyses were completed after the feeding trial in chapter 6. In-house analysis was performed after the study to avoid introduction of bias that may come from awareness of in-house laboratory analyses and to better simulate real world ration formulation conditions.

There were significant within and between laboratory differences in analysis for almost all components. The in-house (control) laboratory analyses performed on IMG, PBLA, and PBDA forage types were essential to having a constructive and relevant study. Procedures were followed to minimize experimental error. It is stated on the National Forage Testing Association (NFTA, 2019) website that "many laboratories take shortcuts that can produce false results on some samples". Since, deviations from prescribed methods can lead to inaccurate analysis results, efforts were taken to use and perform NFTA recognized DM%, CP%, ADF%, and NDF% analysis methods with exactness. Some systematic errors were likely avoided because one person performed most analyses. In addition, all samples were analyzed under exact, uniform laboratory and seasonal conditions; likely preventing errors observed between commercial labs during this study. Control of experimental error by the in-house laboratory led to lower SD for all components and hay types analyzed, when compared to mean standard deviations observed in all commercial laboratories as shown in Table 3 and 4.

The feed components ADF% and NDF% are used to derive RFV. Herds that were significantly different from the in-house laboratory in RFV for IMG were also significantly different in ADF% and NDF% as would be expected. Similar differences were not seen in the PBLA and PBDA.

In addition, ADF% and NDF% can be used to derive calculated NEL and TDN in feeds. Analyses from the 12 commercial laboratories produced least squares means for NEL (Mcal/lb) values for IMG, PBLA, and PBDA with ranges 0.56 – 0.73, 0.58 – 0.68, 0.68 – 0.82, respectively (Table 10). Least square means for TDN% values produced by commercial labs for IMG, PBLA, and PBDA were 55.4 – 70.7, 56.8 – 67.2, 63.7 – 80.2, respectively (Table 11). There was little relationship between ADF% and NDF% and either energy calculation. The only differences were that almost all laboratories were different from the in-house energy values for the PBDA hay type. There were other differences with this hay suggesting that laboratories had a difficult time getting a correct analysis of alfalfa hay when it is of really high quality. Getting the analyses correct are essential to livestock producers for the creation of animal rations to manage animal performance and health.

CONCLUSIONS

There are many reasons for inter-laboratory variation in connection with forage analysis in the United States. However, it is apparent from data collected and analyzed in this study that change in sample dry matter content is a significant systematic error contributing to inter-laboratory variation. A cause of differences in forage analysis between commercial laboratories in the United States is likely ambient humidity. Levels

of ambient humidity maybe characteristic of a given US region, season of the year, immediate weather pattern, or indoor laboratory environment. Forage samples maybe expose by DM changes due to ambient humidity through permeable sample containers. However, more likely, forage samples are expose to ambient humid through errant laboratory practices, in-house internal laboratory environments, or internal laboratory environments that maintain humidity different from that of forage sample origination.

As livestock and crop producers seek to achieve greater production efficiently and maintain profitability despite greater resource cost and narrowing margins, judicious forage laboratory selection is important and will aid in reliable management decisions. When selecting a laboratory to perform forage analyses, patrons must not only consider laboratory certifications, but scrutinize laboratory local for differences in environmental conditions.

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Table 5.1. Means (range) of analyses from in-house laboratory (n = 6 samples) for selected forage analysis parameters.

	Mixed grass	Pre-bloom alfalfa	Pre-bud alfalfa
DM	96 (95 - 97)	95 (94 - 96)	96 (95 - 97)
CP	12.5 (12 – 13)	23.5 (23 - 24)	26.7 (26.3 - 27)
ADF	28.8(27.8 –29.4)	30.6 (29.4–31.1)	20 (19 – 21.6)
NDF	46.7 (45.4–48.1)	38.3 (37 – 39.7)	25.5 (24.6 – 27.5)
RFV	133 (128 - 138)	158 (152 - 166)	268 (244 - 280)

Table 5.2. Means (range) of analyses from 12 forage laboratories (n = 6 samples) for selected forage analysis parameters.

	Mixed grass	Pre-bloom alfalfa	Pre-bud alfalfa
DM	95.7 (91 - 100)[1]	94.3 (90 - 100)[1]	93.4 (86 - 100)[1]
CP	10.8 (8 - 15)	24.1 (21 - 29)	25.2 (23 - 29)
ADF	32.1 (26 - 42))[1]	33.4 (27 - 40)	22.0 (18 - 29)
NDF	50.7 (40 - 60)[1]	41.7 (35 - 54)	28.7 (24 - 40)[1]
RFV	118 (87 - 161)	141 (101 - 176)	237 (158 - 290)[1]

[1]Effect of laboratory was significant ($P<0.05$) within hay group.

Table 5.3. Standard deviations of analyses in-house laboratory (n = 6 samples) for selected forage analysis parameters.

	Mixed grass	Pre-bloom alfalfa	Pre-bud alfalfa
DM	0.66	0.68	0.80
CP	0.53	0.17	0.28
ADF	0.69	0.59	1.02
NDF	1.01	0.87	1.07
RFV	3.8	4.6	13.0

Table 5.4. Standard deviations (range) of analyses from 12 forage laboratories (n = 6 samples) for selected forage analysis parameters.

	Mixed grass	Pre-bloom alfalfa	Pre-bud alfalfa
DM	0.73 (0.4 - 1.3)	1.2 (0.4 - 1.8)	1.8 (0.5 - 3.8)
CP	0.58 (0.3 - 1.6)	0.93 (0.2 - 2.9)	0.64 (0.3 - 1.7)
ADF	0.96 (0.5 - 2.8)	1.57 (0.5 - 3.1)	1.32 (0.4 - 3.1)
NDF	1.54 (0.2 - 3.2)	1.93 (0.4 - 4.4)	1.89 (0.6 - 5.3)
RFV	4.95 (0.8 - 14)	9.15 (1.8 - 16)	17.8 (6 - 37)

Table 5.5. Least squares means for DM% and significant differences (P< 0.05) between labs and the in-house control wet chemistry value (Lab 4).

Immature grass hay			Alfalfa, pre-bloom			Alfalfa, pre-bud		
Lab	LSM	P<0.05	Lab	LSM	P<0.05	Lab	LSM	P<0.05
12	100.0	**X**	12	100.0	**X**	12	100.0	**X**
6	98.0	**X**	10	97.5	**X**	13	96.1	NS
10	97.8	**X**	11	96.1	**X**	10	95.1	NS
2	96.4	NS	13	95.4	**X**	6	94.9	NS
13	96.2	NS	9	95.0	NS	14	94.9	NS
9	96.1	NS	6	94.9	NS	2	94.3	NS
11	96.0	NS	2	94.9	NS	9	94.1	NS
1	95.8	NS	3	94.7	NS	11	93.4	NS
3	95.7	NS	1	94.1	NS	1	93.1	NS
8	95.7	NS	14	94.0	NS	3	92.6	NS
4	95.7	NS	5	93.2	NS	5	92.6	NS
5	95.4	NS	**4**	92.9	NS	**4**	92.6	NS
14	93.8	**X**	8	92.6	NS	7	91.0	NS
7	91.5	**X**	7	90.8	NS	8	89.3	NS

Table 5.6. Least squares means for CP% and significant differences (P< 0.05) between labs and the in-house control wet chemistry value (Lab 4).

Immature grass hay			Alfalfa, pre-bloom			Alfalfa, pre-bud		
Lab	LSM	P<0.05	Lab	LSM	P<0.05	Lab	LSM	P<0.05
12	13.6	**X**	9	26.3	NS	9	28.1	**X**
13	12.5	**X**	11	24.9	NS	13	26.7	**X**
7	11.5	NS	1	24.8	NS	14	25.8	NS
1	11.4	NS	14	24.7	NS	8	25.7	NS
11	11.1	NS	**4**	24.2	NS	1	25.5	NS
9	11.0	NS	7	24.1	NS	7	25.4	NS
8	10.7	NS	5	23.7	NS	**4**	25.2	NS
10	10.5	NS	8	23.6	NS	11	25.1	NS
2	10.4	NS	13	23.5	NS	5	24.6	NS
3	10.4	NS	3	23.1	NS	6	24.5	NS
4	10.2	NS	12	22.9	NS	3	24.3	NS
5	9.9	NS	10	22.7	NS	10	24.1	NS
6	9.8	NS	6	22.6	NS	2	24.1	NS
14	8.6	**X**	2	22.1	NS	12	23.4	**X**

Table 5.7. Least squares means for ADF% and significant differences (P< 0.05) between labs and the in-house control wet chemistry value (Lab 4).

Immature grass hay			Alfalfa, pre-bloom			Alfalfa, pre-bud		
Lab	LSM	P<0.05	Lab	LSM	P<0.05	Lab	LSM	P<0.05
14	41.3	**X**	12	35.6	NS	12	28.0	**X**
6	33.3	NS	3	34.8	NS	2	23.5	NS
5	33.2	NS	5	34.6	NS	5	23.3	NS
2	32.5	NS	11	34.3	NS	**4**	23.2	NS
3	32.5	NS	2	34.2	NS	7	22.5	NS
11	32.4	NS	**4**	33.9	NS	11	22.3	NS
7	32.3	NS	6	33.9	NS	10	21.7	NS
4	31.7	NS	14	33.7	NS	1	21.6	NS
10	31.7	NS	7	33.6	NS	6	21.3	NS
1	31.2	NS	10	33.3	NS	14	21.1	NS
9	30.7	NS	1	32.7	NS	3	20.3	NS
13	28.8	**X**	8	31.6	NS	13	20.0	**X**
12	28.8	**X**	9	31.0	NS	9	19.7	**X**
8	28.4	**X**	13	30.6	NS	8	19.3	**X**

Table 5.8. Least squares means for NDF% and significant differences (P< 0.05) between labs and the in-house control wet chemistry value (Lab 4).

Immature grass hay			Alfalfa, pre-bloom			Alfalfa, pre-bud		
Lab	LSM	P<0.05	Lab	LSM	P<0.05	Lab	LSM	P<0.05
14	59.6	**X**	12	49.5	**X**	12	37.5	**X**
7	57.7	**X**	7	46.0	**X**	7	34.4	**X**
11	52.6	NS	6	42.7	NS	5	29.4	NS
5	52.2	NS	14	42.0	NS	**4**	28.9	NS
3	51.3	NS	5	42.0	NS	11	28.6	NS
9	51.0	NS	3	41.9	NS	2	28.3	NS
4	50.2	NS	11	41.4	NS	6	28.1	NS
10	49.7	NS	2	41.3	NS	10	27.4	NS
6	49.7	NS	**4**	40.6	NS	1	27.2	NS
2	49.6	NS	10	40.5	NS	9	27.1	NS
8	48.0	NS	1	39.8	NS	3	26.7	NS
1	47.4	NS	8	39.4	NS	14	26.7	NS
13	46.7	**X**	9	39.1	NS	8	26.2	NS
12	43.8	**X**	13	38.3	NS	13	25.5	NS

Table 5.9. Least squares means for RFV% and significant differences (P< 0.05) between labs and the in-house control wet chemistry value (Lab 4).

