EVALUATION OF DIET COMPOSITION AND PERFORMANCE OF GRAZING CATTLE WITH FECAL NIR ANALYSIS AND THE TEXAS A&M NUTBAL MODEL

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TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Figure Page

Figure Page

CHAPTER I

INTRODUCTION

As a result of the difficulty of determining the quantity and quality of ingested forage, evaluating the nutritional status of grazing animals is complicated (Coleman et al., 1989). The ability to accurately and precisely predict the quality of the grazing animal's diet and animal performance would assist producers making decisions concerning forage resource utilization, supplemental feeding regimes and marketing opportunities. Timely estimates of forage quality would provide information necessary to initiate or terminate supplemental feeding. Timely estimates could also improve grazing management decisions such as the movement of cattle through a rotational grazing system. Additionally, predictions of current animal performance would provide crucial budget information for producers considering alternative production and marketing options.

Basically, there are two methods available to estimate the nutrient composition of a grazing animal's diet. Performing laboratory procedures on hand-harvested forage samples is a direct method to analyze the nutrients available for consumption. However, obtaining samples representative of the animal's diet is a problem. According to Holechek et al. (1982b), using fistulated animals for sample collection gives the most accurate representation of forage consumed by grazing animals. Unfortunately, this method of sample collection is not an option for producers.

Several indirect methods have been proposed to predict diet composition, intake and performance of grazing animals. Indirect methods have used chemical constituents within grazed forage and fecal samples. Many of the chemical constituents in forage are highly correlated with forage intake and animal performance (Horn et al., 1979). Likewise, some chemical components of fecal material are also highly correlated with the chemical constituents of ingested forage (Holloway et al., 1981: Holechek et al., 1982c; McCollum, 1990). Historically, these equations have been less than satisfactory in accomplishing the goals for their development, especially for use on a large scale and generalized basis. The limited success of these relationships has been due to the many biological factors affecting intake and weight gain. Numerous prediction equations may be required to account for seasonal changes in chemical and botanical composition of the grazed diet as well as differences in vegetation type. Holloway et al. (1981) had to include several constituents in a single regression equation before acceptable coefficients of determination were achieved.

Near infrared reflectance spectroscopy (NIR) has been proposed as a viable method for determining the nutrient composition of forages (Norris et al., 1976; Shenk et al., 1979; Holechek et al., 1982a; Ward et al., 1982). NIR has been used to predict crude protein, cell wall constituents, digestibility and intake of forages. The predictions of forage constituents with NIR have produced standard errors of prediction comparable to standard errors of accepted laboratory procedures. The success of NIR equation calibration is very promising. The information that NIR analysis can provide in a rapid and timely manner would be beneficial for both researchers and cattle producers. A more recent application with great potential for grazing managers is the estimation of forage quality from NIR analysis of fecal material (Brooks et al., 1984; Lyons and Stuth, 1992).

Previous research of fecal analysis by NIR has been successful (Brooks et al., 1984; Lyons and Stuth, 1992), but the validations of NIR have been performed with a subset of the samples used for instrument calibration. Lyons and Stuth (1992) discussed the need for field validation to determine the broad based application of NIR fecal analysis. Therefore, the objectives of this research were to (1) evaluate NIR analysis of feces to predict the protein content and digestibility of forage consumed by grazing cattle, (2) examine the accuracy and precision of NIR fecal analysis combined with a computer model (Ranching Systems Group, 1993) and evaluate the plane of nutrition and predict performance of stocker cattle.

CHAPTER II

LITERATURE REVIEW

The ability of animals to graze selectively is well documented. Cattle grazing rangeland have a wide diversity of plants available to obtain needed nutrients. In an early study comparing the botanical composition of available forage in plots and esophageal masticate samples, Heady and Torell (1959) demonstrated that the composition of masticate samples was different than the composition of the available forage. Lesperance et al. (1960b) concluded that there was no agreement in the botanical and chemical composition of samples collected from fistulated steers and samples clipped from exclosures.

The diversity of available plants is further complicated by differences in consumption between available plant fractions. Ellis (1978) demonstrated the ability of grazing animals to consume greater quantities of leaf fractions even though the availability of stems may be greater. Esophageal masticate samples collected from heifers grazing bermudagrass were comprised of 82 and 90% leaves while the available forage clipped from plots contained only 34 and 41% leaves in December and June, respectively. These investigations further support the conclusions of Lesperance et al. (1960a) more than 30 years ago that the only practical means of evaluating rangeland is to allow grazing animals to sample the forage.

One of the most difficult aspects of range and pasture nutrition is determining the intake and nutritive quality of the diet consumed by grazing animals (Wofford et al., 1985). The use of esophageal fistulated animals has been the method of choice to collect samples representing the diet since Torell (1954) developed the fistulation procedure. However, due to labor requirements and difficulties involved in sample collection and animal maintenance, the development of indices between diet and fecal samples has received considerable attention (Holechek et al., 1982b). Researchers and producers could benefit from the development of techniques that would allow rapid and easy sampling.

The relationships between diet and fecal constituents, and the advancements in instrument technology have led to the study of Near Infrared Reflectance Spectroscopy (NIR) as a potential analytical tool for analysis of forage quality. NIR offers a rapid, inexpensive analysis of the nutrient composition in forages and other organic materials (Shenk and Westerhaus, 1994). This information could be incorporated into decision support models for the prediction of animal responses to forage systems and the development of supplementation regimes, thereby increasing the efficiency of livestock production (Coleman et al., 1989; Stuth et al., 1989; Shenk and Westerhaus, 1994).

Near Infrared Reflectance Spectroscopy

In the 1960's, the Agriculture Research Service began evaluating NIR to determine the moisture, crude protein (CP) and oil content of cereal grains and oilseeds (Clark, 1985). Norris et al. (1976) used NIR to analyze several constituents of temperate and tropical forages. The NIR analysis of forages decreased the difficulty in selecting specific genotypes in plant breeding due to the speed and ease at which forage quality can be determined.

NIR was also evaluated using extrusa samples from esophageal fistulated cows grazing rangeland (Holechek et al., 1982a). More recent developments have utilized NIR technology to estimate forage CP and digestible organic matter (DOM) analyzing feces of free-ranging cattle (Lyons and Stuth, 1992). Advances in technology, data processing and general knowledge have made the developments of NIR analysis and procedures possible. These improvements have increased both the effectiveness and usefulness of NIR methodology in predicting forage quality.

Speed of sample analysis, simple sample preparation, multiple estimates from a single operation and nondestruction of the sample are some of the advantages of the NIR procedure (Norris, 1985a). The major disadvantages of NIR analysis are calibration procedures, instrument requirements, selection of mathematical procedures to analyze spectral data and a lack of sensitivity for minor constituents (Norris, 1985a). In a review of methods to determine diet quality, Holechek et al. (1982b) stated that NIR potentially offers a rapid advancement in obtaining knowledge of the nutrition of grazing animals.

Chemical and Physical Principles

NIR is an instrumental method that rapidly measures the chemical composition of samples, and is based on the absorption of light (energy) in the near infrared spectra by chemical constituents of the material (Norris, 1985a). Absorption bands in the near infrared region are primarily due to bonds within organic molecules and occur as overtones of fundamental bands and combination bands (Shenk and Westerhaus, 1994). An overtone is a harmonic (one-half, one-fourth, one-eighth, and so on) vibration of the frequency of a mid-infrared fundamental absorption band. Combination bands in the higher wavelengths (2000 to 2500 nm) of the NIR spectrum contains information about the structural bending of the entire molecule (Shenk and Westerhaus, 1994). A combination band is the sum of the difference between the frequencies of two or more fundamental or harmonic vibrations.

Absorption of energy is due to stretching, vibrating, rotating or bending of the carbon, hydrogen, oxygen, nitrogen, phosphorus and sulfur bonds. An absorption band is the result of the NIR radiation frequency matching the vibration frequency of a molecular bond. In the near infrared spectrum, the major absorption bands are actually second and third overtones of fundamental bands in the mid-infrared (2800 to 3000 nm) region (Barton, 1985).

Near infrared radiation is only a small portion of the electromagnetic spectrum. The NIR region of the electromagnetic spectra ranges from 700 to 2500 nm and lies between the visible and mid-infrared regions. The NIR spectrometer emits monochromatic light in the near infrared region. The energy from each wavelength can be absorbed, diffracted, reflected and/or transmitted through chemical constituents in the sample. Radiant energy is either absorbed by the substance or transmitted through the substance. Most analytical instruments measure radiated energy from the sample rather than the absorbed energy. Reflected energy from a substance has been in contact with millions of molecules which comprise the substance. Energy is absorbed by individual constituents at specific wavelengths (Lyons, 1990). Therefore, NIR theoretically measures the number of molecules of each individual constituent present.

The relationship between the transmission of energy through a sample and the concentration of the absorbing molecular bonds is fundamental to spectroscopy. This relationship is known as Beer's Law, and states that the molecular bond concentration is linear with log (1/transmission) (Shenk and Westerhaus, 1994). Data concerning absorption can be acquired from measurements of reflectance, when transmittance is so low it is almost unmeasureable (Lyons, 1990). Therefore, log (1/R) (R equals the amount of reflectance measured from a sample) is proportional to the concentration of the absorber.

Methodology

Three types of NIR instruments are available: (1) scanning monochromator, (2) tilting-filter instrument and (3) fixed-filter instrument. Fixed-filter instruments were used in the early stages of NIR research. Fixed filter instruments were some of the first systems developed and marketed for use by commercial industries. These systems use a single detector, and a rotating wheel containing filters that emit light at specific wavelengths. Tilting-filter instruments are similar to fixed-filter NIR units except that the interference filter tilts as the light is illuminated. As the filter is tilted away from perpendicular to the light source the transmitted energy moves to shorter wavelengths. This allows a limited wavelength region to be scanned. Scanning monochromators have more recently been developed, and these instruments can measure reflectance from a wide range of wavelengths. A scanning monochromator chops the light emitted from a tungsten lamp into an alternating on-off beam. Synchronous detection of the reflected radiation is accomplished through lead sulfide detectors. Light is generally emitted in 10 nm increments and the signal can be detected from 0.1 to 10 nm wavelengths.

The reflectance readings are converted to a digital signal by an analog-to-digital converter (Norris, 1985b). The sample reflectance spectra is coupled with a signal representing wavelengths and stored in a computer. From 20 to 100 scans are averaged and corrected against a ceramic reference to produce the reflectance spectra for each sample. The reflectance curves, usually recorded as log (1/R), are comparable to absorption curves. The peaks in the log (1/R) spectral curves correspond to the wavelengths at which energy is absorbed by the sample (Norris et al., 1976).

NIR reflectance data are collected as individual data points, but it can be considered an estimate of a continuous NIR spectrum, containing many unresolved and overlapping absorption bands (Shenk and Westerhaus, 1994). The reflectance measurements are usually transformed into log (1/R). The log (1/R) spectrum is formed by compressing several individual bands into a composite band. The stored log (1/R) spectra of forage samples is broad and consists of few well defined features (Barton, 1985). Therefore, it is suggested that band characteristics in forage spectra cannot be accurately estimated by the log (1/R) spectra (Shenk and Westerhaus, 1994). This transformation is generally considered to be the function of reflectance most linearly related to sample composition. However, the amount of light scatter within the sample influences the log (1/R) spectrum. Light scatter is produced by differences in sample particle size and shape.

Transformations of the reflectance data reduces noise and isolates information related to the chemistry of the sample (Westerhaus, 1985). A running average of adjacent wavelengths can be used for noise reduction. The actual band locations can be determined using derivative techniques (Norris et al., 1976). This spectral treatment of the reflectance data gives a better resolution to the spectra and can eliminate the effects of particle size variation in the spectrum (Barton, 1985). The second derivative curve produces a minimum at the wavelength where a maximum had occurred in the log (1/R) spectra.

Equation Development

The total chemical and physical properties of a sample are represented by the spectra from an NIR instrument. This information is useful only when it is translated into the form of the laboratory methods. Calibration of the NIR instrument to the laboratory procedures is used to convert spectral reflectance data into usable information. Accuracy of calibration depends on characteristics of the population to be analyzed, representative sampling with accurate laboratory values and advanced statistical procedures (Shenk and Westerhaus, 1994). Calibration must be performed for each constituent being analyzed, and the calibration is valid only for the same type of samples used in the calibration (Abrams, 1985). Composition of samples used for calibration should be broad enough to incorporate the range that will be encountered during routine analysis without lowering the accuracy.

Stepwise multiple regression is used to predict laboratory values from the reflectance data. This procedure selects the individual wavelengths most highly related to the reference laboratory values. Wavelength selection is very time consuming and potentially can be the most erroneous part of calibration (Westerhaus, 1985). Thousands of different wavelength combinations must be evaluated through regression before they can be selected. The model and random errors can be fit to the reference data by selecting the best fitting wavelength or wavelength combinations (Westerhaus, 1985).

The wavelengths selected by the stepwise process may correspond to the areas of known absorbances for the constituent of interest, or they may correspond to other constituents in the sample which are inversely related to the constituent of interest (Lyons, 1990). Additionally, less prominent wavelengths may be selected when an area of least interference from other constituents contains the optimum wavelength. According to Westerhaus (1985), the potential for introducing error into the calibration increases as more spectral treatments and wavelength combinations are used in the stepwise procedure.

Accuracy and Precision

Norris et al. (1976) used NIR to analyze crude protein (CP), neutral detergent fiber (NDF), acid detergent fiber (ADF), lignin (L) and in vitro dry matter disappearance (IVDMD) of a diverse mixture of temperate and tropical forages. Standard errors of prediction were 0.95, 3.1, 2.5, 2.1 and 3.5%, respectively, for the constituents. Park et al. (1983) evaluated cultivars of crested wheatgrass and found correlation coefficients of 0.98 for total N, 0.93 for NDF, 0.91 for ADF and 0.62 for acid detergent lignin (ADL). Gabrielsen et al. (1988) found similar correlation coefficients for IVDMD and cellulase digestion of smooth bromegrass and crested wheatgrass. Both Gabrielsen et al. (1988) and Park et al. (1983) indicated that NIR was a viable tool for the selection of genotypes in a plant breeding program, especially when ranking forages in terms of quality is more important than absolute values.

Ward et al. (1982) reported standard errors of calibration of 0.37% for CP, 1.26% for ADF and 0.67% for ADL from a diverse set of masticate samples collected from esophageal fistulated cattle grazing mountain ranges in New Mexico. Holechek et al. (1982a) collected masticate samples from esophageal fistulated cows grazing forest and grassland ranges in eastern Oregon. Standard errors of prediction by NIR were 0.41% and 1.74% for CP and IVDMD, respectively. These values are comparable to the standard errors of duplication from the wet laboratory methods. Villalobos et al. (1991) had standard errors of validation for IVDMD, in vitro organic matter disappearance (IVOMD) and NDF of 1.99, 1.98 and 1.69%, respectively, from masticate samples collected from esophageal fistulated steers grazing flaccidgrass in North Carolina.

Typically, NIR calibration equations have been limited to a single forage species and type (silage, hay, or fresh forage) to achieve a high degree of prediction accuracy (Shenk and Westerhaus, 1993). However, recent advances in computer and instrument technology have increased the possibility of developing generalized calibrations.

Brown et al. (1990) evaluated the accuracy in analyzing quality constituents in several tropical forage species using broad based and species specific NIR equations. Four tropical grass hay samples, collected from 1982 to 1987, represented a wide variation in maturity, fertilization rates and weather conditions at the time of harvest. Standard errors of validation for the species specific equations ranged from 0.77 to 0.92% for CP, 1.97 to 3.16% for IVOMD and 1.45 to 2.03% for NDF, while the standard errors associated with the broad based equations were 0.82, 3.28 and 1.94%, respectively. Shenk and Westerhaus (1993) reported similar standard errors for single and multiple product equations analyzing hay, haylage and small grain silage samples. The broad based equation contained hay, haylage, and small grain silage samples from around the world. They concluded that multiple product equations could be used with the same degree of accuracy as a single product equation. Contrarily, Stuth et al. (1989) combined four data sets to create a master prediction equation. The samples reserved for validation produced an acceptable standard error for CP, but the standard error for in vitro organic matter digestibility was excessive.

Prediction of Forage Quality using Fecal Indices

Relationships between fecal indices and dietary N, diet digestibility, forage intake and animal performance have been investigated for many years. The use of fecal indices was partially developed to decrease the need to sample forage with grazing animals (Cordova et al., 1978). The physiological basis for this method is that feces contain plant, animal and microbial residues produced in response to the diet. Precision of the regression equations are influenced by the variation between plant fractions, species composition, season of the year and level of intake (Holloway et al., 1981; Holechek et al., 1982b).

Fecal N

Raymond (1948) proposed that the nitrogen content in the diet of grazing sheep could be accurately predicted from fecal nitrogen (N). The observed increases in forage quality due to pasture rotations could also be shown through fecal N equations. McCollum (1990) concluded that fecal N potentially can be useful to monitor the immediate plane of nutrition and performance of grazing cattle. The slope of the relationship between diet N (y) and fecal N (x) ($y=.79x-.17$; $r^2=.74$) developed from four years of data collected on tallgrass prairie was similar to that of Raymond (1948) ($y=.795x+.14$). Fecal N was also highly correlated ($r=.91$) with the N concentration of masticate samples collected from cows grazing forest and grassland pastures in Oregon (Holechek et al., 1982c). The equation for predicting diet N was not improved by adding fecal in vitro digestibility as an independent variable. Other researchers have compared the relationships between multiple fecal N fractions and diet N when soluble phenolics and tannins are high in the diet (Wofford et al., 1985; Leite and Stuth, 1990). However, the equations developed were assumed to have limited predictive capability for diets comprised mainly of forbs and shrubs and when fecal NDF-N concentrations exceed 1 percent.