Immature grass hay			Alfalfa, pre-bloom			Alfalfa, pre-bud		
Lab	LSM	P<0.05	Lab	LSM	P<0.05	Lab	LSM	P<0.05
12	142.2	**X**	13	158.0	NS	13	268.2	NS
13	132.6	**X**	9	155.0	NS	8	262.3	NS
8	129.5	**X**	8	152.0	NS	3	254.5	NS
1	126.8	NS	1	149.7	NS	9	253.0	NS
10	120.0	NS	10	144.7	NS	14	252.8	NS
2	119.4	NS	**4**	143.3	NS	1	250.3	NS
4	118.9	NS	2	140.7	NS	10	246.0	NS
9	118.5	NS	11	140.5	NS	6	241.3	NS
6	118.0	NS	14	138.8	NS	11	233.5	NS
3	115.3	NS	3	137.5	NS	2	232.8	NS
5	112.7	NS	5	137.5	NS	**4**	229.3	NS
11	112.7	NS	6	136.7	NS	5	224.7	NS
7	102.5	**X**	7	128.0	NS	7	197.8	NS
14	88.3	**X**	12	115.3	**X**	12	166.7	**X**

Table 5.10. Least squares means for NEL (Mcal/lb) and significant differences (P< 0.05) between labs and the in-house control wet chemistry value (Lab 4).

Immature grass hay			Alfalfa, pre-bloom			Alfalfa, pre-bud		
Lab	LSM	P<0.05	Lab	LSM	P<0.05	Lab	LSM	P<0.05
8	0.73	**X**	13	0.68	**X**	8	0.82	**X**
13	0.72	**X**	8	0.67	NS	13	0.81	**X**
10	0.67	NS	10	0.65	NS	6	0.80	**X**
6	0.67	NS	14	0.65	NS	14	0.79	**X**
4	0.66	NS	**4**	0.64	NS	10	0.79	**X**
12	0.66	NS	6	0.64	NS	11	0.77	NS
11	0.65	NS	12	0.64	NS	2	0.75	NS
2	0.65	NS	2	0.63	NS	**4**	0.74	NS
3	0.64	NS	11	0.62	NS	12	0.70	**X**
1	0.63	**X**	5	0.62	NS	5	0.69	**X**
5	0.57	**X**	1	0.59	**X**	1	0.69	**X**
14	0.56	**X**	3	0.58	**X**	3	0.68	**X**

Table 5.11. Least squares means for TDN% and significant differences (P< 0.05) between labs and the in-house control wet chemistry value (Lab 4).

Immature grass hay			Alfalfa, pre-bloom			Alfalfa, pre-bud		
Lab	LSM	P<0.05	Lab	LSM	P<0.05	Lab	LSM	P<0.05
8	70.7	**X**	9	67.2	**X**	9	80.2	**X**
13	69.7	**X**	13	66.0	NS	8	78.0	**X**
9	67.3	**X**	8	64.9	NS	13	77.3	**X**
11	65.6	**X**	10	63.1	NS	6	76.6	**X**
10	64.8	NS	11	62.9	NS	14	76.1	**X**
6	64.5	NS	14	62.6	NS	10	75.5	**X**
4	64.2	NS	6	62.5	NS	7	74.7	**X**
12	64.2	NS	**4**	62.5	NS	**4**	70.8	NS
2	62.9	NS	12	62.3	NS	11	70.7	NS
3	62.0	NS	7	60.9	NS	12	68.3	NS
1	61.4	NS	2	60.7	NS	1	67.0	**X**
7	61.0	X	5	59.5	NS	3	65.9	**X**
5	58.3	**X**	1	58.2	**X**	2	65.3	**X**
14	55.4	**X**	3	56.8	**X**	5	63.7	**X**

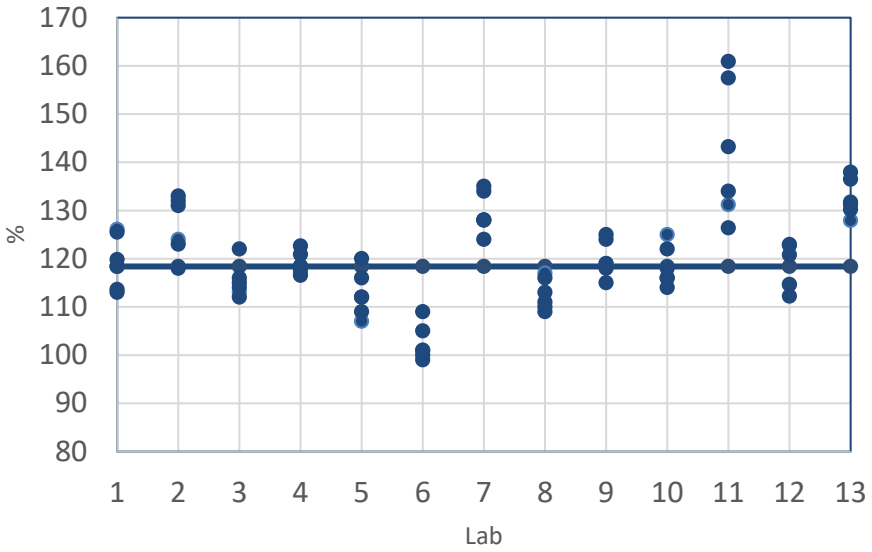

Figure 5.1. Scatter plot of individual relative feed values (RFV%; n=6) for immature grass hay, by laboratory during a blind ring test. Laboratory 13 was an in-house laboratory that used wet chemistry methods. The solid line is the overall mean of all samples. The forage was submitted in duplicate, three times, to each laboratory at irregular intervals during a 6-month period.

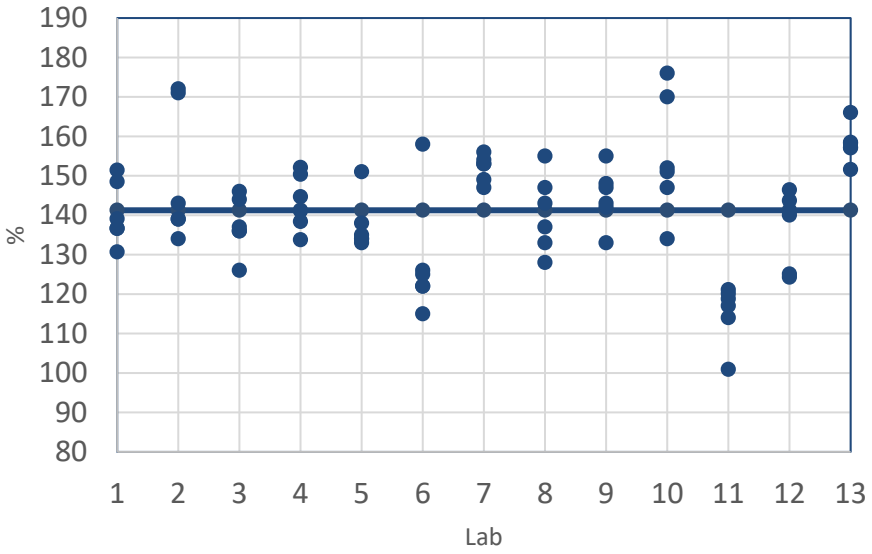

Figure 5.2. Scatter plot of individual relative feed values (RFV%; n=6) for pre-bloom alfalfa hay, by laboratory during a blind ring test. Laboratory 13 was an in-house laboratory that used wet chemistry methods. The solid line is the overall mean of all samples. The forage was submitted in duplicate, three times, to each laboratory at irregular intervals during a 6-month period.

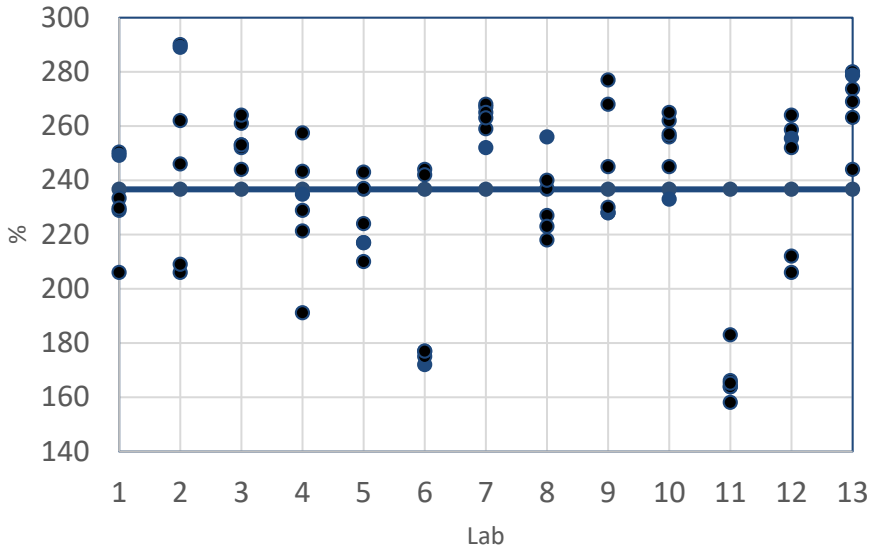

Figure 5.3. Scatter plot of individual relative feed values (RFV%; n=6) for pre-bud alfalfa hay, by laboratory during a blind ring test. Laboratory 13 was an in-house laboratory that used wet chemistry methods. The solid line is the overall mean of all samples. The forage was submitted in duplicate, three times, to each laboratory at irregular intervals during a 6-month period.

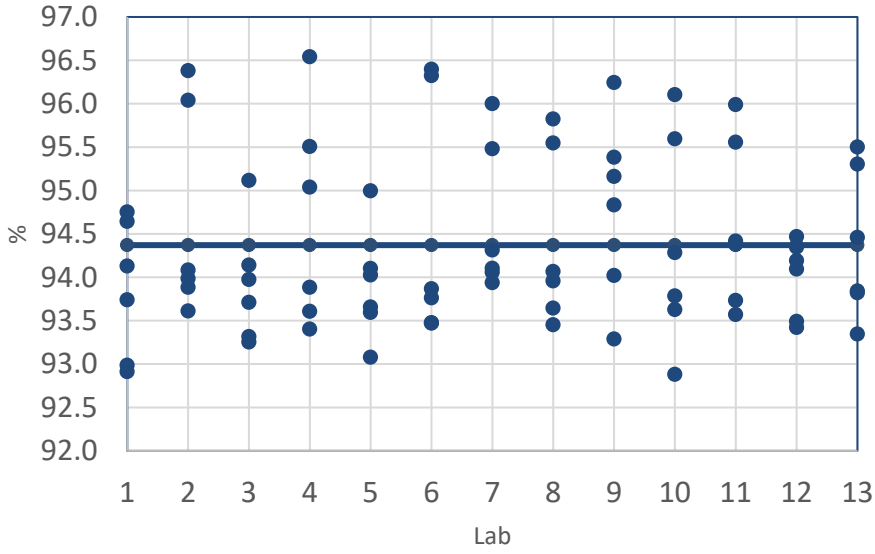

Figure 5.4. Scatter plot of individual dry matter (DM%; n=6) values for immature grass hay, by laboratory during a blind ring test. Laboratory 13 was an in-house laboratory that used wet chemistry methods. The solid line is the overall mean of all samples. The forage was submitted in duplicate, three times, to each laboratory at irregular intervals during a 6-month period.

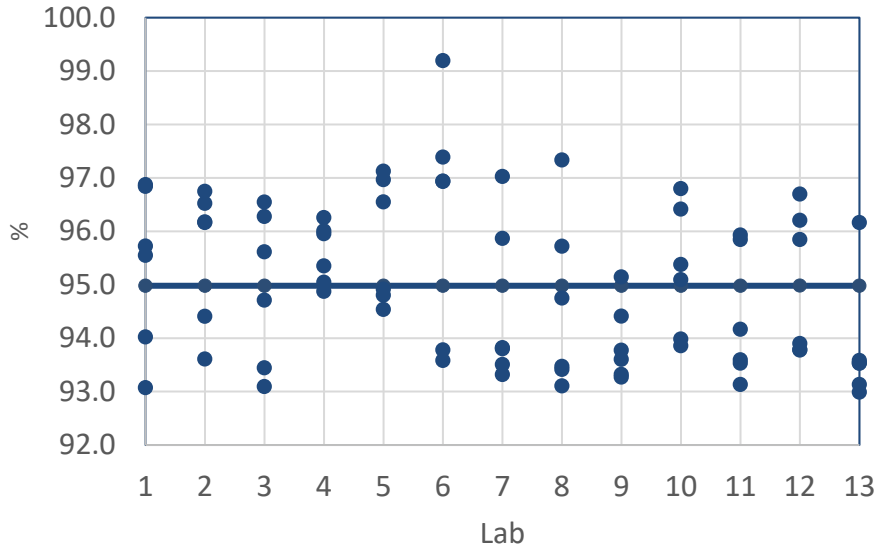

Figure 5.5. Scatter plot of individual dry matter (DM%; n=6) values for pre-bloom alfalfa hay, by laboratory during a blind ring test. Laboratory 13 was an in-house laboratory that used wet chemistry methods. The solid line is the overall mean of all samples. The forage was submitted in duplicate, three times, to each laboratory at irregular intervals during a 6-month period.

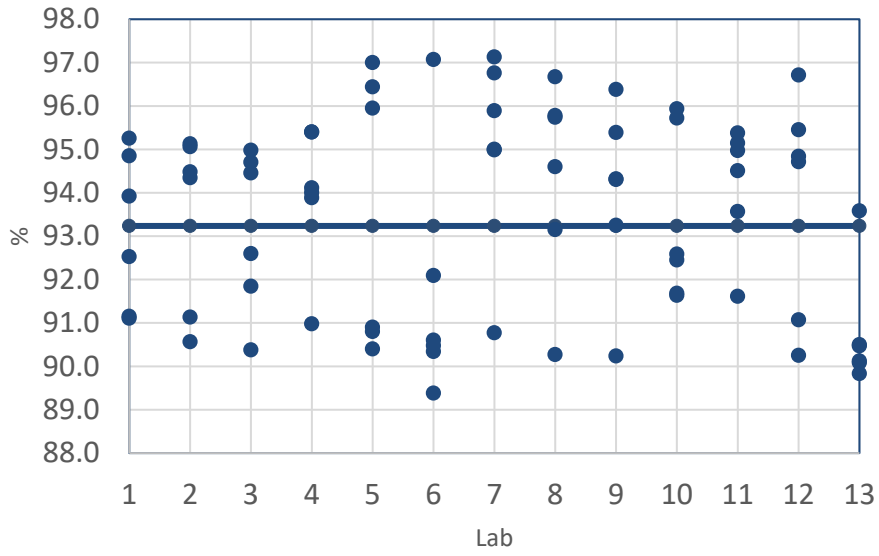

Figure 5.6. Scatter plot of individual dry matter (DM%; n=6) values for pre-bud alfalfa hay, by laboratory during a blind ring test. Laboratory 13 was an in-house laboratory that used wet chemistry methods. The solid line is the overall mean of all samples. The forage was submitted in duplicate, three times, to each laboratory at irregular intervals during a 6-month period.

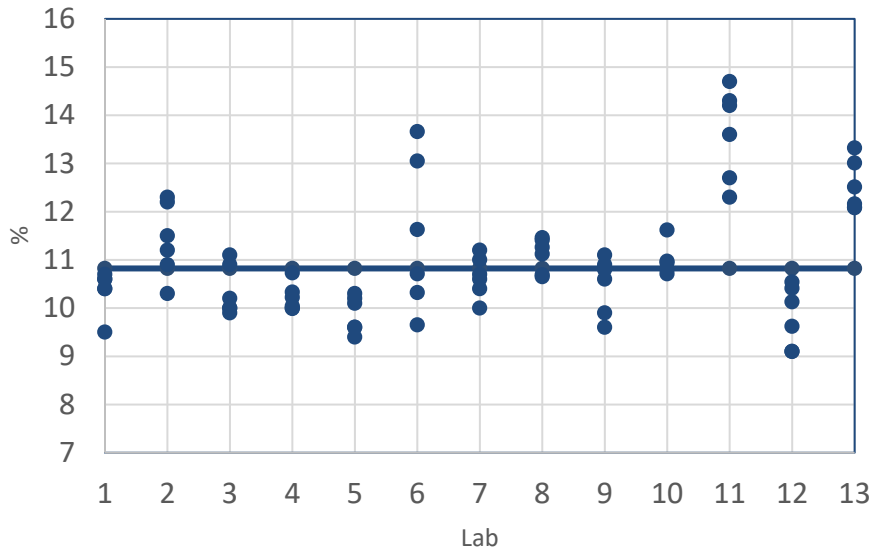

Figure 5.7. Scatter plot of individual crude protein (CP%; n=6) values for immature grass hay, by laboratory during a blind ring test. Laboratory 13 was an in-house laboratory that used wet chemistry methods. The solid line is the overall mean of all samples. The forage was submitted in duplicate, three times, to each laboratory at irregular intervals during a 6-month period.

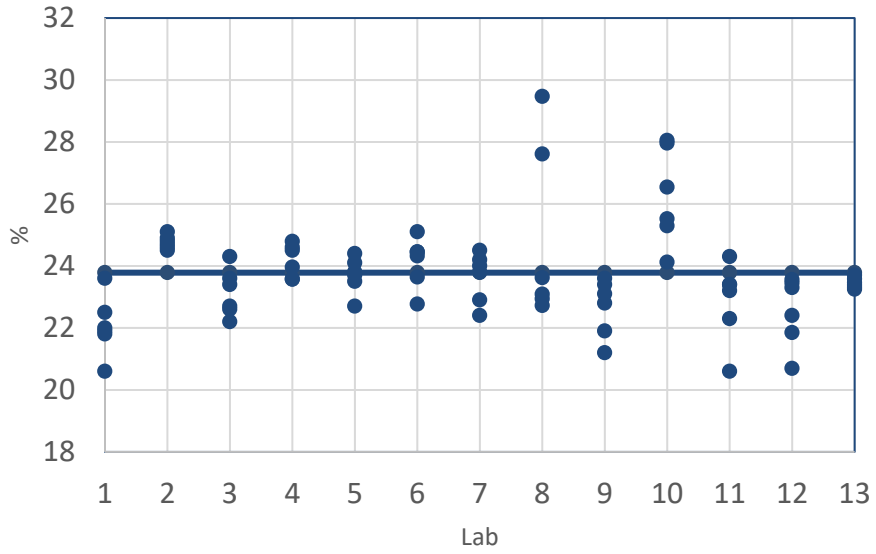

Figure 5.8. Scatter plot of individual crude protein (CP%; n=6) values for pre-bloom alfalfa hay, by laboratory during a blind ring test. Laboratory 13 was an in-house laboratory that used wet chemistry methods. The solid line is the overall mean of all samples. The forage was submitted in duplicate, three times, to each laboratory at irregular intervals during a 6-month period.

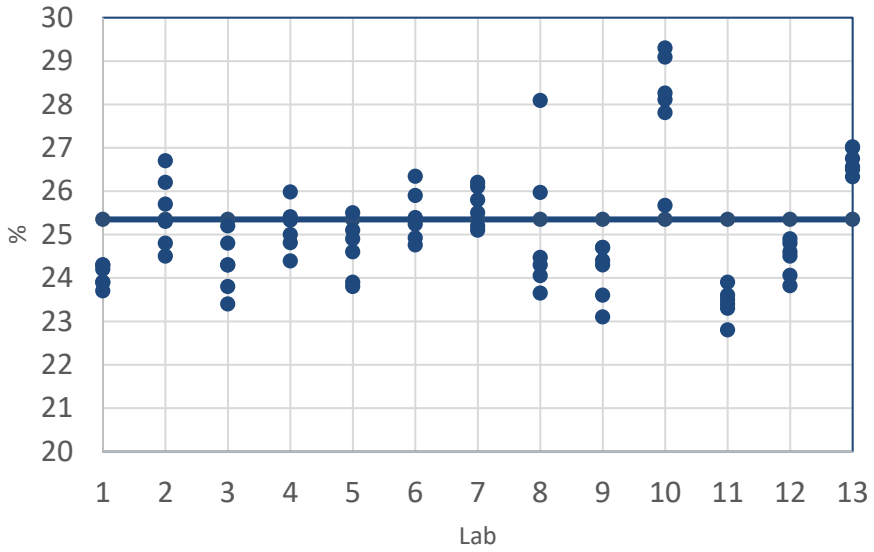

Figure 5.9. Scatter plot of individual crude protein (CP%; n=6) values for pre-bud alfalfa hay, by laboratory during a blind ring test. Laboratory 13 was an in-house laboratory that used wet chemistry methods. The solid line is the overall mean of all samples. The forage was submitted in duplicate, three times, to each laboratory at irregular intervals during a 6-month period.

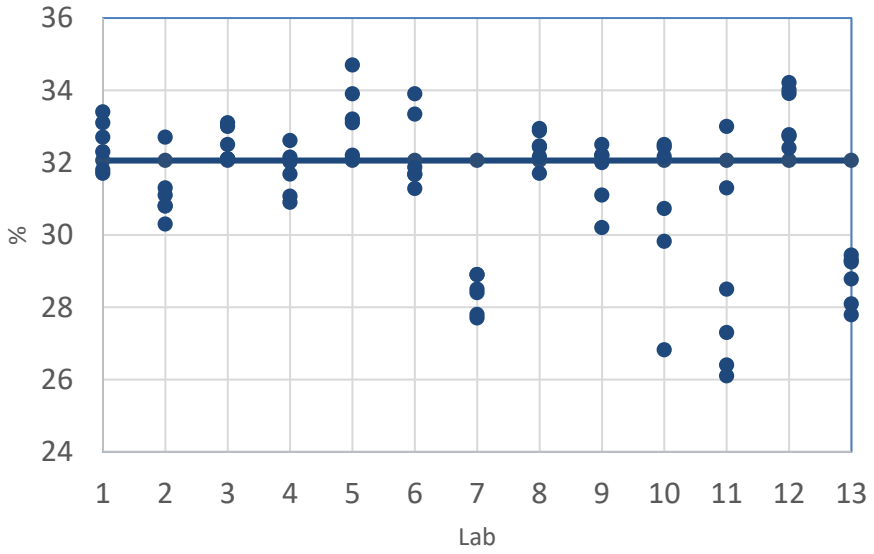

Figure 5.10. Scatter plot of individual acid detergent fiber (ADF%; n=6) values for immature grass hay, by laboratory during a blind ring test. Laboratory 13 was an in-house laboratory that used wet chemistry methods. The solid line is the overall mean of all samples. The forage was submitted in duplicate, three times, to each laboratory at irregular intervals during a 6-month period.