Fecal N concentration and several other constituents have also been related to the digestibility of the diet. Digestion coefficients from conventional digestion trials were in close agreement with the values predicted by fecal N equations when sheep were fed masticates from esophageal fistulated steers (Wallace and Van Dyne, 1970). Wilson et al. (1971) reported that fecal N was less reliable than the two-stage in vitro digestion method as a predictor of digestibility for four different forage types. These findings were in agreement with Langlands (1969) who concluded that fecal N gave unsatisfactory estimates of digestibility because of variations in intake and forage availability. On the other hand, Holloway et al.

(1981) analyzed fecal samples from steers consuming fescue or mixtures containing legumes to relate a number of fecal components to digestibility and intake. Fecal N alone did not explain adequate amounts of the variation in digestibility (r^2=.45) and intake (r^2=.32) for predictive purposes. However, including up to ten other fecal components ranging from cell wall constituents to interactions containing sodium increased the coefficients of determination to 0.79 and 0.87, respectively. The investigators did suggest that development of useful fecal indices with broad application was possible, but developing predictive equations containing the number of independent variables as in the scope of their study reduces the applicability of the procedure.

Using only fecal N to estimate diet quality and intake has met limited success and should be used only in specific situations with defined conditions (Hobbs, 1987). Developing multivariate models, as in the case of Holloway (1981) and Holechek (1982c), is possible and the predictive capability of these equations can be considerably improved. This point theoretically demonstrates the potential to use NIR for diet quality predictions. Relationships between multiple absorbance bands that describe an array of constituents can be developed to predict diet quality characteristics.

NIR Fecal Profiling

Brooks et al. (1984) pioneered research using NIR analysis of fecal material to predict forage quality for elk. Even though the data set was limited (36 fecal samples), the results were encouraging. Fecal samples were collected from elk fed seven grasses and two legumes in conventional digestion trials. Coefficients of determination for the prediction equations for CP, NDF and IVDMD were 0.99, 0.95 and 0.88, with corresponding standard errors of 0.76, 2.01 and 4.35, respectively. Coleman et al. (1989) developed calibration equations using four data sets, two from Tennessee and two from Texas. Each calibration from a data set was used to predict digestibility and intake from subsets of the other data sets. The validations were considered unsuccessful because coefficients of determinations were low and the standard errors were higher than the standard deviations of the reference data. The undesirable validation statistics were attributed to the differences in dietary substrates and methods used to collect the data in the reference data sets. By combining two data sets (one from each location), predictions of the individual data sets improved with the r^2 ranging from 0.69 to 0.85. Recently, Lyons and Stuth (1992) expanded a calibration equation developed at College Station, TX by adding fecal samples collected at La Copita, TX. The calibration equations were considered adequate because standard errors of calibration and validation were similar to the standard errors of the laboratory procedures for CP and DOM. The relationship between NIR predicted and reference CP and DOM produced coefficients of determinations of 0.93 and 0.80, respectively. Precision of fecal spectra equations used to predict diet quality were found to be equal to or better than reported statistics for NIR equations developed from forage spectra.

Further investigations were conducted to determine the effects of supplemental feeding on NIR-based forage quality predictions of cows (Lyons et al., 1993). In two trials, supplemental feeding was determined to have an effect on both CP and DOM predictions. However the magnitude of difference in predictions of DOM between control and treatment groups was considered not to be biologically important. In contrast, differences in CP predictions for the control and treatment groups continued up to 36 h after the termination of daily feeding of supplements. When a supplement was offered three times per week, differences in NIR-based CP estimates were still detected after 2 d from the previous feeding.

The authors concluded that fecal samples used for NIR analysis should not be collected until 48 h after the last supplemental feeding period.

Research has also been conducted to standardize sample preparation procedures and to increase the speed of the analysis, while maintaining accuracy and precision (Lyons and Stuth, 1991; Pearce et al., 1993). Predictions of forage quality from fecal samples dried in either a microwave or forced-air oven were significantly different. The magnitude of the differences were small, but by including microwave dried samples in the calibration equations, these differences could be overcome.

Continued investigations by researchers have made considerable improvements in the standardization of NIR sample preparation procedures and a better understanding of the NIR analysis. It does appear that fecal analysis by NIR can potentially provide rapid, reliable estimates of forage quality that are both precise and accurate. However, recalling the work by Coleman et al. (1989) and Stuth et al. (1989), it does appear that regional limits exist for application of NIR calibrations. The success of NIR lies in the calibration equations. Accordingly, NIR should not be expected to accurately predict a sample or population of samples whose characteristics were not included in the calibration (Windham and Coleman, 1985).

Decision Support Systems

There have been several different weight gain models developed over the past few years. These models can be very simple in nature or very complex and include all factors known to influence gain. A specific model recently developed to incorporate NIR diet quality estimates is the Nutritional Balance Analyzer (NUTBAL) (Ranching Systems Group, 1993). As stated by the NRC (1987), appropriate dry matter intake and energy requirement equations must be used to accurately predict performance of cattle. The success of the NUTBAL model is dependent upon several main assumptions: (1) the intake equations correctly project actual intake, (2) the diet quality estimates for CP and DOM are accurate, (3) the adjustments in fecal output and energy requirements for environmental effects and animal variations are sound, and (4) the user can supply accurate and pertinent information.

Prediction of Intake

Numerous factors control feed intake by ruminants. The factors associated with a continually changing intake include: animal weight, physiological state, energy content and digestibility of the diet, feed processing and preservation, and environmental conditions (ARC, 1980).

As stated by Grovum (1987), if digestibility and total fecal output are known, intake can be calculated. The error associated with estimates of fecal output have a constant effect on intake predictions, while the error in digestibility estimates have a variable effect on forage intake predictions (Galyean et al., 1987). Unlike the convenience of pen fed studies where intake is known and digestibility can be calculated, digestibility of the diet with grazing animals must be estimated indirectly. Fecal output can be determined directly from total fecal collections, but indirect marker-based approaches are often used. The forage consumption algorithm in NUTBAL ratios fecal output to indigestibility of the diet (Stuth and Lyons, 1995). This approach allows separate modeling of both factors comprising the equation. The algorithm uses the early concepts of Conrad (1966) which assumed fecal output of dairy cows was a constant function of body weight. The NUTBAL model then adjusts fecal output for a variety of dietary, physiological and environmental factors. Hence, diet indigestibility is held constant and intake is adjusted by adjusting fecal output. This fecal output equation may seem somewhat crude at estimating forage intake, which in turn has a crucial effect on determinations of animal weight gains. However, considering the application of the model to grazing animals, this equation is potentially useful due to the methods required to determine forage intake in grazing situations.

Digestibility and Fecal Output

The general hypothesis of the work conducted by researchers in the 1960's was that forage intake should increase as diet digestibility increased until the digestibility of the diet reaches approximately 65% (Ellis, 1978). Based on these relationships, Conrad (1966) developed an equation in which a constant fecal output (5.4*body weight (kg)) was ratioed with indigestibility of diet (1-TDN) to predict feed intake by dairy cows. To examine the relationship between dry matter intake and fecal output, Owens et al. (1991) using data summarized from three independent data sets, regressed dry matter intake on fecal output. Fecal output ranged from .4 to 1.3% of body weight and explained from 59 to 83% of the variation in intake by cattle and sheep.

Owens et al. (1991) could explain only 8 and 15% of the variation in intake by regressing dry matter intake against dry matter digestibility across forages in three combined data sets from forages fed to cattle and sheep. The relationships did show that intake increased as digestibility increased, but the amount of variation explained was lower than expected. This suggests that other factors are involved in the regulation of intake than simply digestibility of the diet.

Some researchers have suggested that fecal output varied across forages but Owens et al. (1991) concluded that fecal output appeared relatively constant within a single forage type. Because fecal output appears to be relatively constant within a forage and animal class, assuming fecal output is a constant function of body weight may be useful for the prediction of intake in models such as NUTBAL.

A similar approach was used by Brorsen et al. (1983) to estimate intake and model performance of stocker cattle grazing pastures. In this model, fecal output was assumed to be a constant (.0107) percent of body weight. Brorsen et al. (1983) suggested that determining forage intake from a constant percentage of body weight rather than using a ratio, creates problems when forage digestibility varies greatly as in most cases with grazing animals.

Fecal output and energy requirement adjustments

NUTBAL baseline fecal output estimates were obtained from previous reports, other researchers, and unpublished data (Stuth and Lyons, 1995). Extensive changes have been made in the baseline fecal output factors for both steers and heifers, while the factors for mature animals have remained virtually unchanged. Further adjustments in the fecal output factors have been included for breed type, impact of DOM/CP ratio, forage availability and metabolic modifiers. Hence, the NUTBAL model adjusts forage intake by adjusting fecal output for these factors while holding digestibility constant.

Forage Availability: Forage availability is usually considered as a primary factor limiting forage intake by grazing livestock (NRC, 1987). The forage availability at which intake is maximized is 2,250 kg /ha and rapidly declines to 60% of maximum intake at 450 kg/ha (NRC, 1987). Stuth and Lyons (1995) reported that the decline in fecal output was similar to the decline in forage intake proposed by NRC (1987) when standing crop was greater than 1000 kg/ha. On the other hand, when standing crop was below 1000 kg/ha fecal output declined at rates that were less severe than those reported for forage intake by NRC (1987). NUTBAL reduces fecal output when standing crop is less than 2000 kg/ha, but as forage availability falls below 1000 kg/ha, the reduction in fecal output is not as severe as the reduction in intake reported by NRC (1987).

Breed Type: Baseline fecal output factors in NUTBAL assume a medium frame, *Bos taurus* cow, bull, steer or heifer with a body condition score of 5 as a base (Stuth and Lyons, 1995). Differences in intake between beef cattle breeds and their crosses can be mainly accounted for by differences in mature weight (NRC, 1987). Additionally, because intakes are greater at equal weights for dairy cattle than beef cattle, feed intake is increased 8% for dairy cattle and 4% for dairy crossbreds (Fox and Black, 1984; NRC, 1987; Fox et al., 1988). All other inputs deviating from this standard are adjusted according to the model of Fox et al. (1988).

In NUTBAL, the net basal metabolism of *Bos indicus* breeds have been adjusted down by 10% as compared to the *Bos taurus* breeds. In contrast, the NEm requirements of dairy are 20% higher than beef cattle breeds.

Metabolic modifiers: Ionophores included in the diet of ruminants are known to improve feed efficiency and increase rate of gain. Due to the dynamics of ionophores on intake, NUTBAL adjusts only the net energy for maintenance (NEm) values for the feedstuffs consumed (Stuth and Lyons, 1995). Fox and Black (1984) reported that NE values should be increased by 11% and 6% when monensin and lasalocid are included in the diet.

The effects of anabolic implants are accounted for in NUTBAL by increasing the fecal output factor by 8%. This adjustment is similar to Fox et al. (1988) where feed intake was increased by 8%.

DOM/CP ratio: The interaction between protein and energy can effect digestion in the rumen and amino acid metabolism at the tissue level (Hogan, 1981). Dietary crude protein is degraded by rumen microorganisms into ammonia and amino acids. Part of the degraded protein is used for the synthesis of microbial protein. This process requires the input of energy in the form of high energy phosphates which is derived from the fermentation of carbohydrates. In the ruminant animal, a relatively constant proportion of the total tract digestion of organic matter occurs in the rumen. Therefore, a decrease in digestibility would decrease the amount of energy available to tissues and rumen microbes, which would suggest the need for energy supplementation (Hogan, 1981). However, excesses of protein would not be present in the rumen, because as plants mature the decline in protein content is more rapid than digestibility of organic matter. This situation demonstrates the need to consider the effects of digestibility and protein content together.

According to Hogan (1981) a ratio of digestible organic matter to crude protein (DOM:CP) of 4 would be considered optimum while a DOM:CP of 10 would limit the synthesis of microbial protein. Using the NRC equations for bacterial protein yield, McCollum (1995) indicated that 20.1 g of degradable N/kg TDN intake is needed in the rumen to allow microbes to efficiently synthesize protein from available energy substrates. Additional calculations of rumen degradable protein showed that regardless of the ruminal degradability of CP (% of CP) only DOM/CP ratios of 4 or less provided the prescribed 20.1 g of N/kg TDN. NUTBAL adjusts the baseline fecal output factor to account for differences in the DOM:CP. Fecal output is adjusted to the same extent for growing bulls, steers and heifers, whether the ratio is above or below a four. Animal age and weight, DOM:CP, and diet DOM are used to calculate the adjustment factor.

Environmental conditions: Voluntary intake and maintenance energy requirements can be significantly affected by the environment if temperatures deviate from the thermal neutral zone (15° to 25°C) (NRC, 1984). According to Fox and Black (1984), the effects of temperatures less than 15°C on intake are not consistent. Forage intake should be increased as much as 16% when temperatures fall below -15°C, but intake should be decreased from 15 to 30% if the effective insulation is reduced by rain, snow and(or) mud. Under heat stress conditions, Fox and Black (1984) decreased intake 35% with no night cooling and 10% with night cooling.

Maintenance energy requirements should also be adjusted to account for the effects of cold and heat stress (Fox and Black, 1984; Fox et al. 1988). Based on the temperatures prior to the exposure of cold or heat stress, NRC (1981) and Fox and Black (1984) increased NEm requirements .0007 for each degree above or below 20°C. Furthermore, the multiplier 1.07 and 1.18 can be used to increase NEm requirements when cattle show signs of rapid, shallow panting or deep, open mouth panting, respectively. Fox et al. (1988) used an additional step to adjust the NEm required for cold stress. The body surface area, internal insulation (body condition), external insulation (hair length, hide thickness, and coat condition), and the lower critical temperature are used to adjust original maintenance requirements. The maintenance requirements predicted by the Fox et al. (1988) model were similar to those calculated from independent data sets.

NUTBAL calculates the NEm requirements as is described by Fox et al. (1988) which uses an adjustment for the temperature prior to the exposure of heat or cold stress and an adjustment for degree of animal stress (panting for stress and insulation factors for cold stress) (Stuth and Lyons, 1995).

NUTBAL decreases fecal output 5 to 10% for muddy conditions and up to 30% when the ground is snow covered and the animal's coat is wet. Additionally, fecal output is increased when temperatures are above or below 25° and 15°C.

To evaluate the accuracy and precision of NUTBAL, field validations must be conducted. Currently, few field validations have been conducted to test stocker cattle performance predictions by NUTBAL. The majority of information used in the development of the model was derived from studies involving cows. Additionally, cows were the main focus for the development of NUTBAL. The benefits of a decision support system such as NUTBAL to livestock producers are numerous, but to make the system applicable, diverse field validations must be conducted.

Conclusions

NIR has been proposed as a rapid, reliable analysis of forage quality that is both potentially accurate and precise. The standard errors of prediction and repeatability have often been similar to that of laboratory analysis. However, potential limits for NIR analysis have been shown to exist when samples vary greatly from the calibration set. NIR analysis of feces is especially attractive because of the ease of sample collection and the ability to receive results usually within 48 hours. However, reliability of estimates across a wide variety of forage conditions has not been established.

The NUTBAL model is similar to many other weight projection models that have been developed. The prediction of intake however, is based on fecal output and indigestibility of the diet rather than animal weight and energy concentration of the diet. NUTBAL will also calculate a deficiency in the requirements necessary to meet a performance goal and provide information for the amount of supplement needed on a least cost basis. The adjustments within the model are due mainly to environmental considerations and forage-animal interactions. Possibly, the greatest limit to the model may be in the ability of producers to supply accurate information.

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CHAPTER III

PRECISION OF FORAGE QUALITY ESTIMATES FROM NIR ANALYSIS OF FECES FROM CATTLE GRAZING PLAINS BLUESTEM AND MIDGRASS, SANDSAGE AND TALLGRASS PRAIRIE

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Abstract

Esophageal fistulated cattle were used to collect diet and fecal samples on old world bluestem (OWB) and native range pastures at 3 locations in Oklahoma between April 27, 1994 to February 18, 1995. A series of regression analyses were conducted to evaluate the relationships between masticate DOM and CP values and estimates from near infrared reflectance spectroscopy (NIR) analysis of the fecal samples. Based on simple linear regression, NIR estimates accounted for 61% and 51% of the variation in actual CP (Lab=.820 NIR-1.61) and DOM (Lab=.632 NIR+24.19), respectively, of the entire data set (n=125). NIR overestimated diet CP with accuracy decreasing progressively as diet CP increased. Diet DOM was overestimated with accuracy progressively decreasing as diet DOM decreased. Multiple regression analyses revealed the relationships between NIR estimates and laboratory values were not similar across locations and forage types. Location and forage type had more influence on the accuracy of

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CP estimates than DOM estimates. Results suggest that the NIR calibration equations used to derive these estimates are not applicable to a wider range of forage conditions. Across the three locations, NIR estimates accounted for more variation in the OWB data (CP r^2=.65; DOM r^2=.54) than the native range data (CP r^2=.53; DOM r^2=.47). This, in addition to the slope coefficients, suggests that NIR predictions of CP may be better for OWB (slope=.902) than native range (slope=.661), but no advantage was observed between forage types for the prediction of DOM (range slope=.671; OWB slope =.615). Based on these analyses, it appears the current NIR calibration equations need to be modified by including data points from a wider array of forages. Equations for different range communities or pasture types may be necessary to improve accuracy to a level that allows confident adjustments in nutritional management of grazing cattle.

Key Words: Nutrition, Diet Composition, Rangeland, Pasture

Introduction

The plane of nutrition of grazing animals is difficult to assess because of problems associated with determining the quantity and quality of consumed forage. Selective grazing is well documented and complicates forage sampling and evaluation. Several techniques have been proposed to sample forage available to grazing animals, but these procedures are laborious and time-consuming, and no such procedure is applicable at the producer level.

Near infrared reflectance spectroscopy (NIR) is a rapid, instrument-based method for measuring the chemical composition of organic samples. NIR has been found to be relatively accurate and precise when determining the composition of the diet from esophageal masticate samples (Holechek et al., 1982; Ward et al., 1982). Recently, fecal samples have been profiled with NIR to estimate diet quality (Brooks et al., 1984; Coleman et al., 1989; Lyons and Stuth, 1992). The use of fecal samples simplifies the process, especially for producers, of obtaining samples that represent the diet of grazing animals.