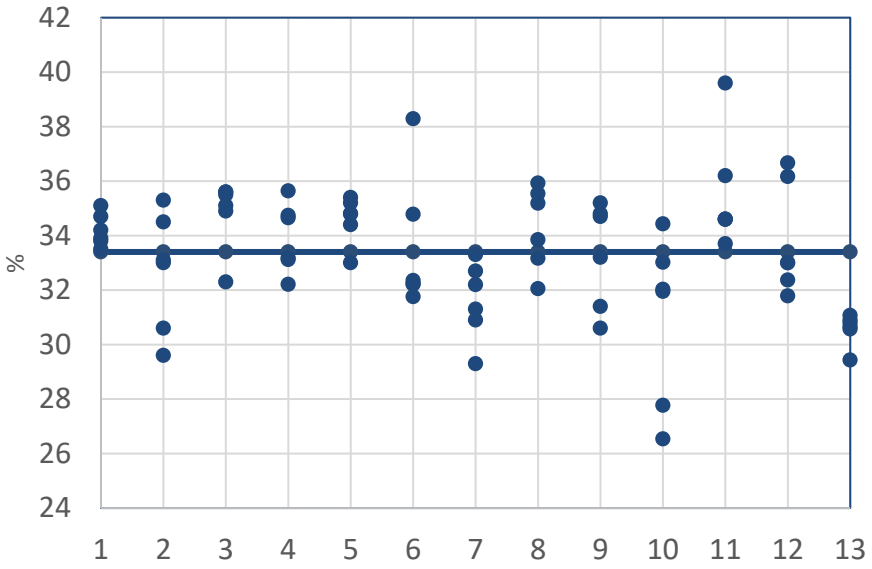

Figure 5.11. Scatter plot of individual acid detergent fiber (ADF%; n=6) values for pre-bloom alfalfa hay, by laboratory during a blind ring test. Laboratory 13 was an in-house laboratory that used wet chemistry methods. The solid line is the overall mean of all samples. The forage was submitted in duplicate, three times, to each laboratory at irregular intervals during a 6-month period.

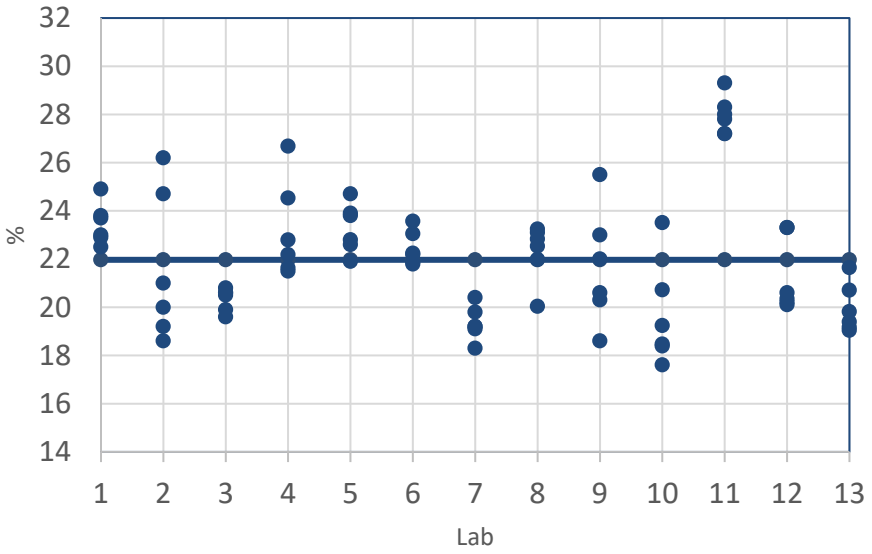

Figure 5.12. Scatter plot of individual acid detergent fiber (ADF%; n=6) values for pre-bud alfalfa hay, by laboratory during a blind ring test. Laboratory 13 was an in-house laboratory that used wet chemistry methods. The solid line is the overall mean of all samples. The forage was submitted in duplicate, three times, to each laboratory at irregular intervals during a 6-month period.

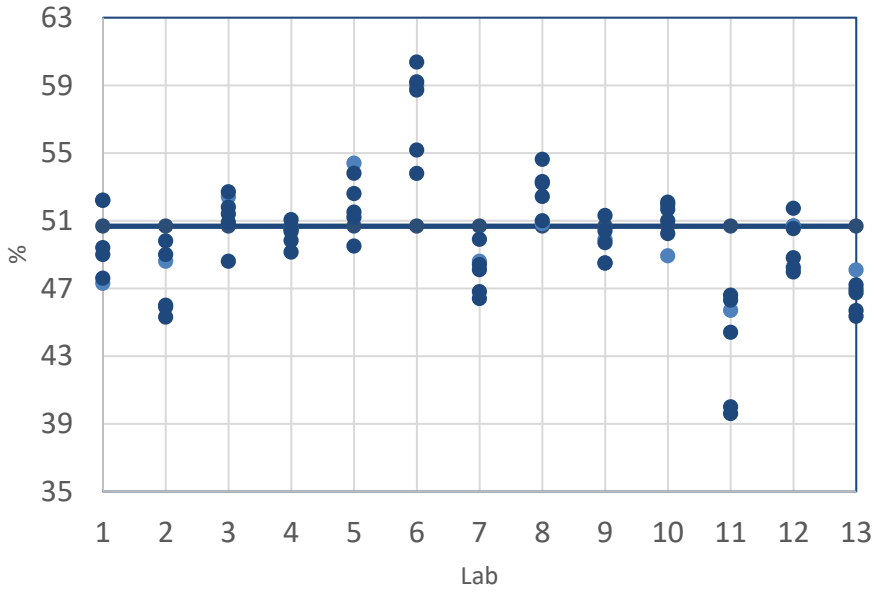

Figure 5.13. Scatter plot of individual neutral detergent fiber (NDF%; n=6) values for immature grass hay, by laboratory during a blind ring test. Laboratory 13 was an in-house laboratory that used wet chemistry methods. The solid line is the overall mean of all samples. The forage was submitted in duplicate, three times, to each laboratory at irregular intervals during a 6-month period.

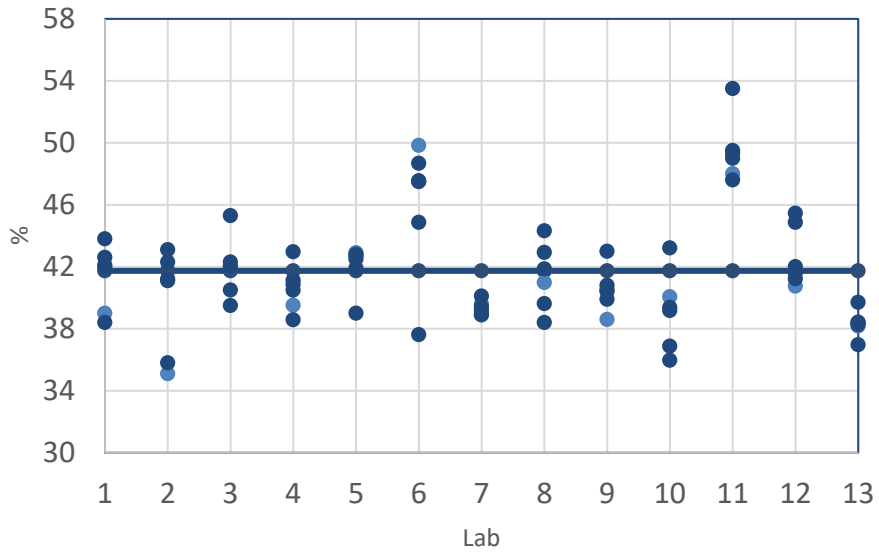

Figure 5.14. Scatter plot of individual neutral detergent fiber (NDF%; n=6) values for pre-bloom alfalfa hay, by laboratory during a blind ring test. Laboratory 13 was an in-house laboratory that used wet chemistry methods. The solid line is the overall mean of all samples. The forage was submitted in duplicate, three times, to each laboratory at irregular intervals during a 6-month period.

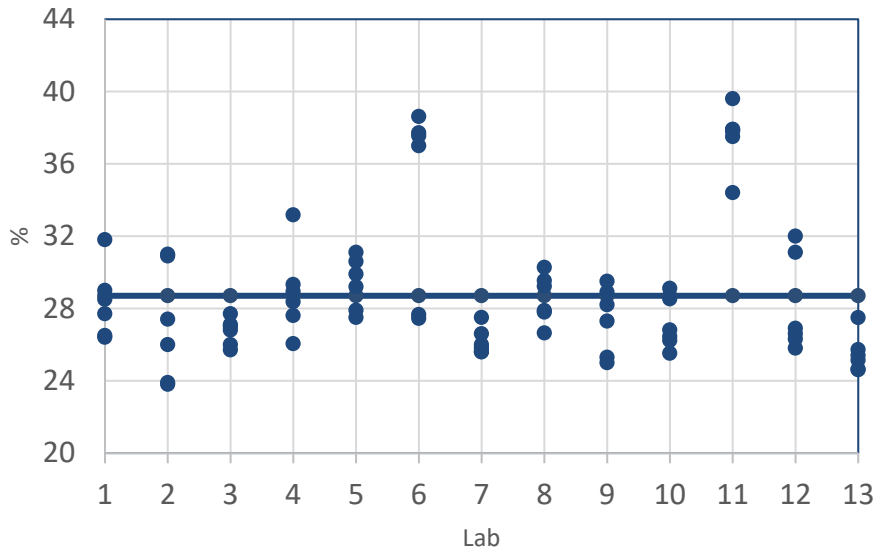

Figure 5.15. Scatter plot of individual neutral detergent fiber (NDF%; n=6) values for pre-bud alfalfa hay, by laboratory during a blind ring test. Laboratory 13 was an in-house laboratory that used wet chemistry methods. The solid line is the overall mean of all samples. The forage was submitted in duplicate, three times, to each laboratory at irregular intervals during a 6-month period.

CHAPTER 6

IMPACT OF INACCURATE OR VARIABLE FEED ANALYSES, PERFORMED BY COMMERCIAL LABORATORIES, ON THE EFFICIENCY AND PROFITABILITY OF STOCKER/BACKGROUND CATTLE PRODUCTION

ABSTRACT

Laboratory analysis of animal feed is vital to progressive and efficient feed management. Many U.S. livestock producers rely on commercial laboratories for feed analyses. In a 2-treatment feeding trial, impacts of laboratory accuracy and variation on stocker cattle production were studied. Identical grass hay samples were submitted blind to 12 U.S. commercial feed laboratories in duplicate 3 times. Laboratories were located in 8 of 9 U.S. regions. Feed analyses were significantly different between laboratories for samples submitted. Over all means, standard deviations, and ranges for DM, CP, ADF, and NDF analyses produced by laboratories were: 96.2, 2.1, 90.9 - 99.6; 10.86, 1.18, 9.1-14.7; 31.6, 1.91, 26-34.7; and 50.26, 3.62, 39.6-60.4, respectively. Means, standard deviations, and ranges for RFV and TDN were: 119.7, 10.9, 99-161 and 63.9, 3.43, and 56-72, respectively. A total mean TDN of 63.9 with a SD of 3.43 was calculated from 72 TDN values provided by all 12 feed laboratories included in the blind ring test, for the grass hay. TDN values provided by laboratories that were above or below one standard deviation from the total TDN mean for all laboratories in the ring test were used to classify laboratories as either high or low testing. Feed components were averaged for high and low testing laboratories, respectively. Two isonitrogenous and isocaloric rations (treatments) were formulated to achieve an ADG of 0.91 kg 2 lbs. /d and DMI of 2.41%

BW for 208.7 kg 460 lb. Angus/Gelbvieh crossbred steers. Treatments 1 and 2 were based on high and low average component test results supplied by laboratories, respectively. Each treatment was assigned 8 steers that were fed for 60 days. During the 60-day trial DMI as percent BW exceeded the 2.4% established for both treatments with mean DMI % BW of 3.26% and 3.30% for Treatment 1 and Treatment 2, respectively. Steers in both treatment groups experienced gains that exceeded average target weight of 300 kg 660lbs by an average of 27.2 kg 60 and 19.1 kg 42 lb., respectively. Steers in treatment 1 had an ADG of 1.68 kg 3.7 lbs. for an average ending live weight of 326.6 kg720 lbs. Steers in treatment 2 had an ADG of 1.53 kg 3.37 lbs. for average live weight of 318.4 kg 702. CP, ADF, NDF, and TDN determinations by laboratories met or exceeded in-house laboratory analyses in 14%, 15%, 19%, and 11% of commercial analyses, respectively. Steers in Treatments 1 and 2 were over supplemented and daily feed cost were 33% and 16% greater than needed to achieve 0.91 kg 2 lb. ADG production target.