Even though NIR fecal calibration equations have been used successfully to predict forage quality, few attempts have been made to validate calibration equations under a broad array of conditions. Objectives of this research were to conduct a field validation of NIR fecal analysis to evaluate the accuracy of the forage quality estimates. The laboratory analysis of esophageal masticate samples were compared to NIR predictions from fecal profiles of the esophageal fistulated cattle.

Materials and Methods

Research Site: Native range and old world bluestem (*Bothriochloa ischaemum* var. Plains; OWB) pastures were sampled at the Marvin Klemme Range Research Station in (Klemme) Washita County, OK, the Southern Plains Experimental Range (Woodward) in Woodward County, OK, and the Oklahoma Agricultural Experiment Station Research Range (Stillwater) in Payne County, OK. Range soils at the Klemme station are in the Cordell series and mapped as Red Shale range sites and OWB soils are in the St. Paul series. At Woodward, soils are in the Pratt and Tivoli series and are mapped as deep sand and dune range sites, respectively. Range sites at the Stillwater site are classified as shallow and loamy prairies with soils in the Grainola and Coyle series and soils for the OWB site included Gainola-Lucien complex, Grainola-Ashport complex, Pulaski and Renfrow. At Klemme, the midgrass prairie was dominated by sideoats grama (*Bouteloua curtipendula* (Michx.) Torr.), blue grama (*Bouteloua gracilis* (H.B.K.) Lag. ex Steud.), and buffalo grass (*Buchloe dactyloides* (Nutt.) Engelm), with some little bluestem (*Schizachyrium scoparium* Nash). The sandsage prairie community at Woodward was comprised primarily of sand bluestem (*Andropogon* *hallii* Hack), little bluestem (*Schizachyrium scoparium* Nash), sand dropseed (*Sporobolus cryptandrus* (Torr.) Gray), sand lovegrass (*Eragrostis trichodes* (Nutt.) Wood), and sand sagebrush (*Artemisia filifolia* Torr.). The midgrass prairie and sandsage prairie have a larger forb component in the spring than the Stillwater site. Tallgrass prairie at Stillwater was dominated by big bluestem (*Andropogon gerardii* Vitman), little bluestem (*Schizachyrium scoparium* (Michx.) Nash), switchgrass (*Panicum virgatum* L.), and indiangrass (*Sorghastrum nutans* (L.) Nash).

Precipitation from January to December, 1994 measured 49.6, 70.6 and 48 cm at Klemme, Stillwater and Woodward, respectively. Long-term average precipitation at each location is 70, 83.1 and 57.5 cm, respectively. Rainfall from April to September averages 48.4, 54, and 37.4 cm at Klemme, Stillwater, and Woodward. In 1994 only 23, 39.9, and 29.8 cm, respectively, was received at each location during this same time period.

Pasture size used in the study was 1.6, 1.2 and 20.2 ha of OWB and 16.2, 43.3 and 3.6 ha of native range at Klemme, Woodward and Stillwater, respectively. At Woodward and at Stillwater, the OWB was burned in the spring (April), and 52 kg of N/ha was applied at Stillwater and 40 kg of N/ha was applied at Woodward. At Klemme, the OWB was neither burned or fertilized.

Sampling Procedures: Masticate and fecal samples were collected on native range and OWB from esophageal fistulated steers or heifers at each location from April 27, 1994 to February 18, 1995. During the growing season (April-October), samples were collected monthly. Samples were collected at 6 week intervals during the dormant period (October-February.) Cattle had ad libitum access to water and a mineral mixture[4]. Beginning in the late summer at Klemme and Stillwater, and the fall in Woodward, the cattle were supplemented with cottonseed cake. The supplement was withdrawn 5 days prior to each collection period.

Three steers were allocated to Klemme and Woodward, while three heifers were used at Stillwater. Surgical procedures were conducted by veterinarians at the Oklahoma State University College of Veterinary Medicine. All procedures were approved by the University Animal Care Committee. Between collection periods at both Klemme and Woodward, the steers grazed the rangeland pastures used in the study. At Stillwater, the heifers were maintained on range or hay between sampling periods, but were acclimated to the study pastures for 7 days prior to each collection period.

During each sampling period, masticates were collected from the rangeland then the fistulates were rotated onto the OWB paddocks for a 7 day adaptation period. This sequence was used because the cattle were maintained on native range between collection periods, hence no adaptation period was required prior to sampling. Masticate samples were obtained on two consecutive days from each forage source in each sampling period. At each location, the fistulates were penned approximately 4 h prior to the first collection period which occurred 1 h before sunset. The second collection period occurred the next morning approximately 1 h after sunrise. The fistulates were fitted with screen-bottom bags at Klemme and Woodward and solid bottom bags at Stillwater. If necessary, the fistulated cattle were herded as they grazed during the 30 to 45 minute collection period in order to obtain a sample that would better represent the diet. Following the first collection,

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[4] Salt 50%, Dicalcium Phosphate 49.15%, Copper Sulfate .40%, and Zinc Oxide .45%.

the samples were immediately removed from the collection bags, and refrigerated in plastic bags. After the second collection, the samples were composited across days within each animal and frozen in a plastic bag.

Fecal samples were also collected from the fistulated cattle during each sampling period. One sample was collected from each fistulated animal during each diet collection period (2 per sampling period/animal.) Fecal samples were composited across days within animal and stored frozen in a plastic bag.

Laboratory Analyses: The masticate samples were lyophilized[5] and ground in a Wiley mill through a 2 mm screen. The fecal samples reserved for NIR analysis were dried in a forced-air oven (50°C) and shipped to Texas A&M University, Grazing Nutrition Lab, Department of Rangeland Ecology and Management.

Masticate samples were analyzed for DM and ash content (AOAC, 1991). Nitrogen analyses were performed using a LECO®[6] instrument. In vitro organic matter disappearance from the masticate was determined using a modified two-stage Tilley and Terry (1962) procedure. Incubation tubes were inoculated with 10 ml of rumen fluid and 40 ml of McDougall's buffer solution containing trypticase. Rather than acid-pepsin digestion, the second stage was a cell wall extraction as described by Van Soest and Wine (1967). Ruminal fluid was collected from ruminally cannulated cows consuming prairie hay and a protein supplement. Four forage standards of known in vivo digestibility (alfalfa hay 76.3%, kleingrass hay 65%, prairie hay 59% and wheat hay 54.8% OMD) were included in each in vitro run (Hunt et al., 1990). Sample values were adjusted to an in vivo basis using regression analysis. This in vitro procedure was utilized because the NIR-

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[5] Virtis Freeze Drier. Model 10-100v, Virtis Corp., Gardiner, NY.

[6] LECO Model FP-428, LECO Corp., St. Joseph, MI.

calibration equations were developed using this procedure (Lyons and Stuth, 1992). All in vitro analysis were conducted in triplicate. All CP and DOM values are expressed on a DM basis because the NIR calibration equations were developed from reference CP and DOM values expressed on a DM basis (Lyons and Stuth, 1992).

The fecal samples sent to Texas A&M University for NIR analysis were ground in a Udy cyclone mill to pass a 1 mm screen and moisture was stabilized before scanning. NIR fecal scans and spectral analysis were conducted as described by Lyons and Stuth (1992).

Statistical Analysis: The final data set contained 125 observations. The relationships between fecal NIR estimates and laboratory values for diet CP and DOM were evaluated using simple and multiple regression (SAS, 1985). Initially, a model containing NIR estimates and indicator variables for location and forage type was analyzed to determine if relationships differed among and within forage types and locations. Stillwater native range was the base regression data set. The full model was reduced by individually eliminating the variable displaying the largest *P*-value. This process was repeated until the model only contained variables with *P*-values less than .1. Additionally, simple linear regression (SAS, 1985) was used to develop relationships between laboratory values and NIR estimates for the full data set, both forage types across locations, and for each forage type within location.

Results and Discussion

Crude Protein: Crude protein content of the esophageal masticate samples ranged from 3.55 to 20.33% (Table 3-1). The range of CP values for the entire data set and each forage type appear to be normal. Maximum CP values were higher for OWB than native range at Stillwater and Woodward. However, at Klemme the maximum CP content of OWB was equal to that of native range. Fertilization and burning of the OWB at Stillwater and Woodward are two factors that probably contributed to the higher CP values (Minson, 1990).

The range of CP values for OWB and native range at Klemme are in close agreement with those reported by Gunter (1993) when the same time periods are compared. Additionally, the range of CP values reported by Campbell (1989) for native range at Stillwater are similar to those encountered in this trial.

Throughout the collection periods, NIR CP predictions for native range and OWB at Klemme, Stillwater, and Woodward followed a similar pattern to actual CP values (Fig. 3-1, 3-2, and 3-3). However, NIR predictions were generally higher than actual CP concentrations for both forage types at each location.

The regression relationship between actual and NIR predicted CP from OWB and native range at Klemme, Stillwater, and Woodward is presented in Figure 3-4a. NIR fecal predictions of CP explained 61% of the variation in the masticate CP content of the entire data set. This is similar to the amount of variation (62%) explained by Lyons (1990) in the comparison of NIR predicted values from a 144-sample calibration set. However, the r^2 (.75) of the relationship between NIR predicted and actual CP was improved when an 88-sample calibration set was used. The increased r^2 was attributed to less variation in the CP content of the masticate samples for the 88-sample calibration set. The r^2 value for the CP equation in the present study was disappointing when compared with the r^2 of .99 reported by Brooks et al. (1984). However, this relationship was developed using a limited data set (n=36).

Fecal NIR overestimated diet CP across the range of data in this trial. An NIR estimate of 5% corresponded to a laboratory value of 2.5% CP while an estimate of 15% corresponded to a lab value of 10%. Lyons (1990) suggested that the problems encountered with the relationship between actual and predicted CP were due to the narrow range in masticate CP values (6.93 to 12.92%). The range in masticate CP (Table 3-1) values used in this study, however, closely resembled that of Brooks et al. (1984) (3.0 to 23.3%).

Multiple regression analysis indicated that forage type and location were significant sources of variation (Table 3-2). Intercepts for native range at Klemme and Woodward were significantly different (*P*<.08 and *P*<.05, respectively) from the intercept for native range at Stillwater. The individual relationships for native range at Klemme (Fig. 3-6) and Woodward (Fig. 3-8) had intercepts of .013 and 2.42, respectively, compared to the intercept of -1.60 (Fig. 3-7) for native range at Stillwater. The final model contained no adjustments for slope coefficients on native range (location x NIRCP interactions). If a higher probability is accepted, the slope values for Woodward rangeland would be different from Stillwater. Of the three locations, rangeland at Stillwater had the better agreement between laboratory and NIR data (higher r^2 and slope coefficient approaching 1). This may be attributed to the similarities in the rangeland species sampled in Stillwater and those used to develop calibration equations. Little bluestem and brownseed paspalum (*Paspalum plicatulum* Michx.) dominated the pastures where the calibration samples were collected (Lyons and Stuth, 1992). The pastures collected at Klemme were dominated by shortgrasses and midgrasses. At Woodward the pastures were comprised of some tallgrasses, but palatable forbs were in greater abundance than at Stillwater. Specific botanical composition estimates were not recorded at the three locations.

The fit of NIR predicted CP to actual CP (Fig. 3-5) suggests that NIR predictions of CP are more accurate for OWB than native range. This conclusion is based on the slope coefficient of .902 and r^2 of .65 for the OWB equation compared to the slope coefficient of .661 and r^2 of .53 for the native range equation. In the multiple regression analysis, the OWB main effect and location x OWB interactions were highly significant, indicating the intercept for OWB was different than rangeland at all 3 locations (Table 3-2). However, the only significant slope coefficient (location x OWB x NIR CP) was noted at Woodward. The ability of NIR to more accurately predict diet CP of OWB may be attributed to two factors. First, OWB is a monoculture and would be relatively homogeneous across locations compared to native range which has a wider variation in species composition. The diversity of the N containing constituents in the feces of cattle grazing native range may affect the spectral properties and increase the variation of the CP predictions. Second, it is possible that the esophageal masticate samples may have been more representative of the actual diet on OWB because it is a monoculture, and the rangeland pastures at Klemme and Woodward were larger.

The intercepts for OWB at Klemme and Woodward were also significantly different from the intercept for OWB at Stillwater (Table 3-2). The intercept of the individual regression equation at Stillwater (.936; Fig. 3-7) was greater than the intercepts at Klemme (-2.48; Fig. 3-6) and Woodward (-2.74; Fig. 3-8). The lack of fertilization and prescribed burning at Klemme may have influenced this relationship. The slope for OWB at Woodward approached 1 and was different (P=.073) than the slope for OWB at Stillwater (Figure 3-8). The slope was not different between Stillwater and Klemme.

Digestible Organic Matter: The ranges in DOM values (Table 3-1) used in this study appear to be normal, and the magnitude of the ranges are consistent to those reported by Gunter (1993) for OWB and native range in western Oklahoma and Campbell (1989) for native range at Stillwater. The range in OWB DOM values was greater than the DOM values for native range at Klemme. Gunter

(1993) found that OWB was significantly more digestible than native range at Klemme in 1990 and 1991. However, ranges in DOM at Stillwater and Woodward were similar between OWB and native range .

It appeared that NIR estimates of DOM more closely tracked actual DOM than was observed for actual and NIR predicted CP (Fig. 3-1, 3-2, and 3-3). Based on this, predictions of DOM by NIR appeared to be more accurate than predictions of CP. The deviations between actual and NIR predicted DOM at Klemme and Stillwater occurred in a consistent pattern. However, at Woodward the magnitude of the deviations between actual and NIR for both OWB and native range appeared to be greater from October to February than the rest of the collection periods. The reason for this effect is unclear.

The regression relationship for DOM across both forage types and across all three locations only accounted for 51% of the variation in actual DOM values (Figure 3-4). Additionally, the slope coefficient of .632 was disappointing compared to the slope (.820) for the CP equation. Across the range of data in this trial, NIR underestimated laboratory DOM when estimates where below 65% DOM. An NIR estimate of 50% DOM corresponded to a laboratory value of 55.8% while an estimate of 60% corresponded to a lab value of 62.1%. The r^2 (.51) of the regression equation was much lower than the r^2 (.88) reported by Brooks et al. (1984) in which fecal samples from elk were used to predict in vitro dry matter digestibility. However, the range (40.8 to 66.8) in the in vitro dry matter digestibility values was greater than the range in the present study. Lyons (1990) obtained an r^2 of .69 for the calibration equation for DOM. Stuth et al. (1989) obtained r^2 values ranging from .57 to .78 from NIR predictions of DOM using fecal samples from stocker cattle. Coleman et al. (1989) on the other hand, reported r^2 values ranging from .19 to .75 for the relationship between reference values and NIR predicted digestibility.

The final multiple regression model contained no significant slope or intercept coefficient adjustments for OWB or Klemme (Table 3-3). The multiple regression analysis did indicate that the intercept (Woodward) and slope (Woodward x NIR DOM) for native range at Woodward is significantly different (intercept P=.0539; slope P=.0685) than native range at Stillwater. This difference is evident in the individual regression relationships (Fig. 3-7 and Fig. 3-8) between actual and NIR predicted DOM. The intercept (38.22) at Woodward was larger than the intercept (13.62) at Stillwater. However, the slope coefficient at Woodward (.417) was smaller than the slope coefficient (.814) at Stillwater. The differences between the slope and intercept coefficients led to more accurate predictions of DOM at Stillwater than Woodward when actual DOM was less than 65%. An NIR estimate of 50% DOM corresponded to a laboratory value of 54.3% at Stillwater and 59.1% at Woodward while an estimate of 60% corresponded to a lab value of 62.5% and 63.2% for Stillwater and Woodward, respectively. As was the case with CP, this may be explained by errors introduced from the collection of samples in the larger native range pasture and from a more diverse plant community at Woodward.

This conclusion may help to explain some of the relationships developed in the present study. Regression relationships (Fig. 3-5) between actual and NIR DOM values produced a r^2 of .47 and .54 for native range and OWB, respectively. Perhaps, by increasing the range of DOM values and adding samples above 65% and below 60% DOM, the relationships would improve. The slope (.671 for native range and .615 for OWB) and r^2 (.47 for native range and .54 for OWB) of the equations for each forage type do not indicate that NIR is more accurate or precise in predicting DOM for either OWB or native range.

Comparisons of the relationships developed for each forage type within location did not illustrate a definite advantage in the ability of NIR to predict DOM at a given location for either forage type. In general, NIR explained the most variation (84%; Fig 3-6) in the actual DOM values on OWB at Klemme. However, at Stillwater the slope coefficients (native .814; OWB .734) were closer to 1 and the intercepts (native 13.62; OWB 16.90) were lower compared to both forage types at Klemme or Woodward. From the individual regression relationships, it appears that NIR predictions of DOM are more accurate for OWB at Stillwater than either forage type at Klemme and Woodward. From the regression equation for OWB at Stillwater, estimates of 50 and 60% DOM by NIR would correspond to 53.6 and 60.9% DOM from laboratory analysis. Lyons (1990) concluded that the relationship between NIR estimates and lab values could have been improved by increasing the range of DOM values by adding samples greater than 64% to the data set. In contrast, relationships developed in the present study suggests that the improvements might have been made by increasing the range of DOM values and adding samples of lower digestibilities to the data set.

Implications

NIR was not useful as a general predictor of forage quality in this study. The individual relationships within location and forage type indicate that the accuracy of NIR for a specific forage at a given location can vary considerably and estimates from a general calibration may produce highly erroneous results given a specific set of conditions. Therefore, the present research suggests that the value of NIR will be limited for the individual producers in Oklahoma unless the calibration equations are improved.

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TABLE 3-1. RANGE, MEAN, AND STANDARD ERRORS FROM THE LABORATORY ANALYSIS OF ESOPHAGEAL MASTICATE SAMPLES AT KLEMME, STILLWATER, AND WOODWARD FOR NATIVE RANGE AND OLD WORLD BLUESTEM. (APRIL 27, 1994 TO FEBRUARY 8, 1995.)