INTRODUCTION

Laboratory analysis of animal feed is the foundation of progressive and efficient feed management. Through laboratory analysis livestock producers can obtain nutrient composition such as: protein, fiber, fat, minerals and vitamins, etc. Knowing nutrient content of feeds facilitates efficient management so that nutritional requirements of livestock are satisfied, and resources conserved. Feed analysis provides producers with nutritional information needed to improve animal health (Da Silva, 2013), reproduction (Campanile et al., 2010), and profitability (Gizzi and Givens, 2004).

Progressive feed management pursues specific targets by which livestock producers meet production, health, and marketing objectives. These objectives often require that animals are fed within narrow nutritional parameters such as in the case of transition dairy cows (Drackley and Dann, 2008) or in development of replacement heifers. Adding minimal weight to beef calves in preparation for pasture is another instance where feeding within parameters is important for optimum production and profits (Rush, 1994). It has been shown that precision feeding can reduce feed cost, improve herd health, reduce pollution, and conserve resources (Klopfenstein et al., 2002; Tedeschi et al., 2006; Sova et al., 2014).

A correct description of the nutrient composition of ingredients in the ration is required for effective feed management (James and Cox 2008). However, Mueller-Harvey (2004) described large variations in feed analysis results between feed laboratories in Europe. McCabe (2008) reported that forage producers and consumers have suspected accuracy problems among feed laboratories “for years”. McCabe also reported results of a University of Nebraska blind comparison study conducted on ten

feed labs based in Colorado, Illinois, Nebraska, New York, Missouri, and Wisconsin. The results of the blind study showed significant variations between laboratories for protein and other feed components. In a similar study, 21 labs were given blind samples and "less than half of the labs produced consistent results" (Holin, 2008).

Peer-reviewed research into accuracy problems among United States feed laboratories has been limited. However, Hristov et.al. (2010), conducted an open study of 10 commercial and 4 research feed laboratories. He found that significant variations in protein and fiber analysis occurred between the laboratories in the study. Cromwell (1999) reported significant variability in the analysis of corn and soybean meal components. In a blind study (unpublished data) submitted three forages to 12 different feed laboratories in the United States. Each forage type was submitted to each feed laboratory 6 times. Forages submitted to feed laboratories consisted of high relative feed value alfalfa hay, moderate relative feed value alfalfa hay and grass hay. Feed analysis for each forage type was significantly different between laboratories and large variations were observed within labs for each forage type.

Evidence of accuracy and precision problems among U.S. feed laboratories has been documented in trade and professional publications and through a recent blind study. Inaccurate feed analysis performed by commercial laboratories in the United States could be costing both feed and livestock producers in terms of over or under priced feed, in lost production and wasted resources. This study focused on the impact of variation of feed analysis on the production of stocker steers.

The objectives of this study were to: a) determine the effects of forage analysis variability on steer growth; and b) determine the impact of forage analysis variability on feed costs.

MATERIALS AND METHODS

The study was conducted at the Brigham Young University-Idaho Livestock Center in Rexburg, Idaho. Animal handling procedures for this study were approved by the Brigham Young University-Idaho Institutional Animal Care and Use Committee.

Forage Analysis Selection. Mixed grass hay samples were prepared and submitted to feed laboratories. Feed laboratories selected for this study were operated by universities (n=4) and by commercial entities (n = 8) and most frequently used by trade organization members (unpublished data). Near infrared analysis was used by 4 labs and wet chemical methods were used by 8 labs.

The grass hay was from a single source and comprised of several of grass species: Orchard grass (Dactylis glomerata), Smooth brome (Bromus biebersteinii), Kentucky bluegrass (*Poa annua*), and Tall fescue (Festuca arundinacea).

Two blind grass hay samples were submitted to each of the 12 laboratories 3 times, totaling 6 replications. Feed analysis results for blind grass hay samples were compiled into an Excel spreadsheet for analysis.

Ration formulation. TDN describes feed quality and theoretically includes a broad range of feed components in its calculation and is commonly used to formulate beef rations. TDN was used to determine which laboratories produced high or low feed analyses. The overall mean TDN was calculated for all grass submissions (n= 72) and was 63.9%. TDN values that were above or below one standard deviation from the mean for all laboratories were used to classify laboratories as high or low. Feed component analysis results from high testing laboratories were averaged and feed analysis results from low testing laboratories were averaged separately (Table 1).

Based on grass hay analysis for either low or high laboratories, two isonitrogenous and isocaloric rations were formulated using TAURUS Beef Cattle Ration Formulation and Evaluation Software (Oltjen and Ahmadi, 2006) (Table 2). The low ration (Treatment 1) was formulated based on means from 3 laboratories (n = 18 samples) that produced TDN values one standard deviation below (TDN = 60.5%) (Table2). This ration required that each steer be supplemented with 2.1 kg/d of shelled corn (DM basis) to meet energy requirements for ADG of 0.91 kg/d. The high ration (Treatment 2) was formulated based on analyses from 2 laboratories (n = 12 samples) that produced TDN values one standard deviation above the mean (TDN = 67.3%) (Table 2). This ration required that each steer be supplemented with 0.7 kg/d of shelled corn (DM basis) to meet energy requirements for ADG of 0.91 kg/d.

In-house laboratory analysis of grass hay was performed after completion of the feeding trial to avoid introducing bias that may come from being conscious of in-house laboratory analyses and to better simulate real world ration formulation conditions. At completion of the feeding experiment both rations and grass hay (n = 6 samples) were analyzed for DM, CP, ADF, and NDF by the in-house laboratory using forage analyses procedures described by Undersander (1993). In-house laboratory TDN and NE_L for rations were calculated using Penn State equations: $NE_L = 1.044 – (0.0119*ADF)$ and $TDN= 4.898 + (89.796*NE_L)$ (Rogers et al., 2014). Feed energy values (NE_M and NE_G) were determined using University of Florida feed energy calculator (RCREC, 2009).

Livestock preparation and facilities. Sixteen Angus/Gelbvieh crossbred steers were obtained from a single-source private producer and housed at the Brigham Young University – Idaho Livestock Center beginning March 15, 2014. Each steer was

individually weighted, fitted with radio frequency identification (RFID) button ear tag, and an Allflex ear tag for visual identification. Both identification tags were attached to the left ear of each animal. In addition, each steer was administered 7-way clostridial vaccine (Ultrabac-7, Pfizer Animal Health) and vaccinated against bovine respiratory disease complex (bovine respiratory syncytial virus, infectious bovine rhinotracheitis, bovine viral diarrhea, and parainfluenza 3) with Bovi-Shield Gold 5 (Pfizer Animal Health, Exton, PA) and treated for internal and external parasites with Ivomec-Plus (Merial Animal Health, Duluth, GA). All animals received a 2 mL booster of 7-way, 37 days after the initial vaccination.

All steers were housed in a 39 x 9.8 m open-front-cattle shed that was divided into 8 pens; open to the south. Each pen provided 4.9 x 19.5 m of under-roof and 4.9 x 19.5 m of uncovered pen space. Each pen had automatic waters and a single GrowSafe feed bunk.

Steers were stratified by weight and randomly assigned by weight into pens within 4 weight blocks. Two steers were place in each pen. All steers were acclimated to feeding facilities and adapted to the GrowSafe automated feeding system (GrowSafe Systems Ltd., Airdrie, Alberta, Canada) for 10 days. Pre-study, all steers were fed oat-alfalfa mixed hay and trace mineral salt was made available ad libitum.

Main Feeding Trial. During a 23-day acclimation period sixteen steers, ranging from 169 kg to 228 kg were fed an alfalfa-oat hay mix. Then the sixteen steers ranging from 185 kg to 244 kg were stratified according to weight and then randomly assigned to one of two treatments. Each group of steers was randomly assigned to one of the two rations. Both groups were fed the rations for 60 d using the Grow Safe Feeding System.

Daily intake, time feeding, number of times entering bunk space, and feed consumed during each meal were measured. All steers were individually weighed on two consecutive days beginning on day 1, 15, 32; 46, and 59 of the study.

After the 60th day of the feeding study, body composition of each steer was measured via ultrasound by Snake River Bull Test, LLC of Twin Falls, Idaho. Ultrasound measurements were taken indoors, and animal were restrained using a squeeze chute. Body components measured or calculated were ribeye area per 100 pounds (REA/CWT), ribeye area (REA), percent intramuscular fat (IMF), rib fat thickness (RFT), rump fat thickness (RFT), and calculated percent yield grade (CPYG). Digital photos were taken of each steer at the end of the feeding study. Photos of each steer were judged and assigned BCS by each of 25 trained USU Animal Science students. Statistical analyses were performed on ultrasound and BCS measurements to determine the impacts of the two rations on steer growth and cost of growth.

RESULTS AND DISCUSSION

Phase I

Laboratory Sample Submission. Mean chemical analyses for components above and below one STD for mixed grass hay are given in Table 1 along with results of in-house analyses. As hypothesized, there were clear differences in grass hay component analyses between high and low testing laboratories (Table 1). In planning the study, it was thought that in-house laboratory analyses would fall within SD margins. Unexpectedly, the results produced by the in-house laboratory indicated greater CP and energy than observed in analyses produced by most commercial laboratories.

Feeding Trial. To achieve an ADG of 0.91 kg/d, steers were fed 6.1 kg of TMR/d. NCR recommendations for daily CP were 11% or about 0.69 kg/d. Average CP analyses of the grass hay for low TDN and high TDN producing laboratories were nearly the same with mean CP analyses of 10.9% and 10.8%, respectively (Table 1). Consequently, based on the commercial analyses, Treatments 1 and 2 needed protein supplementations to achieve targets for ADG. Treatment 1 and Treatment 2 met those needs by supplementing of 0.30 kg and 0.24 kg of dried corn distillers grain/steer per day, respectively (Table 2). Less protein was supplemented for Treatment 2 due to higher hay content (Table 2). However, analysis of the grass hay by the in-house laboratory indicated that CP was over supplied by as much as 14% (Table 2).

Based on NRC minimum recommendatations, steers needed NE_M of 1.73 Mcal/kg or 71.6% TDN to achieve 0.91 kg/d ADG. This recommendation required that steers assigned to Treatment 1 be supplemented with 2.1 kg/d of shelled corn (DM basis) and that steers assigned to Treatment 2 be supplemented with 0.7 kg/d of shelled corn (DM basis).