Item	Range	Mean	SEM[1]
		%	
Total[2]			
CP	3.55-20.33	8.99	.34
DOM	53.94-71.03	62.83	.35
Native range			
CP	3.55-15.26	8.14	.37
DOM	54.04-68.93	62.37	.46
Old World Bluestem			
CP	3.65-20.33	9.85	.55
DOM	53.94-71.03	63.29	.52
Native range, Klemme			
CP	3.76-12.13	7.46	.51
DOM	54.04-65.88	60.51	.71
Old World Bluestem, Klemme			
CP	3.65-12.13	6.94	.60
DOM	59.00-70.03	63.34	.71
Native range, Stillwater			
CP	3.55-14.09	7.48	.68
DOM	56.27-68.93	62.94	.90
Old World Bluestem, Stillwater			
CP	5.97-20.18	11.23	.89
DOM	53.94-71.03	62.64	1.17
Native range, Woodward			
CP	6.22-15.26	9.69	.63
DOM	59.13-67.04	64.00	.56
Old World Bluestem, Woodward			
CP	6.67-20.33	11.72	1.04
DOM	57.88-67.75	64.03	.69

[1] SEM = standard error of the mean.

[2] Contains data from Klemme, Stillwater, and Woodward for both native range and Old World Bluestem.

TABLE 3-2. RESULTS OF MULTIPLE REGRESSION RELATING LABORATORY CRUDE PROTEIN VALUES FROM ESOPHAGEAL MASTICATES AND FECAL NIR ESTIMATES AT KLEMME, WOODWARD, AND STILLWATER FOR BOTH NATIVE RANGE AND OLD WORLD BLUESTEM

	Model[1]				
Item	1	2	3	4	5
	-------------------*P*-value--------------------				
Base regression equation					
Stillwater Native Range (Intercept)	.3866	.1407	.1313	.0848	.1535
Stillwater Native Range NIR CP (Slope)	.0001	.0001	.0001	.0001	.0001
Intercept Adjustments					
Location					
Klemme	.5478	.4501	.0692	.0643	.0756
Woodward	.1756	.1115	.1136	.0997	.0405
Forage type					
OWB	.2885	.0001	.0001	.0001	.0001
Location x Forage Type					
Klemme x OWB	.1817	.0830	.0527	.0001	.0001
Woodward x OWB	.0519	.0149	.0144	.0141	.0236
Slope Adjustments					
Location					
Klemme x NIR CP	.8666	.8163	---	---	---
Woodward x NIR CP	.3755	.2773	.2863	.2581	---
Forage type					
OWB x NIR CP	.9525	---	---	---	---
Location x Forage type					
Klemme x OWB x NIR CP	.7999	.7219	.7865	---	---
Woodward x OWB x NIR CP	.1231	.0410	.0402	.0394	.0728
R-square	.7069	.7069	.7068	.7066	.7033
Root MSE	2.14	2.13	2.12	2.12	2.12

[1] Variables with the largest *P*-value were eliminated individually until only variables with a *P*-value less than .1 remained in the model.

TABLE 3-3. RESULTS OF MULTIPLE REGRESSION RELATING LABORATORY DIGESTIBLE ORGANIC MATTER VALUES FROM ESOPHAGEAL MASTICATES AND FECAL NIR ESTIMATES AT KLEMME, WOODWARD, AND STILLWATER FOR BOTH NATIVE RANGE AND OLD WORLD BLUESTEM

	Model[1]								
Item	1	2	3	4	5	6	7	8	9
					P-value				
Base regression equation									
Stillwater Native Range Intercept	.2068	.1146	.0091	.0088	.0049	.0001	.0001	.0001	.0001
Stillwater Native Range NIRDOM Slope	.0001	.0001	.0001	.0001	.0001	.0001	.0001	.0001	.0001
Intercept Adjustments									
Location									
Klemme	.4950	.2263	.2279	.2260	.2742	---	---	---	---
Woodward	.0962	.0627	.0561	.0270	.0384	.0767	.0536	.0611	.0539
Foage type									
OWB	.8005	.7050	---	---	---	---	---	---	---
Location x Forage type									
Klemme x OWB	.9933	---	---	---	---	---	---	---	---
Woodward x OWB	.6857	.6347	.7482	---	---	---	---	---	---
Slope Adjustments									
Location									
Klemme x NIR DOM	.4450	.1779	.1766	.1749	.2267	.1994	---	---	---
Woodward x NIR DOM	.1002	.0653	.0585	.0293	.0469	.0941	.0729	.0813	.0685
Foage type									
OWB x NIR DOM	.7072	.5776	.0580	.0571	.1189	.1487	.2978	---	---
Location x Forage type									
Klemme x OWB x NIR DOM	.8851	.0260	.0200	.0195	.0401	.0656	.1846	.3393	---
Woodward x OWB x NIR DOM	.6333	.5751	.6722	.2580	---	---	---	---	---
R-square	.5590	.5590	.5585	.5581	.5532	.5486	.5422	.5380	.5344
Root MSE	2.72	2.71	2.70	2.69	2.69	2.69	2.70	2.70	2.70

[2]Variables with the largest *P*-value were eliminated individually until only variables with a *P*-value less than .1 remained in the model.

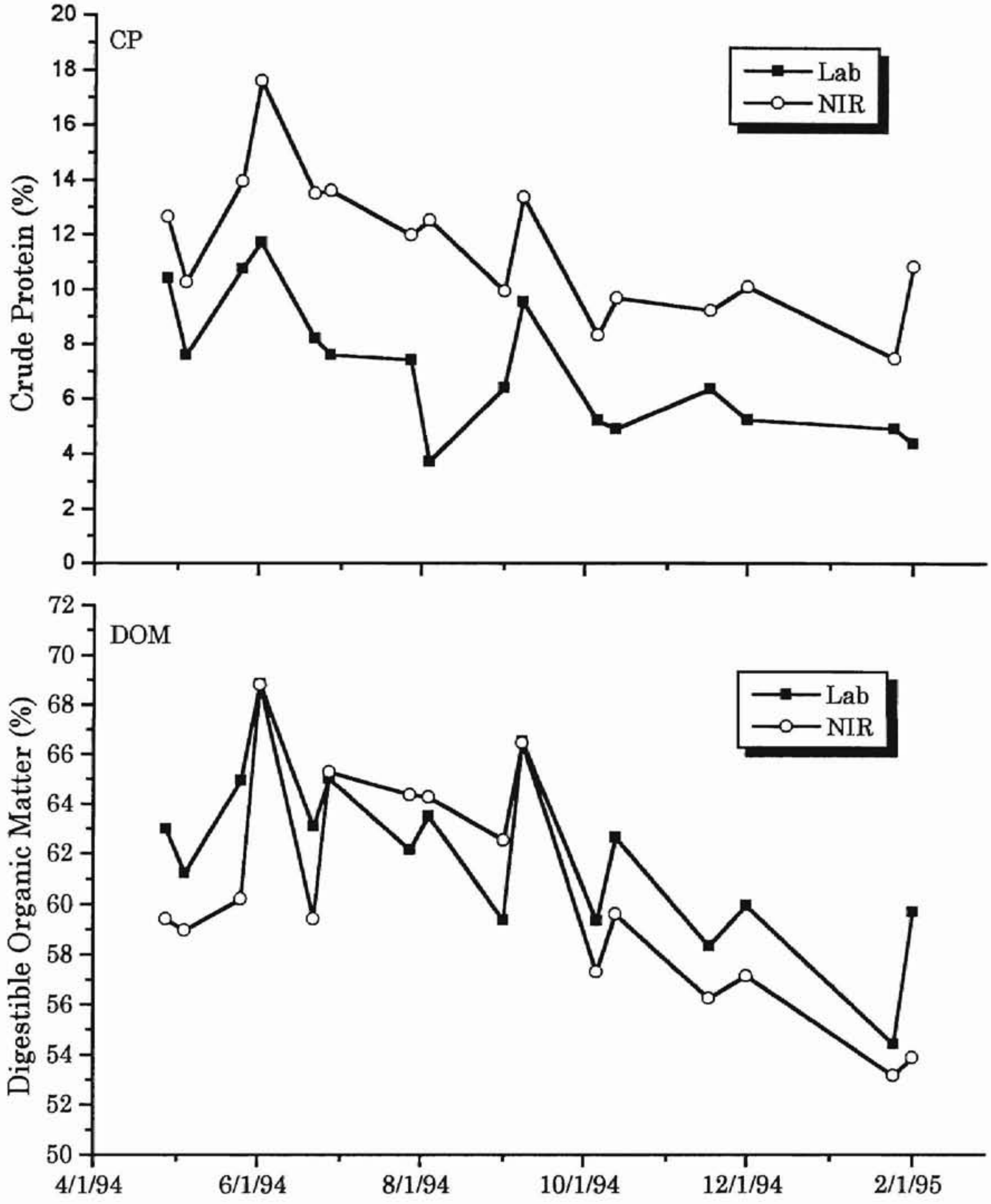

FIGURE 3-1. NIR PREDICTED AND ACTUAL LABORATORY CRUDE PROTEIN AND DIGESTIBLE ORGANIC MATTER AT KLEMME RANGE RESEARCH STATION FROM APRIL 28, 1994 TO FEBRUARY 1, 1995.

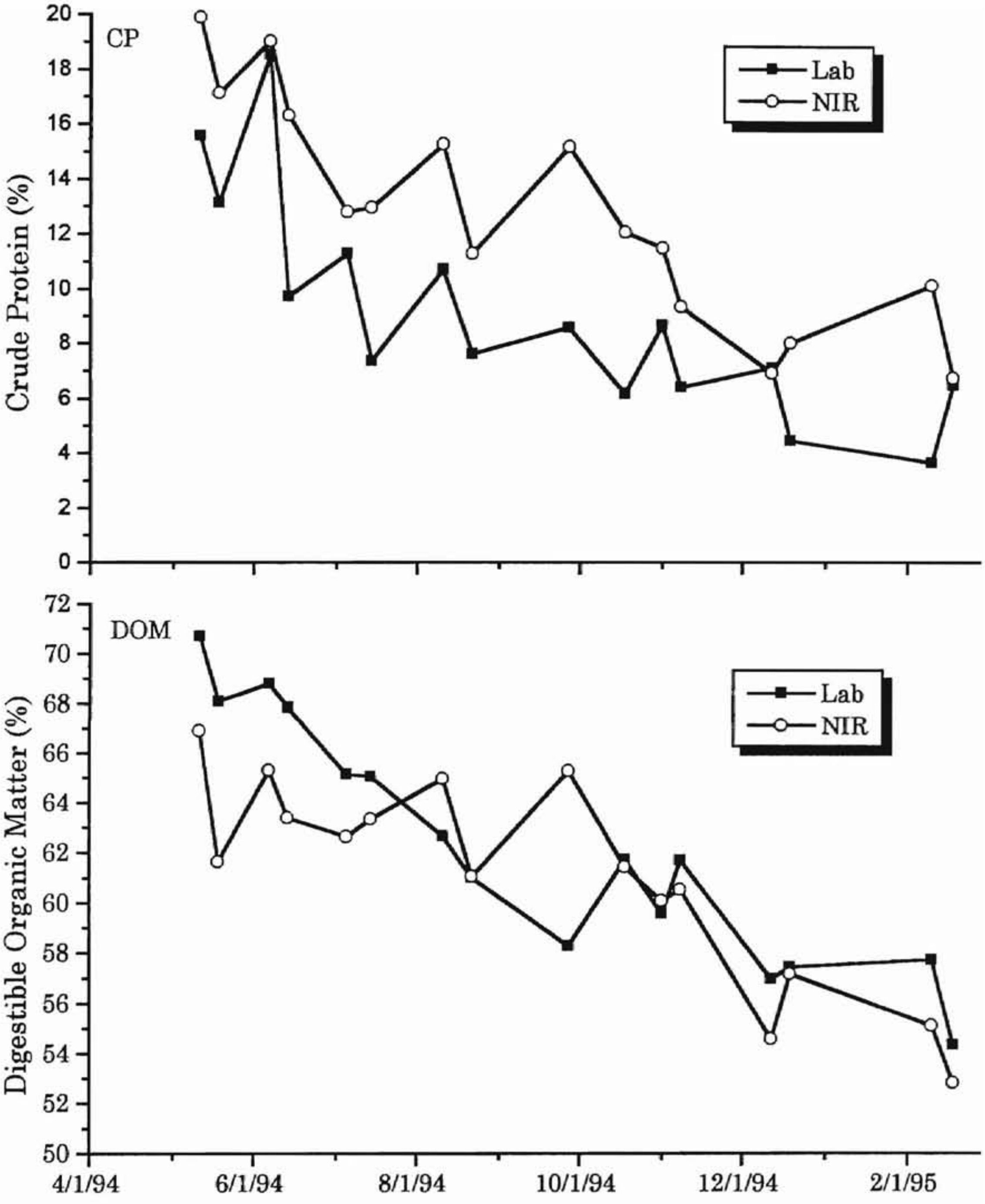

FIGURE 3-2. NIR PREDICTED AND ACTUAL LABORATORY CRUDE PROTEIN AND DIGESTIBLE ORGANIC MATTER AT STILLWATER FROM MAY 15, 1994 TO FEBRUARY 18, 1995.

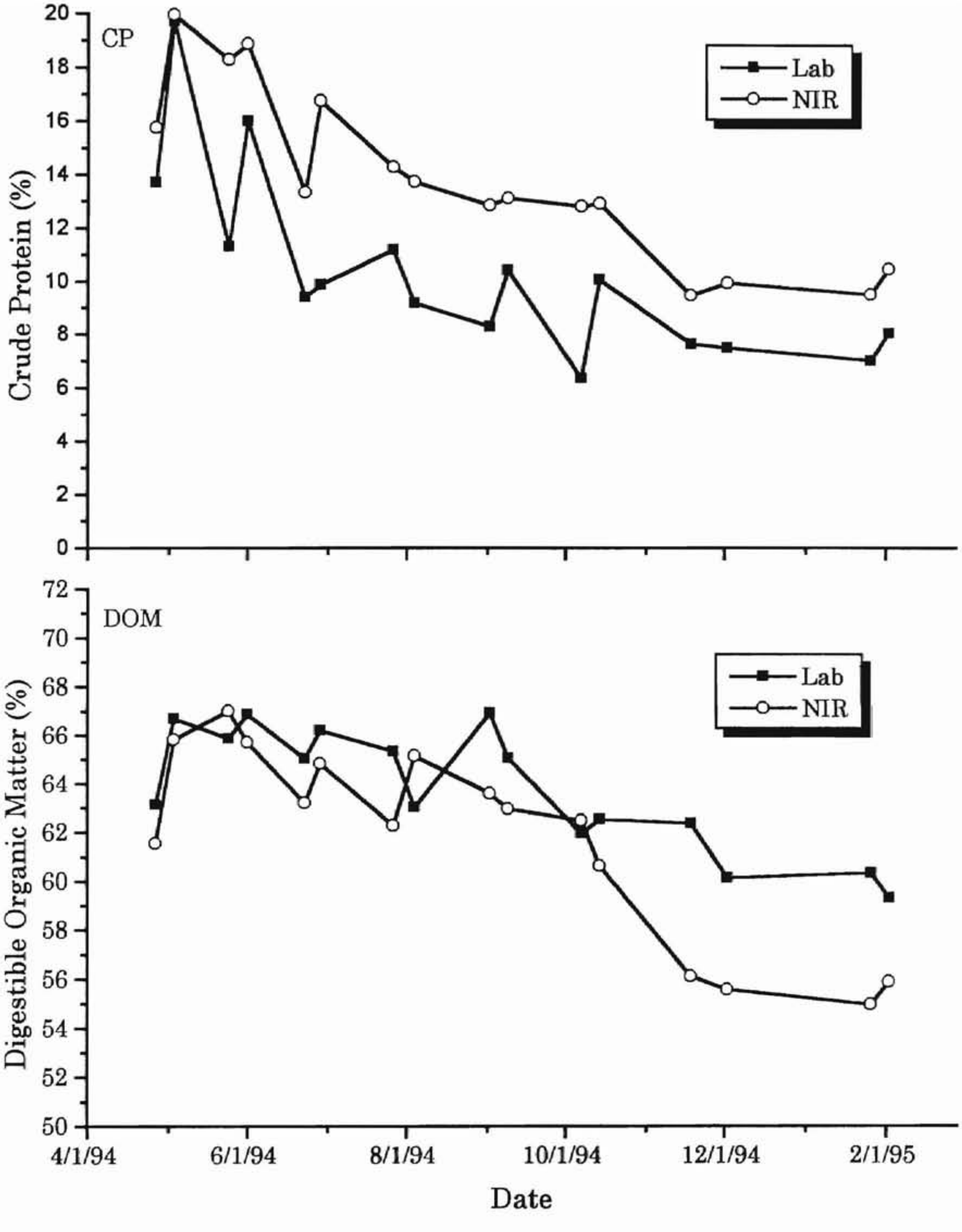

FIGURE 3-3. NIR PREDICTED AND ACTUAL LABORATORY CRUDE PROTEIN AND DIGESTIBLE ORGANIC MATTER AT WOODWARD FROM APRIL 27, 1994 TO FEBRUARY 2, 1995.

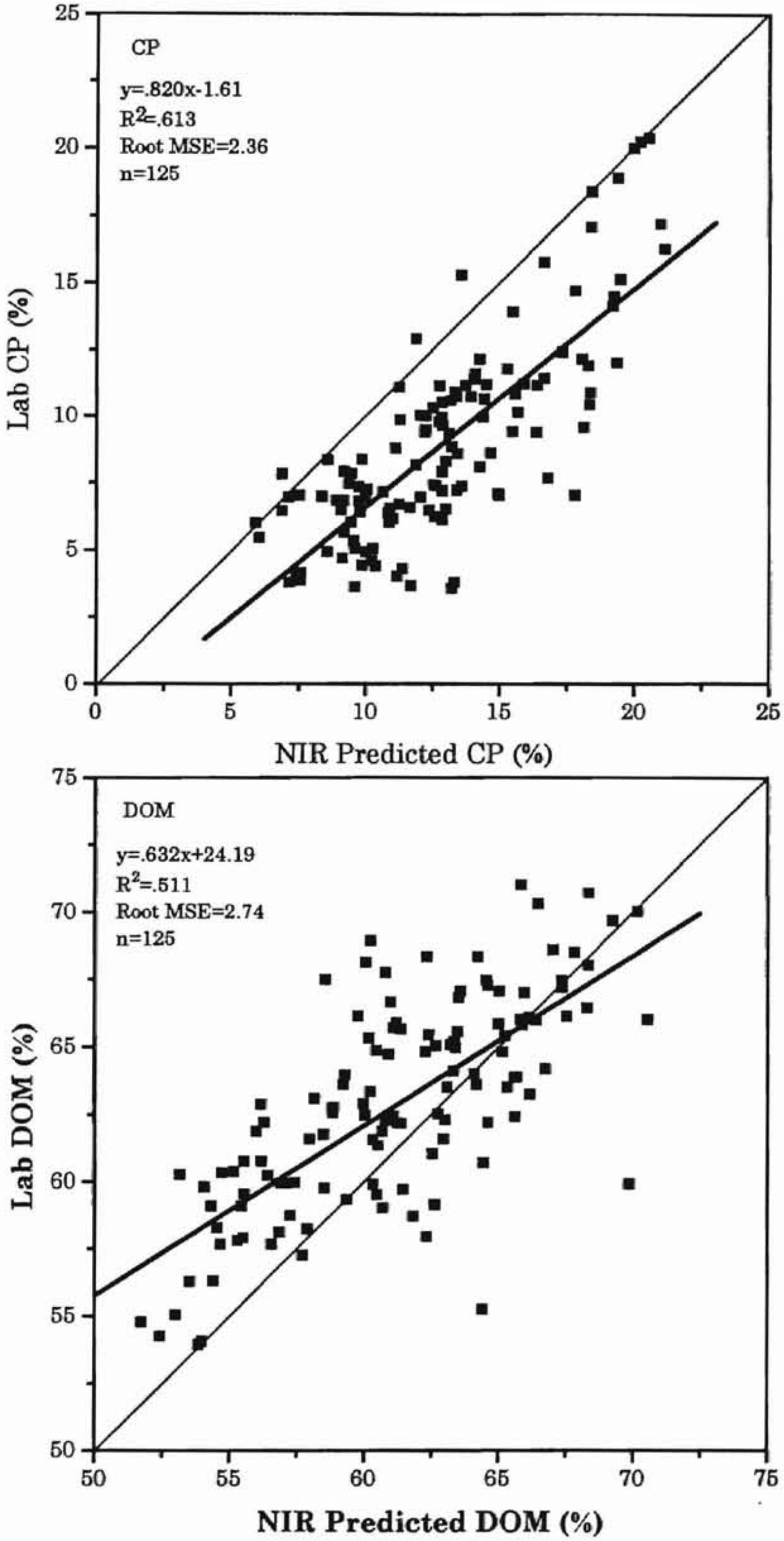

FIGURE 3-4. RELATIONSHIP BETWEEN LABORATORY AND NIR PREDICTED CRUDE PROTEIN (CP) AND DIGESTIBLE ORGANIC MATTER (DOM) AT KLEMME, STILLWATER, AND WOODWARD FOR NATIVE RANGE AND OLD WORLD BLUESTEM.

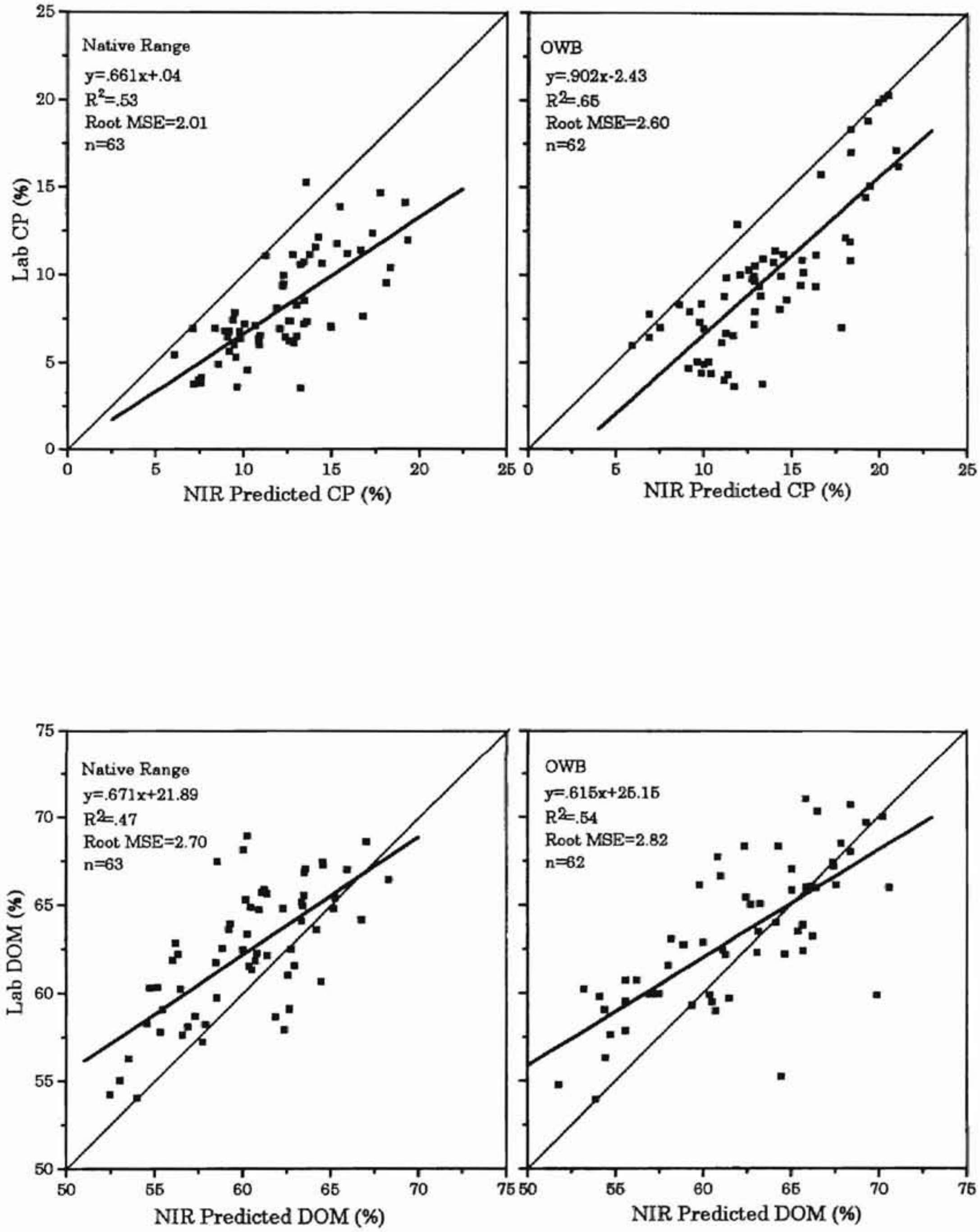

FIGURE 3-5. RELATIONSHIP BETWEEN LABORATORY AND NIR PREDICTED CRUDE PROTEIN (CP) AND DIGESTIBLE ORGANIC MATTER (DOM) FOR NATIVE RANGE AND OLD WORLD BLUESTEM ACROSS ALL THREE LOCATIONS.

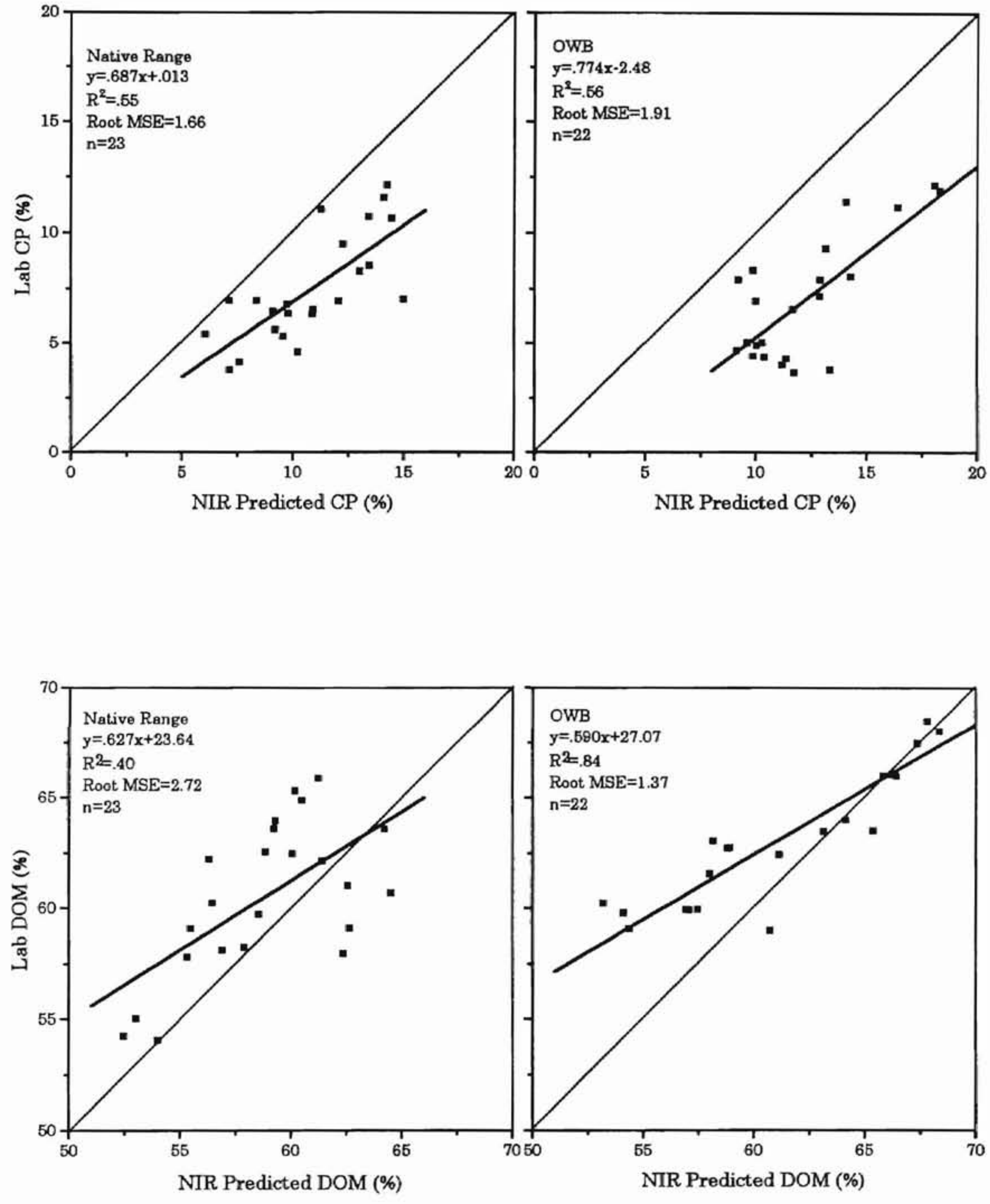

FIGURE 3-6. RELATIONSHIP BETWEEN LABORATORY AND NIR PREDICTED CRUDE PROTEIN (CP) AND DIGESTIBLE ORGANIC MATTER (DOM) FOR NATIVE RANGE AND OLD WORLD BLUESTEM AT KLEMME RANGE RESEARCH STATION.

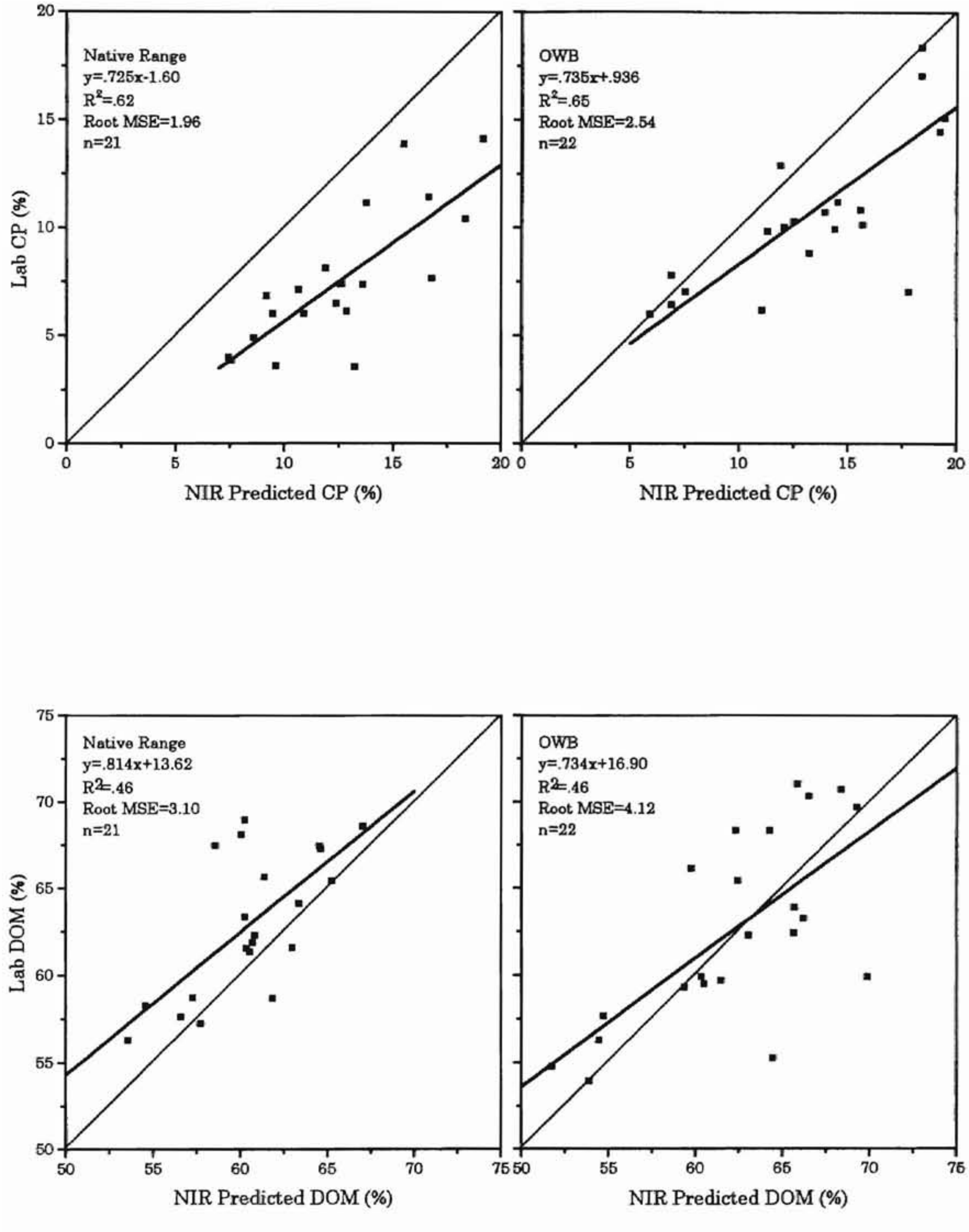

FIGURE 3-7. RELATIONSHIP BETWEEN LABORATORY AND NIR PREDICTED CRUDE PROTEIN (CP) AND DIGESTIBLE ORGANIC MATTER (DOM) FOR NATIVE RANGE AND OLD WORLD BLUESTEM AT STILLWATER.

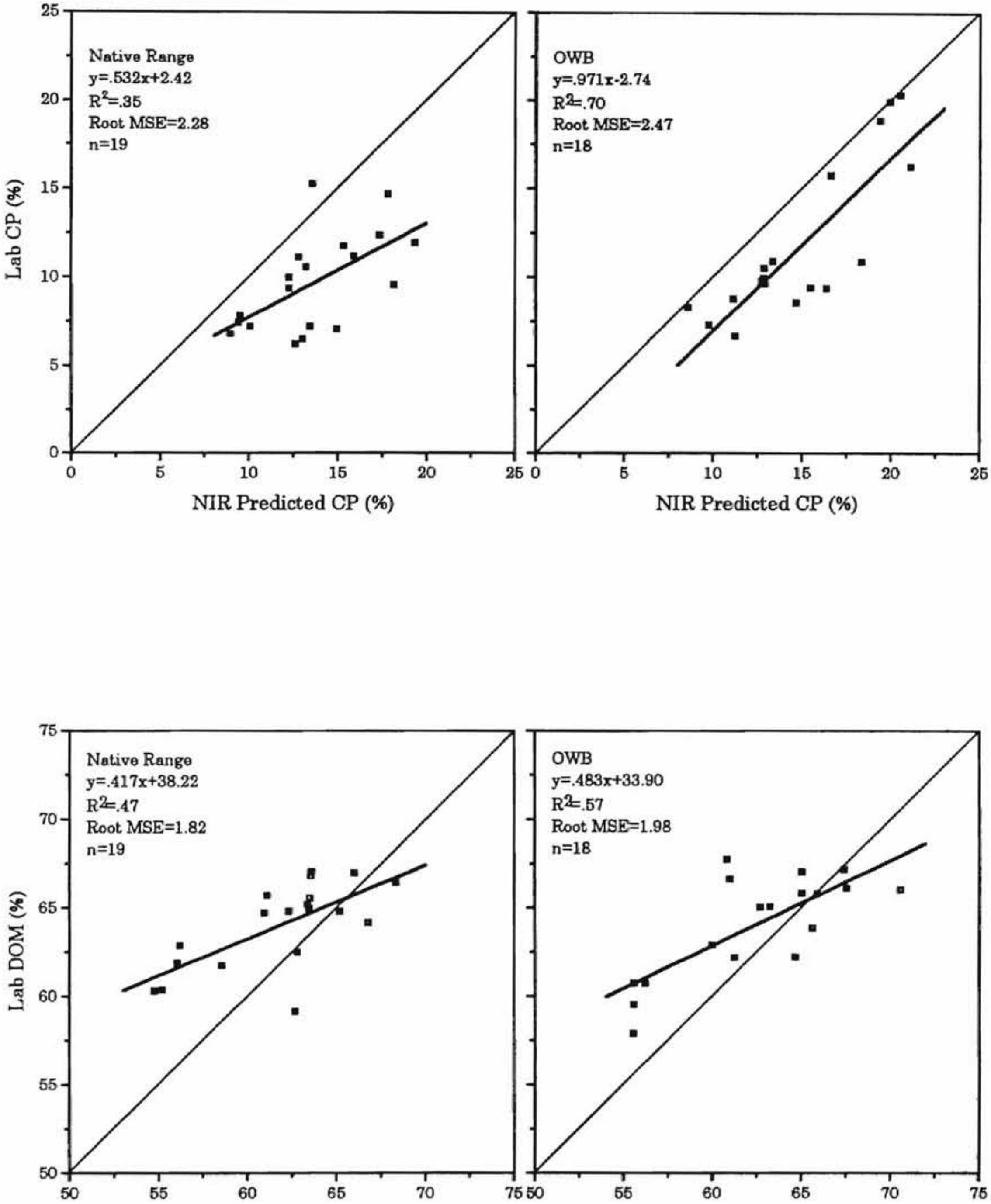

FIGURE 3-8. RELATIONSHIP BETWEEN LABORATORY AND NIR PREDICTED CRUDE PROTEIN (CP) AND DIGESTIBLE ORGANIC MATTER (DOM) FOR NATIVE RANGE AND OLD WORLD BLUESTEM AT WOODWARD.