Steer acclimation data. Mean pre-feeding trial weights for all steers was 206 kg (STD 18.1 kg). Pre-study acclimation feed consisted of alfalfa-oat mix hay with 94.4% DM, 11.2% CP, 35.8 ADF, and 50% NDF. DMI was predicted based on BW and forage NDF (DMI = ((120/NDF)/100) x BW); average DMI was predicted to be 4.9 kg/d. According to nutrient requirement tables (Parsons et al., 2004; Gadberry, 2010), steers provided with feed similar to that fed pre-trial would be expected to have an ADG of about 0.68 kg. During the 23-day pre-trial acclimation period the steers had an ADG of

0.65 kg (STD 0.268 kg). This ADG resulted in an average final weight at the end of the acclimation period for all steers of 220.9 kg (STD 17.7 kg).

DMI was not measured during the 23-day pre-study acclimation period. However, DMI was measured within 48 hours after the acclimation period ended, via the Grow Safe Feeding System, and was a good indicator of DMI for steers during the final days of acclimation period; since gut fill from the alfalfa-oat hay would still be affecting steer DMI (Mertens and Ely, 1979). Average DMI for the first 24 hours (day 1) for all steers measured by the Grow Safe Feeding System was 5.76 kg. After the second 24-hour period (day 2) of intake measurements, average DMI was 5.81 kg (Figure 1). Using the NDF-based equation to predict DMI, expected mean DMI for all steers pre-study was 5.31 kg/d (STD 0.42 kg) and ranged from 4.44 to 5.86 kg/d. The NDF predicted DMI/d was about 0.454 kg/d more than the DMI from Grow Safe measurements. After the first 48 hours, average DMI for all steers increased to 6.67 kg (Figure 1).

Treatments 1 and 2 were formulated for DMI of 2.4% BW of each steer. Figure 1 shows mean daily DMI and maximum daily temperatures for both treatments. Mean DMI were not significantly different for Treatment 1 compared to Treatment 2 with mean intakes of 9.3 kg/d and 9.0 kg/d, respectively, for the entire feeding trial. As a percent of BW, DMI exceeded the 2.4% goal for both treatments (Figure 2).

Aston et al. (1998) showed that protein supplementation can increase DMI in cattle. In addition, Añez-Osuna et al. (2017) showed that energy supplementation increased DMI of beef heifers compared to DMI of non-supplemented cool-season perennial grass hay. The combination of protein and energy supplementation likely increased DMI more than predicted. To observe non-significant differences between intakes for steers fed corn

at 2.09 kg/d verses steers fed corn at 0.73 kg/d seems inconsistent, since a greater ratio of grain in a forage-based ration would stimulate greater DMI. However, Allen (2000) showed that supplements, such as grain, have little effect on DMI. In addition, Añez-Osuna et al. (2017) showed that different levels of energy supplementation (0.6%, 0.9%, and 1.2% of BW) increased total DMI but did not produce different DMI between levels of energy. Consequently, since Treatments 1 and 2 had the same forage fiber source, it is reasonable that DMI for the treatments would be similar. Decisions for protein and energy supplementation were prompted by analyses provided by commercial laboratories. Guthrie et al. (1984) stated that protein and energy supplementation increased intake and utilization of medium quality prairie hay by steers. Steers in this study likely had unanticipated higher DMI and final weights because of excess or unneeded protein and energy supplementation.

In addition, mean DMI, as a percent of BW, for Treatment 1 and Treatment 2 was 3.26% and 3.30%, respectively. It is also likely that no significant differences in DMI were observed between steers in both treatments because all steers had reached the point of maximum DMI.

DMI is the “most important variable that affects animal performance” (Costa e Silva et al., 2016). Since DMI is positively correlated to forage quality, laboratory analysis impacts DMI predictions, which was shown in this feeding study. Inaccurate analysis of feed components can cause unintended under or over protein supplementation. Since NDF content in forges is highly correlated to DMI it stands to reason that inaccurate NDF determinations are a larger problem than protein or energy. When feed laboratories error

in forage analyses, DMI predictions are incorrect causing livestock managers to miss production and management goals.

Production Impact. As in the case with many cattle producers, this study relied upon commercial feed laboratory analyses exclusively in order to formulate the treatment rations. Analysis of grass hay were performed by the in-house laboratory after the feed trial was complete. Unlike commercial cattle producers, we were able to compare commercial laboratory feed evaluations to the in-house laboratory. In-house laboratory analysis showed higher CP%, and lower ADF% and NDF% (Table 1). These values indicate that commercial laboratories understated the true grass hay feed value.

Raising marketable stocker calves was the production goal in this study. The targeted final weight was 299.4 kg, based on an ADG of 0.91 kg/d. The average total BW and ADG for steers in Treatments 1 were 326.6 kg and 1.68 kg/d, respectively, and 318 kg and 1.53 kg/d, respectively, for steers in Treatment 2. Steers in both treatment groups exceeded established production targets (Figure 3).

Financial Impact. Table 3 lists costs of production and feed efficiency for Treatments 1 and 2 and desired targets. Utilizing AMTS Cattle Professional version 4.8.0.10 (Agricultural Modeling and Training Systems LLC, Groton, NY) and analyses of grass hay from in-house laboratory, it was predicted that at 6.35 kg/d DMI could support 1.19 kg ADG based on ME or 1.08 kg based on MP. Feeding 5.44 kg/d of grass hay alone could support 0.92 kg ADG based on ME or 0.88 kg based on MP. Based on in-house analyses for the grass hay fed and predictions using AMTS Cattle Professional 2, the target ADG likely could have been achieved without protein or grain supplementation.

Ration costs per day for Treatments 1 and 2 were $0.175 and $0.154/kg, respectively. If grass hay had been fed without supplementation, daily ration costs would have been $0.132/kg (Table 3). These costs on a per pound basis may appear marginal, yet when multiplied to reflect national herd sizes, production cost differences would be considerable. Wiemers (2009) determined that 50,870 backgrounding operations functioned in United States with total cattle numbering 17,229,903. Troxel (2014) states that steer calves weighing 181 to 272 kg are best suited for most backgrounding programs. Therefore, considering that steers used in this study are ideal for backgrounding and typical of animals used in backgrounding programs nationwide. There was a $0.40 difference in feed cost/d for steers on Treatment 1 compared with the non-supplemented grass hay ration (Table 3). Assuming steers were fed a TMR, additional loading, mixing, and delivery costs would be required compared with grass hay fed alone. Karszes (2016) reported that TMR are loading, mixing, and delivery costs for 26 New York farms (range from $3.15 to $8.16/ton) averaged $5.20/ton or $0.057/kg.

Using total U.S. background cattle numbers provided by Wiemers (2009) unnecessary supplementation could be responsible for losses as high $5.7 billion annually nationwide, assuming all backgrounded cattle are over supplemented to the magnitude seen in this study. Admittedly, not all backgrounding operations use laboratories to balance diets and not all commercial feed laboratories understate feed quality. In fact, comparison of in-house laboratory grass hay analyses with commercial laboratory analyses show that a substantial number of analyses and laboratories met or exceeded results produced the in-house laboratory. Therefore, hypothetical loses described serve mainly to bring awareness to the magnitude of financial impacts of supplementation due

to inaccurate commercial laboratory analysis. It is obvious that impacts of inaccurate feed analysis are much more substantial in larger cattle production sectors, such as dairy, which are heavily reliant on commercial laboratories for feed management.

Another consequence of unanticipated increased DMI was impact on feed inventory. The amount of grass hay purchased for this study was for a 100-day feeding period. Increased DMI caused hay supplies to be exhausted within 60 days. Under real-world conditions inventories exhausted prematurely could lead to untimely animal sales or unplanned or budgeted feed purchases at unfavorable market prices.

Impact on Marketing. Steers used in this study were theoretically backgrounded to be marketed as stocker or grass calves. Beliveau and McKinnon (2008) state that: "the goal of back-grounding is to minimize fat accretion and promote both frame and muscle". Fleshy animals are not attractive to many cattle buyers because it is assumed that cattle with less flesh often gain weight faster. Steers that were assigned to Treatments 1 and 2 had BCS of 6 and 5, respectively (Table 4). Steers with such BCS are likely not as attractive to purchasers as stocker cattle with slightly lower BCS.

Table 4 summarizes carcass qualities and BCS for steers in both treatments. Steers in Treatment 1 had greater mean live weight (LW), ribeye area per 100lbs (REA/CWT), percent intramuscular fat (IMF), ribeye area (REA), calculated percent yield grade (CPYG), rib fat thickness (RIBFT), rump fat thickness (RMPFT), and BCS than Treatment 2. REA, CPYG, and BCS of steers in Treatment 1 were significantly different from steers in Treatment 2 ($P < 0.05$). Troxel (2014) suggested that steers which are in thin to moderate condition are "best suited" for backgrounding operations. This is primarily because purchasers of background cattle expect to profit from weight gains

utilizing grazing resources (Payne, 2011) or in other post weaning growing programs. The purchase of healthy lightweight cattle is fundamental for profitable and successful commercial stocker production. Body and carcass measurements showed that all feeding trial steers had greater fat deposition than desired for commercial stocker production. Body and carcass chacteristics of steers were a result feed management that was guided by feed analyses provided by commercial laboratories. Understated feed analyses affected the quality of animals marketed and market timing.

In addition, market and revenue losses may impact feed producers and traders as well. The 12 commercial laboratories used in this study reported that the grass hay had RFV values ranging from 99 to 161 points. Since feed producers are generally paid for the quality of crops, it stands to reason that when crop quality is understated, producers stand to lose revenue. Several authors have suggested that hay price should be directly equated with RFV (Hedtcke et al., 2004). From an instructional viewpoint, if hay is valued at $1 per RFV point, the producer may have loss up to 60% of possible profits due to inaccurate feed analysis.

Environmental Impact. In this study, minimum percent CP was recommended as 11% (Oltjen and Ahmadi, 2006). Based on commercial feed laboratory, protein supplementation was necessary. However, CP analysis of the grass hay by the in-house laboratory suggested that protein supplementation was unnecessary. Excess or unnecessary protein supplementation clearly impacts cost of beef production. Although not shown in this study, it can also potentially impact herd reproduction management through elevated blood urea nitrogen levels (Elrod and Butler, 1993) and excess nitrogen the environment.

CONCLUSIONS

Knowing the chemical or nutritional composition of livestock feed is the foundation of efficient feed management. Laboratory analysis is the primary means by which livestock producers acquire chemical or nutritional composition of livestock feeds. There can be significant differences in precision and accuracy of feed analyses between commercial feed laboratories. Inaccurate feed analyses can prevent animal production goals from being reached in terms of health, growth, and development. Inaccurate feed analyses can also impact livestock operation marketing and budget strategies. To achieve efficient feed management, livestock producers should be well-informed and judicious when selecting laboratories for feed analyses.

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Table 6.1. Comparison of low, high, and in-house analyses of grass hay. All chemical analyses of grass hay were averaged from commercial laboratories which produced TDN values one standard deviation below (Low Analysis) or one standard deviation above (High Analysis) the populations mean. Rations 1 and 2 were formulated based on means of low and high analyses, respectively. In-house analysis was replicated 6 times by the investigator for each chemical component

Chemical component	Low analysis[1]	High analysis[2]	In-house analysis[3]
DM, %	90.7	90.7	90.8
CP, %	10.9	10.8	12.5
ADF, %	32.2	29.6	28.8
NDF, %	52.4	49.5	46.7
TDN, %[4]	60	69	70

[1] Low analysis = component means from 18 analysis provided by 3 laboratories
[2] High analysis = component means from 12 analysis provided by 2 laboratories
[3] In-house analysis consisted of methods recommended by Undersander (1993)
[4] $TDN = 4.898 + (89.796 \times NE_L)$, NE_L (Mcal/lb) = 1.0876 - (0.0127 x ADF) (Rogers et al., 2014).