CHAPTER IV

APPLICATION OF THE TEXAS A&M NUTBAL MODEL TO PROJECT PERFORMANCE OF STOCKER CATTLE GRAZING RANGELAND IN OKLAHOMA

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Abstract

Trials were conducted to test the Texas A&M NUTBAL model projections for the performance of steers grazing rangeland. In trial 1, 45 crossbred steers (244 kg) grazed tallgrass prairie from April 29 to September 6, 1994. Steers were allocated to three treatment groups: Control (.06 kg/d cottonseed meal), Protein (.45 kg/d cottonseed meal), and Energy (.63 to .72 kg/d cracked corn). Supplemental weight gain and final weight for the control (59 and 359 kg) and energy groups (59 and 366 kg) were similar (*P*=.98 and *P*=.42, respectively). The protein group weighed more (389 kg; *P*<.01) at the end of the trial and gained more weight (78 kg; *P*=.0001) during the supplementation period than the control and energy groups. Diet composition was estimated weekly by NIR analysis of feces. This information along with animal and environmental inputs was used to project weight gain with the Texas A&M NUTBAL model. NUTBAL overestimated gains for all 3 groups, but the greatest bias occurred in the energy supplemented group.

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Estimated performance for the protein supplemented group fell within a 95% confidence interval around the actual weights. Model estimated forage intake had to be adjusted between -45% and +21% for the model to fit actual weight gains. In trial 2, 13 and 21 crossbred steers (221 kg) grazed midgrass prairie rangeland stocked at 3.6 (light) and 1.9 ha/hd (heavy). The steers gained 128 kg (light) and 101 kg (heavy) from April 6 to September 7, 1994. NUTBAL predictions of ADG accounted for 56% of the variation in actual ADG (actual ADG=1.162* NUTBAL ADG -.238) of the entire data set (n=12). The NUTBAL predicted weights did not fall within a 95% confidence interval of the actual weights. NUTBAL predictions improved when actual forage availability from standing crop measurements were used in the model. Model projections were still less accurate for the light stocking rate. Based on these trials, it appears that the current NUTBAL system needs modification to better account for actual performance and the impacts of supplementation and forage environment on estimated forage intake and performance.

Key Words: Near Infrared Reflectance Spectroscopy, Supplementation, Stocking Rates

Introduction

Stocker cattle operations are an important part of Oklahoma's economy. Several management options are available to producers managing stocker cattle grazing native range throughout the growing season including supplementation, grazing management, use of alternative forages and market timing. However, the success of these decisions generally cannot be evaluated until after the cattle have been marketed. Managers could obtain more benefit from this information if it were presented in a framework better suited for tactical decision-making.

One such framework that has been proposed as a decision support system is the Nutritional Balance Analyzer (NUTBAL; Stuth and Lyons, 1995). This computer model estimates livestock performance and supplemental nutrient needs based on diet quality estimates, nutritional requirement standards (NRC, 1984) and environmental conditions that affect animal performance (Fox et al., 1988). The user inputs are designed whereby each producer can develop cases relevant to individual situations.

Conceptually, this model could be very beneficial to livestock managers of grazing cattle. However, few field trials have been conducted to test the mechanics and overall performance of NUTBAL. Accurate economic projections are dependent upon accurate prediction of animal performance. Therefore, the objectives of this study were to evaluate the accuracy and precision of stocker cattle performance projections by NUTBAL. Supplementation practices and stocking rates were used to influence cattle performance and test mechanical aspects of the model.

Materials and Methods

Research Site: The study consisted of two independent experiments. Trial 1 was conducted at the Oklahoma Agricultural Experiment Station Research Range located approximately 21 km southwest of Stillwater, OK. The experimental pasture was 76.5 ha in size with predominantly a Red Clay Prairie range site with soils in the Vernon series. Vegetation in the pasture was dominated by big bluestem (*Andropogon gerardii* Vitman), little bluestem (*Schizachyrium scoparium* Nash), switchgrass (*Panicum virgatum* L.), and indiangrass (*Sorghastrum nutans* Nash). The pasture was burned in early April 1994. The longterm average precipitation from April through September is 54 cm; however in 1994, only 39.9 cm of precipitation was received.

Trial 2 was conducted 16 km south of Clinton, OK at the Marvin Klemme Range Research Station (Klemme) . The soils at Klemme are in the Cordell series and classified as Red Shale range sites. Midgrass prairie at this location is comprised primarily of sideoats grama (*Bouteloua curtipendula*), blue grama (*Bouteloua gracilis* Lag.), and buffalo grass (*Buchloe dactyloides* Engelm.) with some little bluestem (*Schizachyrium scoparium* Nash). Precipitation received from April through September, 1994 was 23 cm compared to the long-term average of 48.4 cm for the same period.

Trial 1. Forty-five Hereford x Angus x Saler steers were allocated to either a control, protein or energy supplementation group based on weight, and previous implant (implanted in January, 1994 with 0, 100, 200 or 300 mg trenbolone acetate) as well as origin (steers originated from two separate research herds). Due to the size of the pasture and the number of trees contained within the pasture, the control group was provided .06 kg of cottonseed meal daily to ensure that all steers were present during a feeding period. During each feeding period, all of the steers were gathered at 0800h and separated into pens for the respective treatment groups. The steers were fed in the morning because of the difficulty of gathering all of the steers at later times during the day. After the steers were separated, the energy and protein supplemented groups were fed the respective feedstuffs in bunks while the control group was fed on the ground outside the pens. The protein supplement group received .45 kg of cottonseed meal daily. Research has shown that protein supplementation of cattle grazing native range late in the summer consistently increases average daily gain from .09 to .18 kg/d compared to unsupplemented cattle. The energy supplemented group was provided from .63 to .72 kg of cracked corn daily based on the mediation section within NUTBAL. The mediation section in NUTBAL calculates the amount of a given feedstuff required to correct nutrient deficencies, then uses a least cost program to select the supplement. Cottonseed meal, cracked corn, and 20% CP range cubes were entered as the possible supplement choices from which NUTBAL could select in order to increase weight gain by a target of .14 kg/hd daily. This level of added weight gain (.14 kg/hd) was selected because previous research at Oklahoma State University suggests that protein supplemented cattle can be expected to increase weight gain by .09 to .18 kg/d.

The steers were managed as a single herd and continuously grazed the experimental pasture, at a moderate stocking rate (1.7 ha/hd), from April 29 to September 6, 1994. All steers had ad libitum access to water and a mineral mixture containing chlortetracycline[4] . Before the initiation of the trial all steers were given a parasiticide for the control of internal parasites and implanted with Synovex®. The steers were reimplanted with Synovex® in early July.

The steers were weighed individually at the beginning of the experiment and at approximately monthly intervals during the trial. All weights were recorded after an overnight shrink. An additional weight was recorded at the beginning of the supplementation period on June 10, 1994.

Fecal samples were collected on Monday of each week and mailed to the Grazing Animal Nutrition Lab, Texas A&M University[5] in a styrofoam mailer containing a cold pack to obtain NIR based estimates of diet digestible organic matter (DOM) and CP. During the supplementation period, this procedure ensured that samples were collected at least 72 h after the supplement was offered (Lyons and Stuth, 1993). Random samples were obtained from at least five

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[4] Salt 50%, Dicalcium Phosphate 49.15%, Copper Sulfate .40%, Zinc Oxide .45% (350 mg CTC/hd daily).

[5] Grazing Animal Nutrition Lab, Department of Rangeland Ecology and Management, Texas A&M University, College Station, TX 77843.

different steers for each treatment group. Fecal samples were composited within treatment group. NIR procedures and diet quality predictions were performed as described by Lyons and Stuth (1992). In early September, 50, .1m^2 quadrats were clipped from the pasture to determine standing crop at the end of the trial.

Trial 2. Two pastures in a large stocking rate study (seven pastures stocked at different rates) were selected based on differences in stocking rate and historical weight gains. Thirteen and 21 British x European crossbred steers were allocated based on weight from a larger group of cattle and continuously grazed on a light (pasture 3) and heavy (pasture 8) stocked pasture, respectively, from April 6 to September 7, 1994. Pasture 3 contained 47 ha and pasture 8 contained 40.1 ha. The stocking rates were 3.6 and 1.9 ha/hd for pastures 3 and 8, respectively. Steers had ad libitum access to water and a mineral mixture containing chlortetracycline. All steers were given a parasiticide for the control of internal parasites and implanted with Synovex® at the beginning of the trial. The steers were reimplanted with Synovex® half way (mid-July) through the grazing season. The steers were weighed initially and at monthly intervals during the grazing season.

Fecal samples were collected monthly when the cattle were weighed. Random samples were collected from at least five individual steers in each pasture. Samples were composited across steers within pasture and stored frozen in a plastic bag. All fecal samples were dried in a forced-air oven (50°C) and shipped to Texas A&M University for NIR analysis of diet composition.

Model Inputs: Inputs for the NUTBAL computer model include animal description, activity level, environmental factors, weight performance goals, diet quality, supplements, and feed additive and ionophore information.

Trial 1. The steers were assumed to be yearling steers, 14 months of age at the beginning of the trial. Age was increased monthly. The Hereford x Angus breed option within NUTBAL was considered to more closely resemble the breed makeup of the steers. The activity level selected was less than 15% slope in the pasture and less than .8 km to water. Environmental inputs were obtained from a local television station's weekly weather forecasts. Initial weights of each treatment group were entered and NUTBAL calculated the weight gain for the first week. The weight gain was added to the initial weight and entered into NUTBAL as the current weight for the next weekly period. This process was repeated throughout the remainder of the experiment.

Diet quality estimates were obtained from the NIR analysis of feces from each treatment group. Forage availability was assumed to be greater than 2240 kg/ha for (Trial 1) based on historical standing crop measurements. NUTBAL decreases forage intake when standing crop drops below this point. In early September, forage availability was determined by clipping the pasture. The clipping data determined that forage availibility was below 1650 kg of DM/ha. Rather than enter another variable that would effect weight gain projections by NUTBAL the trial was ended. For Trial 2, actual standing crop data was available from clipping measurements (Gillen, unpublished data).

NUTBAL does not contain an input for the chlortetracycline provided in the mineral mixture. Therefore, the 22 mg of monensin and implant option was used because research has shown monensin and chlortetracycline have similar impacts on weight gain (McCollum et al., 1988).

NUTBAL calculated average daily gains based on these inputs. Previous research at Oklahoma State University suggested that protein supplementation would increase weight gain by .14 kg/d. Based on this, the mediation routine of

NUTBAL calculated the amount of supplement required to increase average daily gain by .14 kg/d and selected among the three feedstuffs. The selection routine is a least cost algorithm. Price inputs for corn, cottonseed meal and 20% cubes were 133, 205 and 173 $/ton, respectively. Cracked corn was the only supplement selected by NUTBAL during the entire feeding period. Based on this and well-established responses to protein supplementation on tallgrass prairie, it appears that the algorithms in the current NUTBAL system need refinement in relation to protein supplementation.

Trial 2. Animal performance estimates were made after the conclusion of the experiment at Klemme. Model inputs used for the two pastures at Klemme were similar to Trial 1 except for breed composition, environmental factors, and diet quality estimates. The breed option of Hereford x Brangus x Shorthorn was used. Unlike the previous experiment actual weather records from an onsite automated weather station were used for the environmental inputs. Forage quality estimates were provided from NIR analysis of the fecal samples collected monthly from each pasture. Because no supplement was offered, the supplementation input was not used. Forage availability was adjusted based on clipping data. In May, July and September, 45, .1m^2 quadrats were clipped from each pasture to determine forage availability.

Data Analysis: Mean weights and gains for the supplementation groups in Trial 1 were analyzed using the least squares procedure and a completely randomized design. Cumulative weight curves for steers in both experiments were developed from actual weights using regression (SAS, 1985; Figure 4-1). Actual weight was the dependent variable, and the number of days on pasture was the independent variable. The model included both linear and quadratic functions.

Confidence intervals (95%) were established around these functions to determine if weights estimated by NUTBAL fell within these intervals.

Actual rate of weight gain was estimated by solving the 1st derivative of the quadratic weight curves on the dates corresponding to the weekly average daily gain projections by NUTBAL. Simple linear regression was used to compare the relationships between actual and NIR predicted average daily gain.

After evaluating the initial relationships, further adjustments were made in an effort to improve the accuracy of NIR predictions. First, the diet quality estimates from NIR analysis of fecal samples were adjusted using the regression relationships developed by Bogdahn (1995) between the actual diet composition and fecal NIR estimates. The adjusted diet quality estimates were then used to generate new performance predictions which were compared to the 95% confidence interval around the actual weights. Next, the intake adjustment in the model was either increased or decreased from zero (from the original NUTBAL estimates) to force the model to project the actual weight of the steers for each weekly interval. These procedures were conducted for Trials 1 and 2. An additional adjustment was made in Trial 2. Originally, forage availibility was set above 2240 kg/ha to keep this input from affecting weight predictions. Subsequently, actual standing crop measurements were incorporated, and a 95% confidence interval was used to compare actual and adjusted NUTBAL weight predictions.

Results and Discussion

Trial 1. Average steer weights and gains for each treatment are presented in Table 4-1. Weight gains from April 29 until the start of supplementation (early gain) were similar (*P*=.20) for the control and energy groups, but the protein supplemented steers gained more weight (*P*=.0125) than the controls during this time period. Considering this, the animals within the treatments could have been reallocated before the initiation of supplementation. But, composite fecal samples had been collected since the beginning of the trial for NUTBAL diet quality inputs so the groups were not rearranged. Intermediate and late summer weight gains for the energy and control groups were similar ($P>.17$). However, during the supplementation period, the protein supplemented group gained 19 kg more ($P<.05$) weight than either of the other treatment groups. Final weights for the protein supplemented steers were greater ($P<.01$) than for the energy and control groups. The increased weight gain by protein supplementation from June 10 to September 6 was consistent with previous research demonstrating that a small amount of a protein supplement would increase ADG by at least .14 kg/d compared to unsupplemented controls. Actual ADG's during the supplementation period were .89, .93, and 1.11 kg/d for the control, energy, and protein groups, respectively. The effects of supplementation on weight gain in the present study are in close agreement with the weight gains reported by Lusby and Horn (1983). These researchers reported that feeding a 39% CP soybean meal supplement at a rate of .36 kg/d increased ADG by .19 kg/d compared to the controls. Additionally, protein supplemented steers gained .18 kg more weight per day than steers fed a 10% CP corn-based supplement at rate of 1.36 kg/d. This equaled the improvements in ADG observed in the present study.

The original intention of the energy treatment was to allow the NUTBAL model to select the type and level of supplement, based on estimated nutrient intake and supplement composition and cost, that would increase daily weight gain by .14 kg/d in an economically efficient manner. It is interesting to note that throughout the supplementation period, NUTBAL always selected the cracked corn option. This indicates that the algorithms in NUTBAL were considering only the additional energy required to promote the .14 kg/d additional gain. But, this supplementation program did not improve gain. Because the protein group did respond but was not selected as an alternative by NUTBAL, the model is apparently not sensitive to the changes in forage composition and intake associated with the response to protein supplementation.

Figure 4-2 illustrates the range of CP and DOM values predicted by NIR and used for diet composition inputs in NUTBAL. There were no systematic deviations observed for either CP or DOM values from the different treatments.

In general, NUTBAL predictions of ADG appeared to fit the actual values (Fig. 4-3). The regression relationship containing all of the treatment groups accounted for 79% of the variation in actual ADG and had a slope coefficient of 1.01. A slope coefficient of 1 would indicate that estimated performance was biased consistently across the range of data. It does appear, based on the data plots, that NUTBAL predictions may be more accurate when actual ADG is greater than 1 kg/d. This may be an artifact of predicted and actual response to the energy supplement when gains were less than 1 kg/d.

Regression relationships for the treatments are presented in Figures 4-3, 4-3, and 4-3. NUTBAL explained 83, 88, and 83% of the variation in actual ADG for the control, energy and protein groups, respectively. The slope for the controls was near 1. Based on the intercept coefficient, NUTBAL over-estimated ADG by .14 kg/d. The relationship for the energy group had the most severe adjustment for the slope (1.16) and intercept (-.42 kg/d). For the energy group, NUTBAL estimated gains of .5 and 1.5 kg/d would have corresponded to actual gains of .16 and 1.32 kg/d. NUTBAL more accurately predicted ADG for the group receiving a protein supplement. NUTBAL over-estimated actual ADG by less than .08 kg/d over the range of gains recorded for this treatment.

Cumulative weight curves based on actual weights and NUTBAL projections are shown in Figure 4-4. Early in the grazing season (<60 d), projected weights were within the 95% confidence interval for all treatments. Later in the season, the projected weights for the control group remained within the 95% confidence interval but were in the upper end of the interval. Actual final weight was 359 kg/hd while the projected final weight was 378 kg/hd. Similar discrepancies were noted with the energy treatment but the projected gains were well out of the 95% confidence interval and final weight was overestimated by 29 kg/hd. As noted with the ADG analysis, weight projections for the protein groups were within 1 kg/hd of the actual weights.

Several factors may explain the less than desirable predictions for the control and energy groups. First, the actual weights were recorded after an over night shrink. If the NUTBAL algorithms assume live weights with less shrink, NUTBAL will overestimate weight gains compared to the shrunk weights. But, this would not explain differences among treatments. Instead this would only change which treatments had better fits of predicted and actual gains. The intake equation in NUTBAL is based on fecal output as a constant %BW (corrected to a body condition score of 5; scale 1 to 9; 1 = emaciated, 9 = obese). If the initial weight is obtained as a shrunk weight, NUTBAL could correct the lighter weight steer for a specific age to a higher weight than it would for a steer at the same chronological age at a heavier weight (less shrink). The overestimated NUTBAL weight at the start of a period would overestimate intake and underestimate maintenance requirements for the lighter weight steer. This in turn would lead to an overestimated rate of weight gain. Second, the differences in the predictions of weights and gains by NUTBAL among the treatments indicate that the model is responding only to supplemental energy intake. As demonstrated by the energy treatment, gain is not responding simply to calculated additional intake. Hence, the model needs refinement of the intake response to forage characteristics such as CP and DOM.

The model inputs could be changed to improve the accuracy of the model but most inputs that could be changed would be expected to either change the projections of ADG equally for all of the treatments or not change the predictions at all. For example, differences in ADG predictions from changes in the age or breed composition of steers for a given treatment would change ADG predictions of the other treatments by the same magnitude. This point was examined using actual weather measurements by an onsite automated weather station rather than weekly forecasts. This decreased the final predicted weight by only 1.4 kg. Therefore, additional steps were taken to evaluate the accuracy of NUTBAL.

The estimated intake was adjusted to force NUTBAL predicted ADG to equal the observed ADG. The intake adjustments required are plotted against estimated diet CP in Figure 4-5 and diet DOM in Figure 4-6. Intake had to be decreased by as much as -28.6, -45.3, and -20.1% for the control, energy and protein groups, respectively, and increased by as much as 10.5, 3.8, and 21% for the same groups in order for NUTBAL estimates to equal actual ADG during the study period. By comparing Figures 4-5 and 4-6, it appears that DOM was more directly related to the intake adjustments than CP. Intake adjustments opposed changes in estimated diet DOM, especially in the protein and energy treatments. This possibly suggests that the diet DOM values were in error or, the intake function (Fecal Output/1-DOM) was not behaving properly in accordance with changes in diet digestiblity. On the other hand, there was no observable pattern of association between CP and the intake adjustments with the possible exception that declining CP was not reducing intake in a proper fashion during the first 70 d of the grazing season.

In a final attempt to improve the accuracy of NUTBAL, NIR diet quality predictions were adjusted using regression relationships developed between NIR predicted CP and DOM from fecal analysis and actual values (Bogdahn et al., 1995). This proved to be unsuccessful as well (Fig. 4-6). After the adjustments were made, final weight predictions by NUTBAL for all the treatments were outside the lower end of the 95% confidence intervals for actual weight. When diet quality was adjusted, CP became the nutrient limiting performance in the NUTBAL model. The impact of this shift from an energy-driven to a protein-driven performance estimate can be determined by comparing the NUTBAL projection with the projections from adjusted forage quality. It is also illustrated in Figure 4-6 and 4-6 that as time progresses, the deviations in predicted weights are additive. For managerial application, it may be necessary to check the weights of cattle during the grazing season in order to readjust the growth curve.

Trial 2. The effects of stocking rate on animal performance are presented in Table 4-2. The relationships between days on pasture and weight of the steers in pastures 3 and 8 are presented in Figure 4-7. Across the 154 day grazing season, light stocking rate gained 128 kg while the heavy stocking rate gained 101 kg. Weight gains for pasture 3 and 8 appear to be normal and are consistent with the historical ranges in weight gain. From a study utilizing the same pastures, Bogdahn et al. (1995) found that averaged over a five-year period cattle grazing pasture 3 gained more weight (18.1 kg; $P<.01$) than cattle grazing pasture 8. Therefore, the pastures selected accomplished the objective of providing data representing different levels of cattle performance.

NIR predictions of CP and DOM from the fecal samples collected in light and heavy stocked pastures are illustrated in Figure 4-8. Predictions of CP and DOM tended to be higher for the light stocking rate than the heavy stocking rate. The effect of stocking rate on NIR predictions of CP and DOM occurred as expected. According to Minson (1990), the leaves of plants contain twice as much CP as the stems and the dry matter digestibility of plants decreases from the top to the bottom. Therefore, if forage availability and selectivity is reduced due to increased leaf removal by heavier stocking rates, forage quality would be expected to be reduced at heavier stocking rates.

The ADG values for the entire data set predicted by NUTBAL did not fit the actual ADG values as well as noted in Trial 1 (Figure 4-9). NUTBAL predicted ADG explained only 56% of the variation in actual ADG. The regression relationship between NUTBAL predicted and actual ADG for light stocking rate was considerably improved compared to the overall equation. The slope (1.02) was closer to 1 and on average NUTBAL over estimated ADG by .17 kg. The r^2 (.64) was only marginally improved. However, NUTBAL predicted weights for the heavy stocking rate accounted for more variation (r^2=.70) in actual weights than the overall data set or the light stocking rate. The model coefficients indicate that NUTBAL was not accurately projecting weight. Based on the relationship for the heavy pasture , NUTBAL underestimated gains when actual ADG was in excess of .75 kg/d, but overestimated gain when actual ADG was below .75 kg/d. Overestimation at lower weight gains may be due to the lack of adjustment for the limited forage availability. Although estimated diet composition will support higher rates of gain, intake is limited by forage availability.

Standing crop data was used in an effort to improve the performance of weight gain predictions by NUTBAL. Figure 4-10 shows actual ADG plotted over time with NUTBAL predicted ADG using actual clipping data or with forage availibility set at 2801 kg/ha (unlimited). Using the actual clipping data affected NUTBAL weight predictions consistently for both pastures. Neither of the NUTBAL predicted final weights are contained within the 95% confidence interval for the light pasture. In the heavy stocked pasture, both NUTBAL predicted final weights are outside the confidence interval, but the weight predictions from day 100 to 152 more closely approximated actual weights when forage availability was adjusted.

Adjusting the forage quality estimates by NIR with the regression equations developed between actual and NIR predicted CP and DOM values had a positive effect on the accuracy of NUTBAL (Fig. 4-11). By adjusting the diet quality estimates for the heavy pasture, all of the predicted weights with the exception of the final weight were contained within the confidence intervals. Figure 4-12 illustrates the effect of NIR forage quality estimates on NUTBAL performance projections to a greater extent. It is appearant that the adjustments in the CP and DOM values caused the final weight prediction for the heavy stocking rate to be outside of the interval. The large reduction in ADG predicted by NUTBAL when the diet quality was adjusted, is due to a forage CP value of less than 7%. This switch decreases predictions of ADG markedly by adjusting model predicted intake and also using protein as the first-limiting nutrient for performance .

As noted in Trial 1, the intake adjustments required to make NUTBAL predict actual gains were rather large. These assumed unlimited forage availability. The intake adjustments ranged from -35.3 to 3% for pasture 3 and from -36 to 13.1% for the heavy pasture. Based on the changes for the light stocking rate, either DOM was overestimated across the season or fecal output was not behaving as projected by the model.

Implications

This study was a preliminary evaluation of the NUTBAL model, and it was conducted to test the accuracy and precision of the animal performance projections by NUTBAL. In both trials, NUTBAL overestimated weight gains by stocker cattle and variable adjustments in estimated intake were required to make the model fit the actual data. Forage availability and quality were influencing the accuracy and precision of NUTBAL.

In Trial 1, the accuracy of the weight projections by NUTBAL for the protein was surprising. However, the confidence one can place in the accuracy of NUTBAL is limited due to the performance projections for the energy and control groups. Within the conditions of this study, specific applications using NUTBAL to determine supplementation strategies of stocker cattle grazing native rangeland cannot be recommended. The difficulties observed in the predictions of weight gains by NUTBAL indicate that mechanistic problems exist in the model. Implementation of supplementation strategies recommended by NUTBAL in this trial resulted in a loss of potential added weight gain and unnecessary supplement costs.

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TABLE 4-1 EFFECTS OF PROTEIN AND ENERGY SUPPLEMENT ON WEIGHT GAIN OF STOCKER CATTLE GRAZING TALLGRASS PRAIRIE FROM APRIL 29 TO SEPTEMBER 6, 1994.

	Supplement[1]			
Item	Control	Protein	Energy	SEM[2]
	----------------	kg	----------------	
Initial weight	243	244	245	4.15
Final weight	359^a	389^b	366^a	6.18
Early gain (day 0 to 42)	58^a	66^b	62^{ab}	2.31
Intermediate gain (day 42 to 84)	31^a	39^b	28^a	2.09
Late gain (day 84 to 130)	27^a	38^b	31^a	1.91
Supplement gain (day 42 to 130)	59^a	78^b	59^a	3.01
Total gain	116^a	144^b	121^a	4.23

[1] Control = .06 kg/d cottonseed cake, Protein = .45 kg/d cottonseed cake, Energy = .59 to .73 kg/d cracked corn as prescribed by NUTBAL.

[2] SEM = standard error of the mean, n = 15; except for intermediate, late, supplement, and total gain and final weight for protein and energy supplement groups n = 14.

[ab] Row means lacking a common superscript are different ($P < .0125$).

TABLE 4-2. WEIGHT AND GAIN OF STEERS GRAZING MIDGRASS PRAIRIE RANGELAND AT TWO DIFFERENT STOCKING RATES FROM APRIL 6 TO SEPTEMBER 7, 1994.

	Stocking Rate[a]			
Item	Light	SEM	Heavy	SEM
Number of steers	13	-	21	-
Initial weight, kg	221	5.05	221	4.51
Intermediate weight, kg	326	6.20	313	4.67
Final weight, kg	349	5.81	322	4.42
Early gain (day 0 to day 92), kg	105	3.72	92	2.43
Late gain (day 92 to day154), kg	23	2.40	9	2.13
Total Gain, kg	128	3.98	101	2.84

[1] Light= 3.6 ha/hd and heavy = 1.9 ha/hd.

[2] SEM = Standard error of the mean.

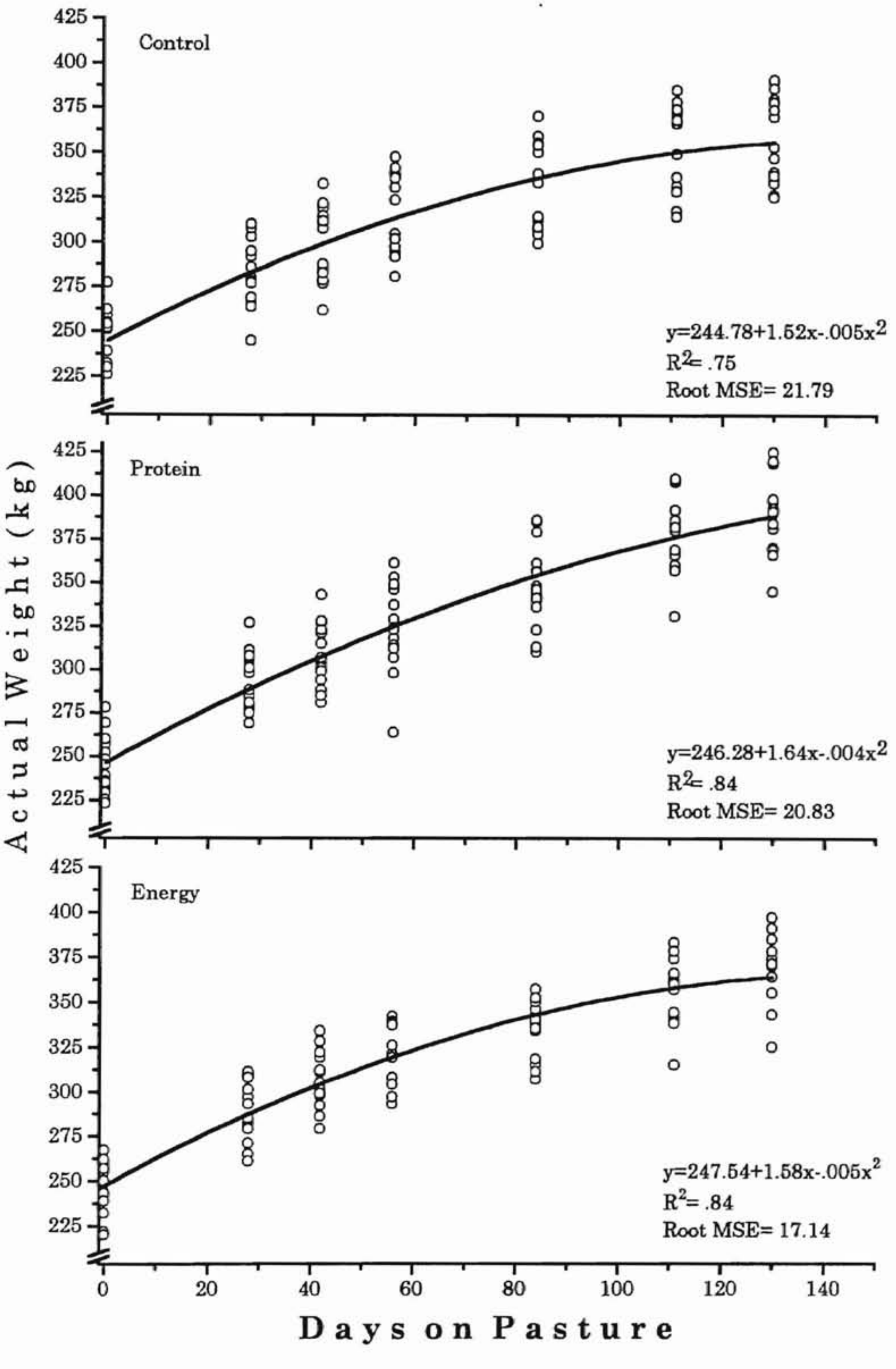


FIGURE 4-1. CUMULATIVE ACTUAL WEIGHTS OF STEERS IN CONTROL, PROTEIN, AND ENERGY SUPPLEMENTED GROUPS GRAZING TALLGRASS PRAIRIE FROM APRIL 29 TO SEPTEMBER 6, 1994. STILLWATER RESEARCH RANGE, STILLWATER, OK.

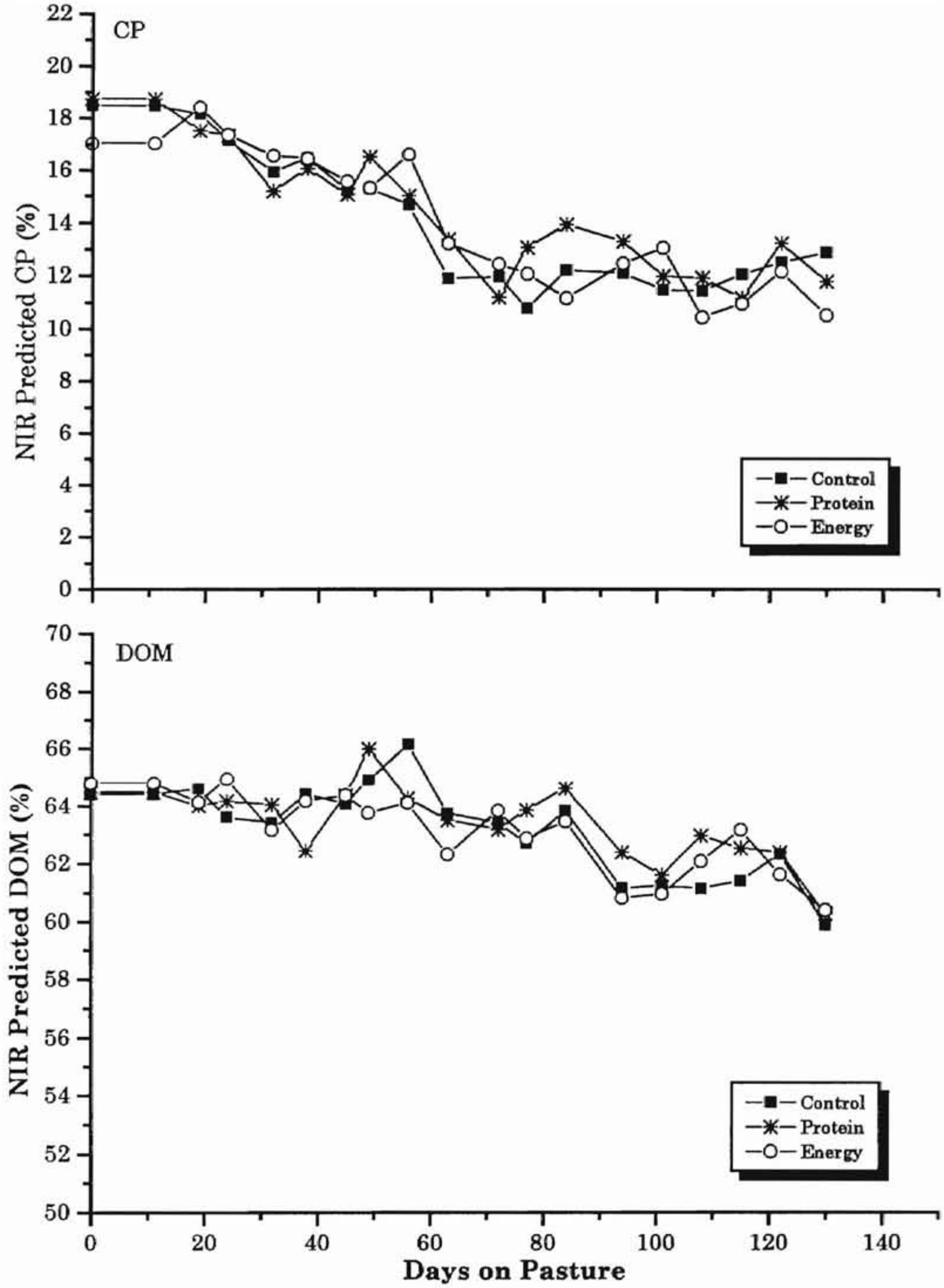


FIGURE 4-2. NIR PREDICTED CRUDE PROTEIN (CP) AND DIGESTIBLE ORGANIC MATTER (DOM) FROM FECAL ANALYSIS OF STEERS GRAZING TALLGRASS PRAIRIE. STILLWATER RESEARCH RANGE, STILLWATER, OK.