Table 6.2. Ration compositions of TMR ingredients for Treatment 1 and 2. Chemical composition of two rations that were formulated based on component means of analyses from laboratories that produced TDN values one standard deviation below (Treatment 1) or one standard deviation above (Treatment 2) the population's mean. In-house laboratory analysis of Ration 1 (R1 In-house) and Ration 2 (R2 In-house) are also given.

Ingredients[1]	Treatment 1[2]	R1 In-house	Treatment 2	R2 In-house
Grass hay	58.9		82.6	
Corn grain, flaked	34.3		11.5	
Corn distillers	4.9		4.0	
Mineral	1.7		1.7	
Chemical composition[3]				
DM, %	78.9	79.2	78.9	82.3
CP, %	11.3	12.8	11.3	12.9
ADF, %	19.9	26.2	25.4	32.0
NDF, %	36.1	42.3	43.6	52.6
TDN, %[4]	71.8	72.8	70.7	66.1
$NE_{M,\ Mcal/kg}$[5]	1.69	1.72	1.67	1.52
$NE_{G,\ Mcal/kg}$[5]	1.08	1.10	1.06	0.92

[1] Percent DM basis

[2]Feed ingredient ratios and energy values were determined using TAURUS Beef Cattle Ration Formulation and Evaluation Software (Oltjen and Ahmadi, 2006).

[3]DM basis

[4]In-house TDN were calculated using, $TDN = 4.898 + (89.796 \times NE_L)$, $NE_L(Mcal/lb) = 1.0876 - (0.0127 \times ADF)$

[5]In-house NE_M and NE_G were using an online feed energy calculator (RCREC, 2009).

Table 6.3. Comparisons of performance, economics, and production targets of steers in study.

Item	Treatment 1	Treatment 2	Target
ADG, kg	1.68	1.53	0.91
DMI, kg	9.25	9.21	9.23
Feed:gain	5.5:1	6.0:1	8:1
Ration cost, $/kg DM	$0.175	0.154	0.132
Ration cost, $/d	1.62	1.42	1.22
Days on feed	60	60	60
Total cost, $	97.20	85.20	73.26

Table 6.4. Ultrasound measures and BCS after 60-day study were used to determine significant differences in carcass characteristics between steers fed rations that constituted Treatments 1 and 2. Treatment 1 produced greater mean body and carcass characteristics than Treatment 2 in every category. CPYG, RIBFT, and BCS were statistically significant between treatments.

Characteristic[1, 2]	Treatment 1	Treatment 2	*P*-value
LW, kg	326.6	318.0	0.58
REA/kg	0.146	0.135	0.18
IMF, %	3.40	3.16	0.43
REA, cm^2	47.74	42.8	0.16
CPYG, %	2.65	2.55	0.04
RIBFT, cm^2	0.66	0.56	0.04
RMPFT, cm^2	0.457	0.406	0.40
BCS[3]	6.0	5.0	0.001

[1]LW= live weight, REA/CWT=ribeye area per kg100lbs, IMF=percent intramuscular fat, REA=ribeye area, CPYG=calculated percent yield grade, RIBFT=rib fat thickness, RMPFT=rump fat thickness, BCS=body condition score.
[2]All carcass characteristic measures are means of 8 steers per treatment.
[3]Each steer was judged and assigned BCS by each of 25 experienced USU Animal Science students. BCS = median value of 25 scores per steer and 8 steers per treatment.

Table 6.5. Cost comparisons of feed ingredients and amounts fed for Treatment 1 and 2. Treatment 1 was formulated based on mean component analyses for grass hay from commercial laboratories which produced TDN values one standard deviation below one standard deviation from population's mean. Conversely, Treatment 2 was formulated based on mean component analyses for grass hay from commercial laboratories which produced TDN values one standard deviation above one standard deviation from population's mean.

	Treatment 1			Treatment 2		
Item	Cost/kg[1]	kg/ration	Total cost	Cost/lb	Lb/ration	Total cost
Grass hay	13.14	232.7	30.57	5.96	326.1	42.85
Corn, flaked	18.14	142.9	25.92	8.23	46.3	8.39
DDGS	19.00	19.5	3.71	8.62	15.9	3.02
Mineral	141.91	6.4	90.1	64.37	6.4	9.01
TMR	0.1725	401.4	69.23	0.1604	394.6	63.28

[1] Cost in cents/kg ration

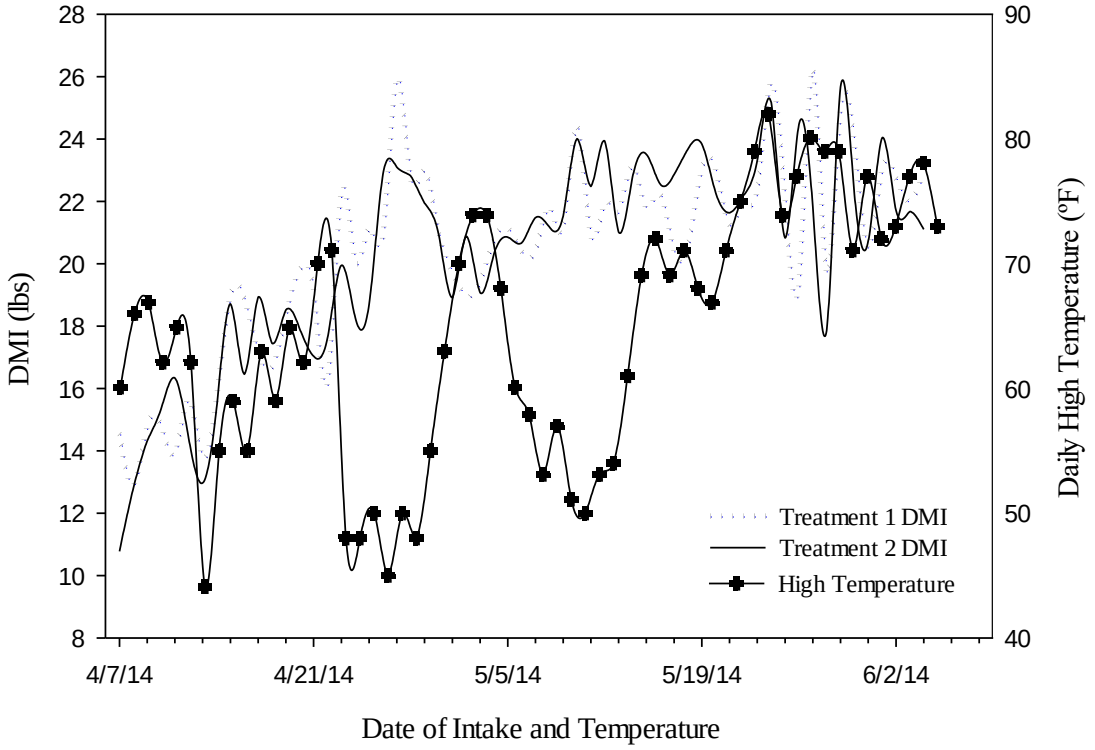

Figure 6.1. Mean daily DMI for steers fed two different rations (Treatment 1 and 2) as measured via GrowSafe automated feeding system (GrowSafe Systems Ltd., Airdrie, Alberta, Canada). Treatment 1 (34% corn) was formulated based on mean component analyses for grass hay from commercial laboratories which produced TDN values one standard deviation below one standard deviation from population's mean. Conversely, Treatment 2 (11% corn) was formulated based on mean component analyses for grass hay from commercial laboratories which produced TDN values one standard deviation above one standard deviation from population's mean. Each treatment was fed simultaneously to 8 Angus/Gelbvieh crossbred steers for 60 days.

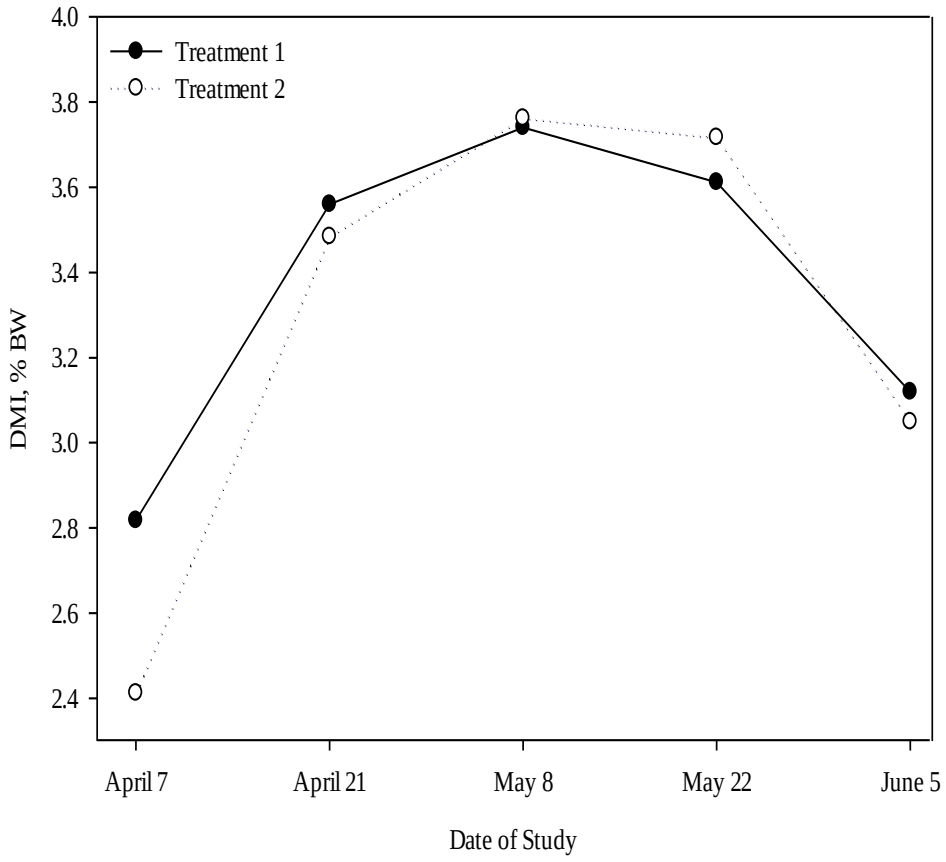

Figure 6.2. Biweekly DMI intakes for Treatments 1 and 2 as a percent of BW. Rations were formulated based on anticipated DMI of 2.4% BW.

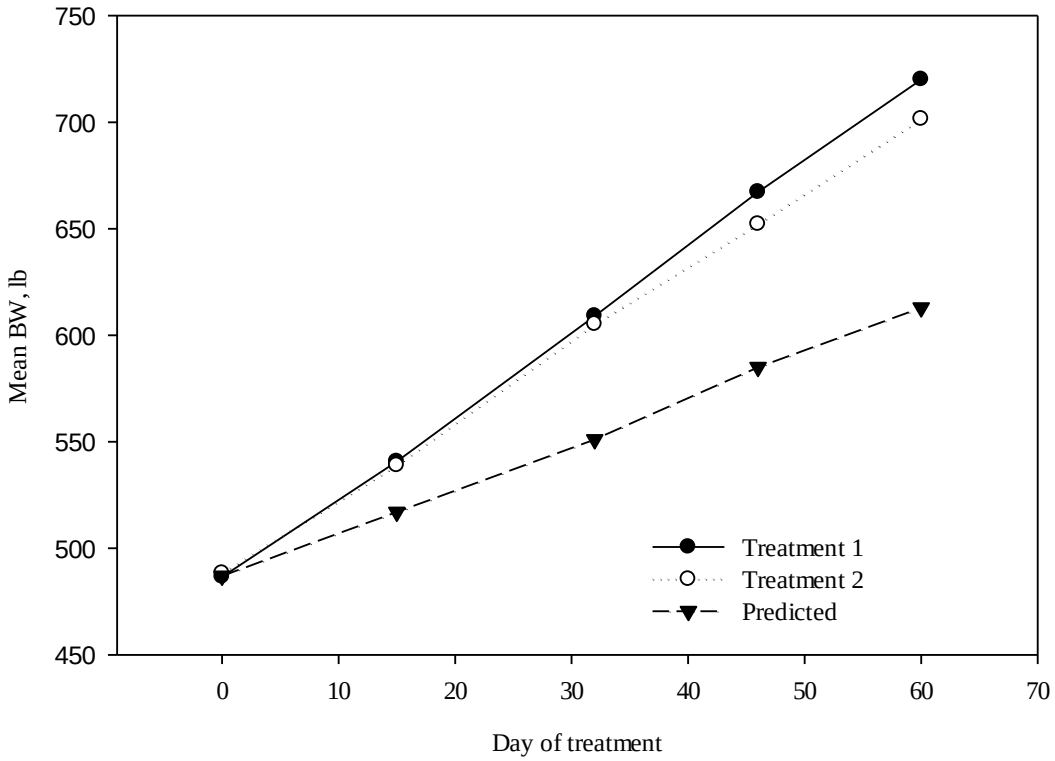

Figure 6.3. Mean body weights for steers on Treatments 1 and 2 and predicted body weight, by day of treatment.

CONCLUSIONS

Laboratory analysis of animal feed provides producers with nutritional information needed to improve animal health, reproduction, and profitability. In addition, has become an important tool in many academic disciplines, government agencies, and agribusiness. To maintain such an important industry a correct knowledge of its utilization and demographics is advantageous. However, without accuracy and precision within and between laboratories, benefactors of feed analysis are confounded and perhaps negatively affected. Accuracy is the primary quality with which feed analysis users are concerned.

There are significant differences in accuracy and precision between laboratories that perform feed analyses. Possible ways to minimize these effects might be to submit critical samples in duplicate, then average the two results. Another would be to only work with laboratories that have current certifications. This data suggests that changes in sample dry matter content were a significant systematic error contributing to inter-laboratory variation; likely due to ambient humidity. When selecting a laboratory to perform forage analyses, patrons must not only consider laboratory reputation and credentials, but consider laboratory atmospheric environment or atmospheric controls.

Inaccurate feed analyses can prevent animal production goals from being reached in terms of health, growth, and development. Inaccurate feed analyses can also impact livestock operation marketing and budget strategies. To achieve efficient feed management, livestock producers should be well-informed and judicious when selecting laboratories for feed analyses.

CURRICULUM VITAE

Jerald H. Severe
1889 East 1500 North, Terreton, ID 83450
Cell: 208-604-2936
Email: severej@byui.edu

EDUCATION

Doctor of Philosophy, Animal Science
Utah State University, Logan, UT
Dissertation Title: Demographics, Accuracy, and Impact of Feed Laboratories in the United States
Major Professor: Dr. Allen Young

Master of Science in Plant Science
Utah State University, Logan, UT
Thesis Title: Effects of Microwave Drying on Near-Infrared Reflectance Analysis of Corn Silage
Major Professor: Dr. Ralph Whiteside

Bachelor of Science in Agronomy
Brigham Young University, Provo, UT
Minor: Chemistry

TEACHING EXPERIENCE AND EMPLOYMENT

Adjunct Faculty, Idaho State University, Pocatello, ID
Hired to instruct Concepts of Chemistry in the Chemistry Department and Nutrition in the Nutrition and Dietetics program

Secondary Education Instructor, West Jefferson School District, Terreton ID
Courses taught: Agriculture Exploration, Environmental Science, Natural Resources, Life Science, STEM, and Physical Science
Contributed to Cornell University research (Biological Control 61(2012):102) https://www.sciencedirect.com/science/article/abs/pii/S1049964411003355
Taught culturally diverse high school and middle school students

Adjunct Faculty, Animal Science, Brigham Young University-Idaho, Rexburg ID
Courses taught: Animal Nutrition, Animal Health, Animal Production Systems, Animal Production Seminar, Careers in Animal Science, and Science Foundations
Organized >100 academic seminars, 7 veterinary CE events and 5 digital media seminars
Built, maintained, and employed beneficial stakeholder relationships in course instruction
Featured in BYU-I Learning and Teaching News, “Not Your Typical Lab Experience”. http://www.byui.edu/learning-and-teaching/news/not-your-typical-lab-experience
Advised students, developed multicultural content for 5 different university courses

Teaching Assistant (organic chemistry laboratory), Brigham Young University, Provo, UT
Graduate Research Assistant, Utah State University, Logan, UT
Undergraduate Research Assistant (Soil Science), Brigham Young University, Provo, UT

INDUSTRY AND GOVERNMENT WORK EXPERIENCE

Idaho State CTE Agriculture and Natural Resource Program Manager, Boise, ID
- Organized stakeholder advisory committees to create Idaho Ag Ed pathway standards
- Presented to multicultural stakeholder groups: State officials, teachers, and students
- Participated on state education and student organization boards and committees
- Qualified 140 Idaho Ag Ed programs for state and federal funds
- Served as Idaho State FFA Advisor

Manager-Owner, Idaho Alfalfa, Inc., Terreton, ID
- Applied for and was awarded numerous state and federal forage supply contracts
- Managed 300 head feedlot livestock (beef steers and dairy replacement heifers)
- Directed and trained up to 10 employees for company and forage laboratory
- Fostered stakeholder relationships: livestock, crop, and feed producers
- Developed domestic and foreign forage markets

General Manager, SEBS Corporation, Terreton, ID
- Sought and was awarded millions of dollars in industry and government supply contracts
- Developed feed manufacturing procedures to meet FDA standards for medicated feeds
- Developed company's domestic and foreign forage and manufactured feed markets
- Consulted and advised company stakeholders: livestock, crop, and feed businesses
- Monitored stocker cattle feed operation

Commercial Pesticide Applicator, Intermountain Farmers Association, Lewiston, UT
- Retained Northwest applicators license, maintained spray equipment and records
- Mixed and applied agricultural pesticides
- Commercial Pesticide Applicator, Private Contractor, Pendleton, OR and Logan, UT
- Obtained Northwest Pesticide Applicator license, maintained spray equipment and records
- Contracted with fruit producers and residential stakeholders for insecticide applications
- Recommended, applied, and prescribed pesticide treatments for fruits and ornamentals
- Contracted with Pure Grow of Adams Oregon for herbicide application

Harvest and Processing Plant Equipment Operator, Smith's Frozen Foods, Weston, OR
- Operated and maintained frozen food processing equipment

Ran, serviced, and repaired pea combines and swathers
Harvested crops in Umatilla and Union counties
Forklift operator

EXTENSION PUBLICATIONS

1. Severe, J. and D. Zobell. 2012. Review: Technical Aspects for the Utilization of Small Grain Straws as Feed Energy Sources for Ruminants: Emphasis on Beef Cattle. Utah State University Extension, Logan, UT https://digitalcommons.usu.edu/cgi/viewcontent.cgi?article=1068&context=extension_curall
2. Severe, J. and D. Zobell. 2011. Major Factors or Inputs Affecting Profitability of Beef Cow Herds in the Western United States. Utah State University Extension, Logan, UT. https://digitalcommons.usu.edu/cgi/viewcontent.cgi?article=1070&context=extension_curall
3. Severe, J. and D. Zobell. 2011. Grass-Fed vs. Conventionally Fed Beef, Utah State University Extension, Logan, UT. https://digitalcommons.usu.edu/cgi/viewcontent.cgi?article=1069&context=extension_curall
4. Severe, J. and D. Zobell. 2011. Utilization of Heterosis in a Beef Cow Herd, Utah State University Extension, Logan, UT. https://digitalcommons.usu.edu/cgi/viewcontent.cgi?article=1071&context=extension_curall

PRESENTATIONS

1. Accuracy of US Forage Laboratories. 2017. National Hay Convention, Canandaigua, NY
2. Documentation for Idaho Quality Program Standards Grants. 2017. UID, Moscow, ID.
3. Adventures in Service Learning, BYU-I. 2016. Fall Faculty Conference, Rexburg, ID
4. Accuracy and Precision of US Forage Labs: Impact on Beef and Crop Producers. 2015. UID, SE Idaho Forage Seminar; Rexburg, ID
5. Precision Testing in US Forage Labs. 2014. UID, SE Idaho Forage Seminar; Rexburg, ID
6. United States Feed Laboratory Accuracy: A Preliminary Study. 2012. Utah State University, 1st Annual ADVS Graduate Student Symposium; Logan, UT

TRADE PUBLICATIONS AND ABSTRACTS

1. Severe, J and A.Young, 2017. Feed laboratory demographics and utilization in the United States, J. Dairy Sci. 100(Suppl. 2):
2. Severe, J and A. Young. 2017. Accuracy and precision of forage analysis by commercial laboratories. J. Dairy Sci. 100(Suppl. 2):
3. Severe, J and A. Young. 2017 Hoard's Dairyman, Same feed samples yield different results. Hoard's Dairyman (July 17, 2017). https://hoards.com/article-21381-same-feed-samples-yield-different-lab-results.html

4. Severe, J and A. Young. 2017. Feed testing most important to dairy. Hoard's Dairyman (July 24). https://hoards.com/article-21331-feed-testing-most-important-to-dairy.html
5. Severe, J and A. Young. 2017. Feed Analysis – A Look at Variability. Hay and Forage Grower (Nov. 27). https://www.hayandforage.com/article-1662-Feed-analysis-%E2%80%94-A-look-at-variability.html

GRANTS

1. Idaho Beef Council, Boise ID, project title: Idaho Grass Finished Beef: creation, evaluation, and development of a uniquely Idaho beef product. 2015.
2. Idaho Beef Council, Boise ID, project title: The Impact of Inaccurate or Variable Feed Analyses Performed by Commercial Laboratories on the Efficiency and Profitability of Idaho Beef Backgrounding and Finishing Operations. 2014.
3. Utah State University, Logan UT, project title: U.S. Feed Laboratory Accuracy Study Grant. 2014.

PROFESSIONAL ORGANIZATION MEMBERSHIPS

- National Association of Supervisors Agricultural Education (NASAE)
- American Dairy Science Association (ADSA)
- Certifications
  Idaho Standard Secondary Teaching Certificate
  Biological Science Endorsement
  Natural Science Endorsement

TECHNICAL AND PRACTICAL SKILLS

- Operation and transportation of production and industrial equipment: balers, chemical sprayers, feed mixers, forklifts, tractors, front end loaders, skid steers, swathers, telehandlers, and trucks
- Experience in Excel, Word, PowerPoint, Outlook, R, and SigmaPlot 12.0
- Proficient in use of office equipment: computer, fax, copiers
- Forage analysis and other laboratory methodology
- Grant writing
- Statistics