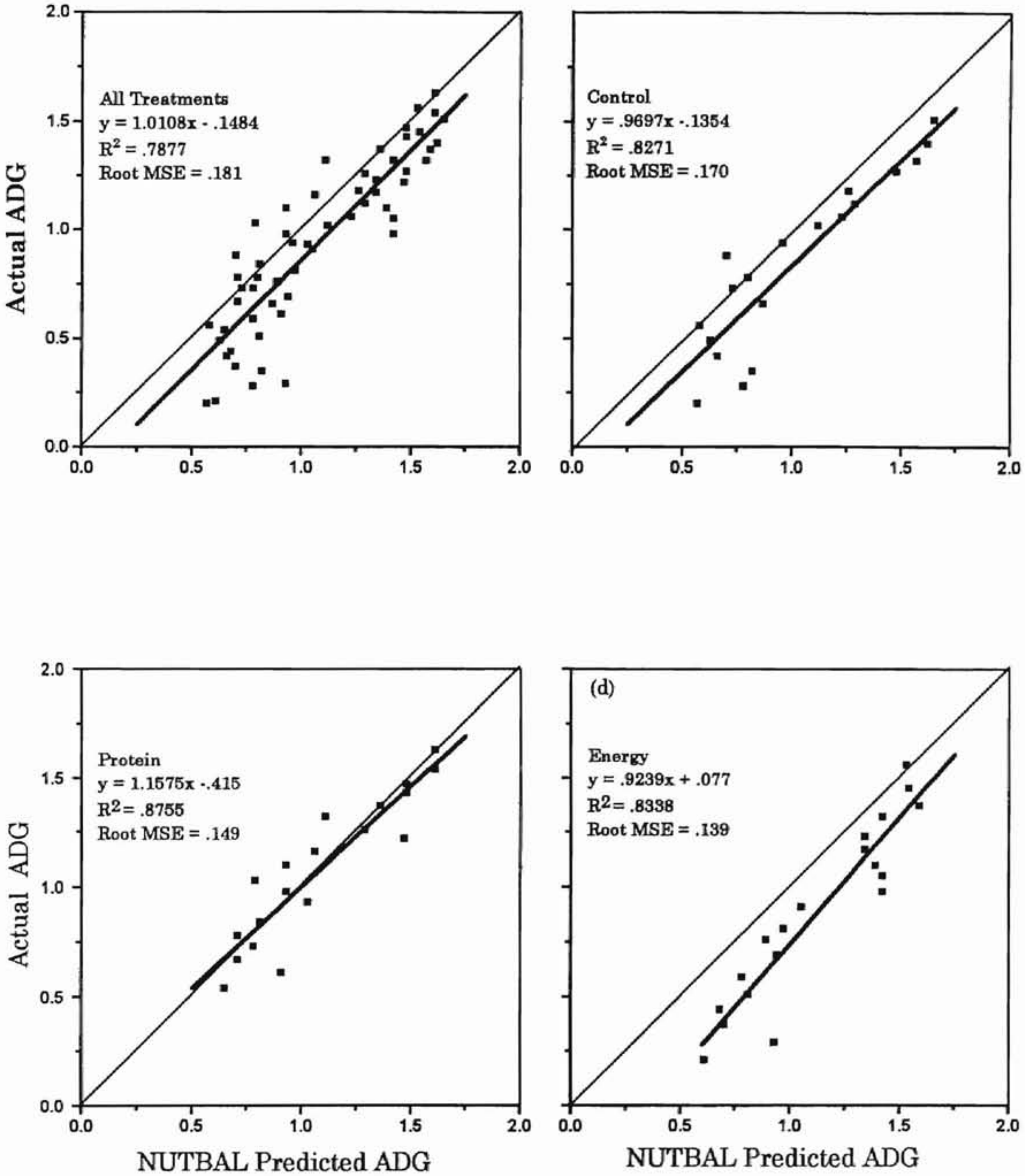


FIGURE 4-3. THE RELATIONSHIP BETWEEN ACTUAL AND NUTBAL PREDICTED WEEKLY AVERAGE DAILY GAIN (kg) OF STEERS GRAZING TALLGRASS PRAIRIE FOR ALL TREATMENTS COMBINED, CONTROL, ENERGY, AND PROTEIN GROUPS. STILLWATER RESEARCH RANGE, STILLWATER, OK.

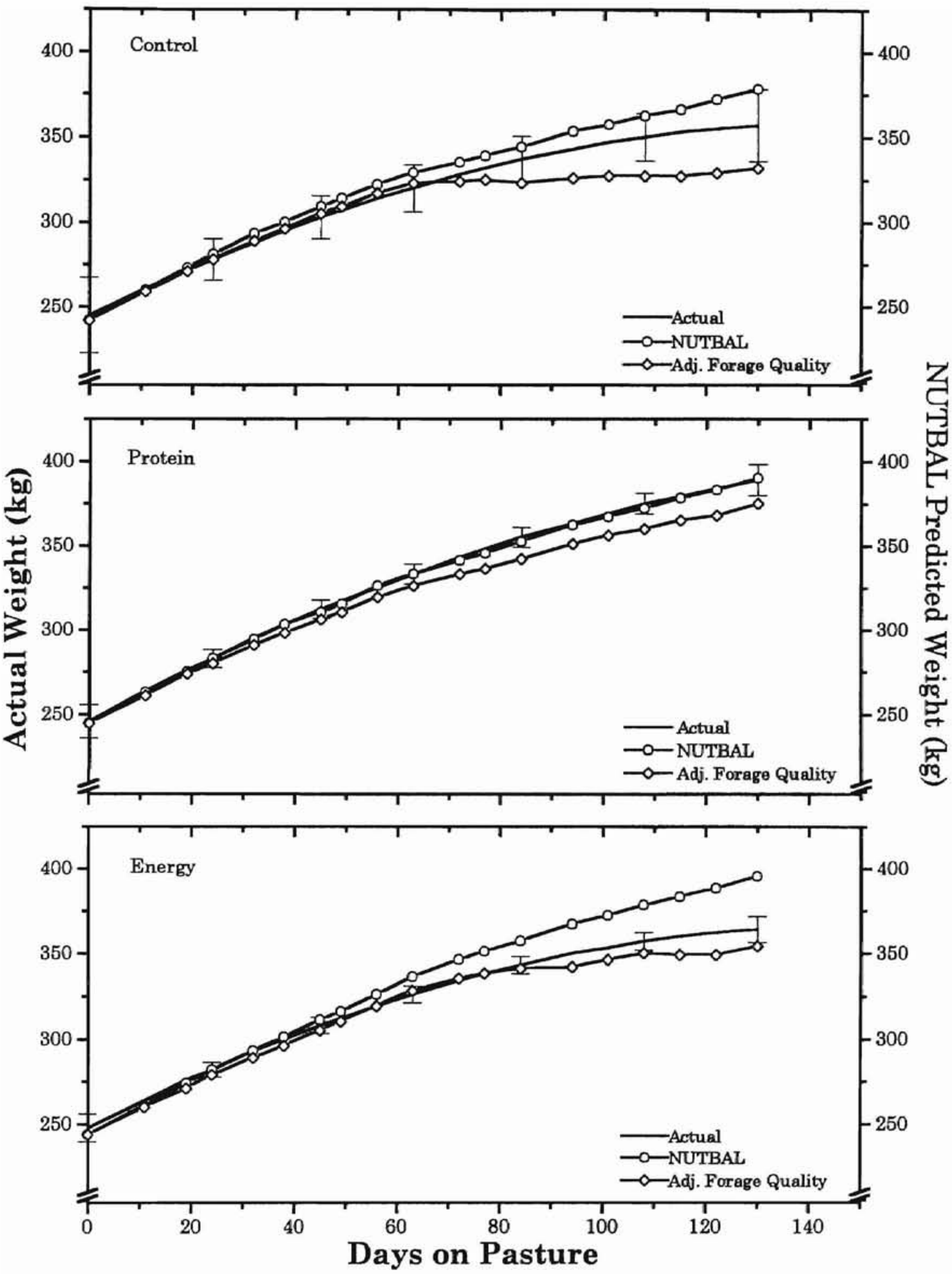


FIGURE 4-4. COMPARISON OF NUTBAL PREDICTED WEIGHT USING NIR ESTIMATED FORAGE QUALITY (NUTBAL), NIR ESTIMATES ADJUSTED TO ESOPHAGEAL DATA AND ACTUAL WEIGHT FOR CONTROL, PROTEIN, AND ENERGY GROUPS. STILLWATER RESEARCH RANGE, STILLWATER, OK. (ERROR BARS=95% CONFIDENCE INTERVAL)

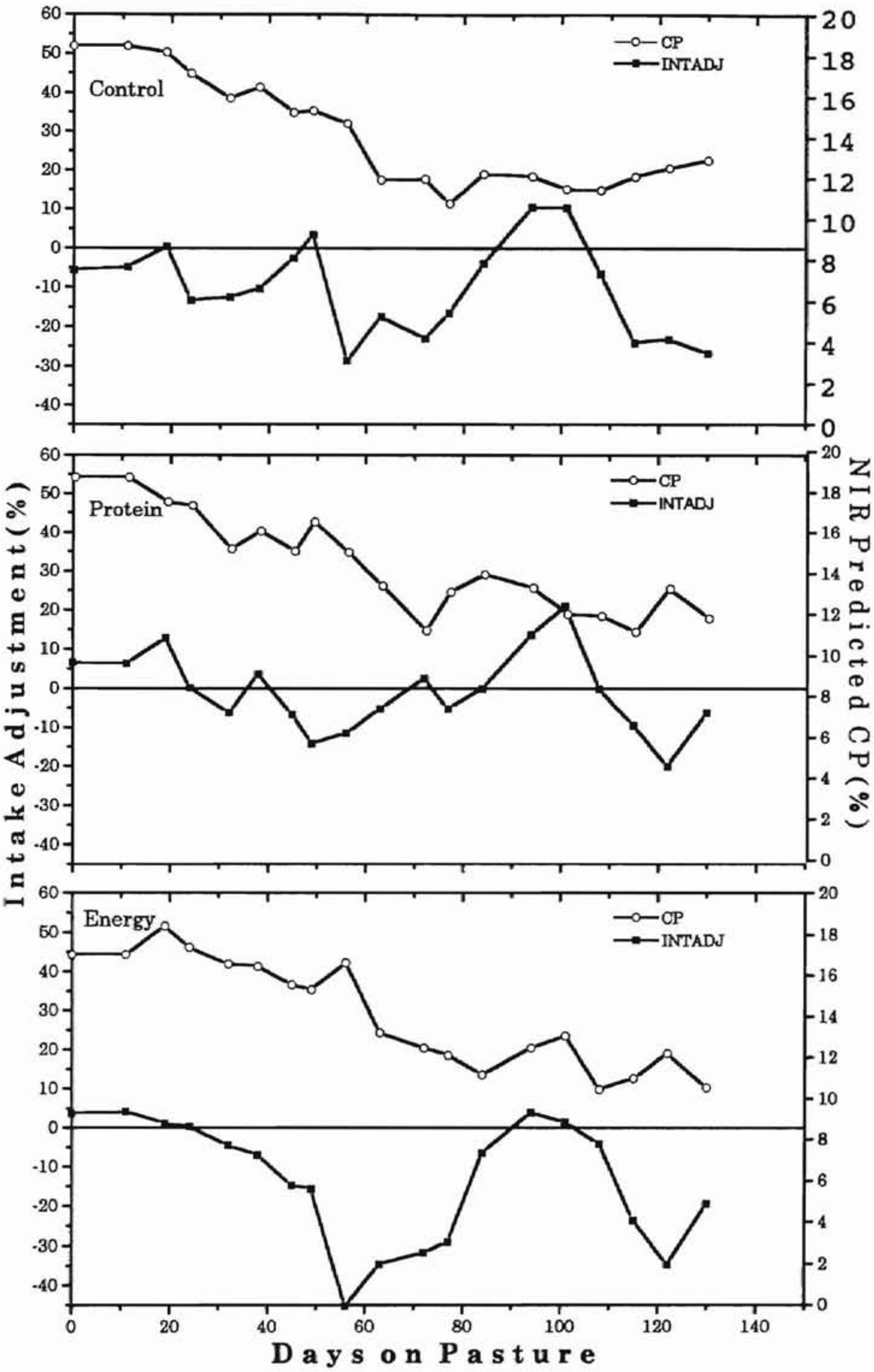


FIGURE 4-5. MODEL INTAKE ADJUSTMENT (INTADJ) REQUIRED FOR NUTBAL TO PROJECT ACTUAL WEIGHT IN RELATIONSHIP TO NIR PREDICTED CRUDE PROTEIN (CP) FOR CONTROL, PROTEIN, AND ENERGY GROUPS. STILLWATER RESEARCH RANGE, STILLWATER, OK.

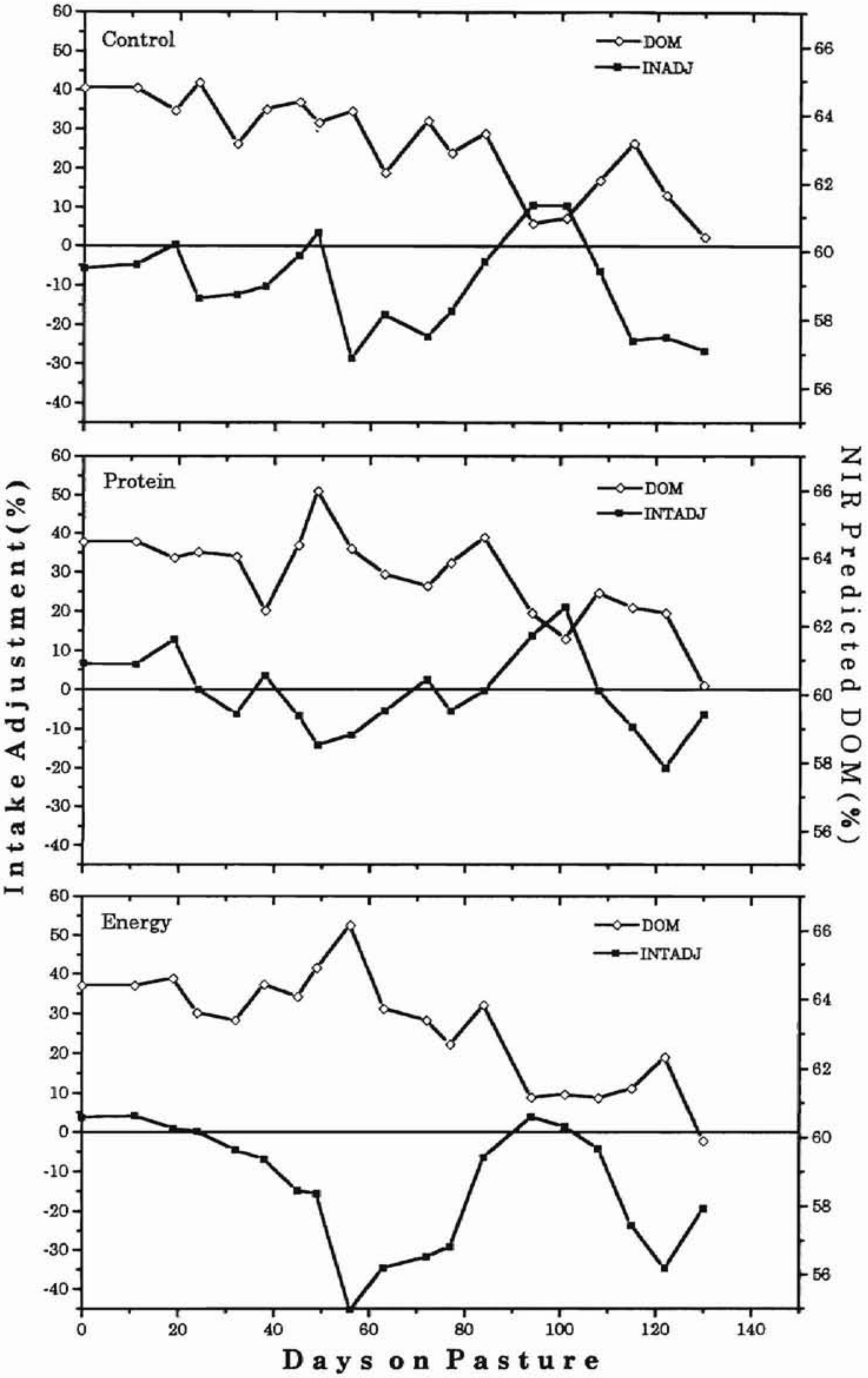


FIGURE 4-6. MODEL INTAKE ADJUSTMENT (INTADJ) REQUIRED FOR NUTBAL TO PROJECT ACTUAL WEIGHT IN RELATIONSHIP TO NIR PREDICTED DIGESTIBLE ORGANIC MATTER (DOM) FOR CONTROL, PROTEIN, AND ENERGY GROUPS. STILLWATER RESEARCH RANGE, STILLWATER, OK.

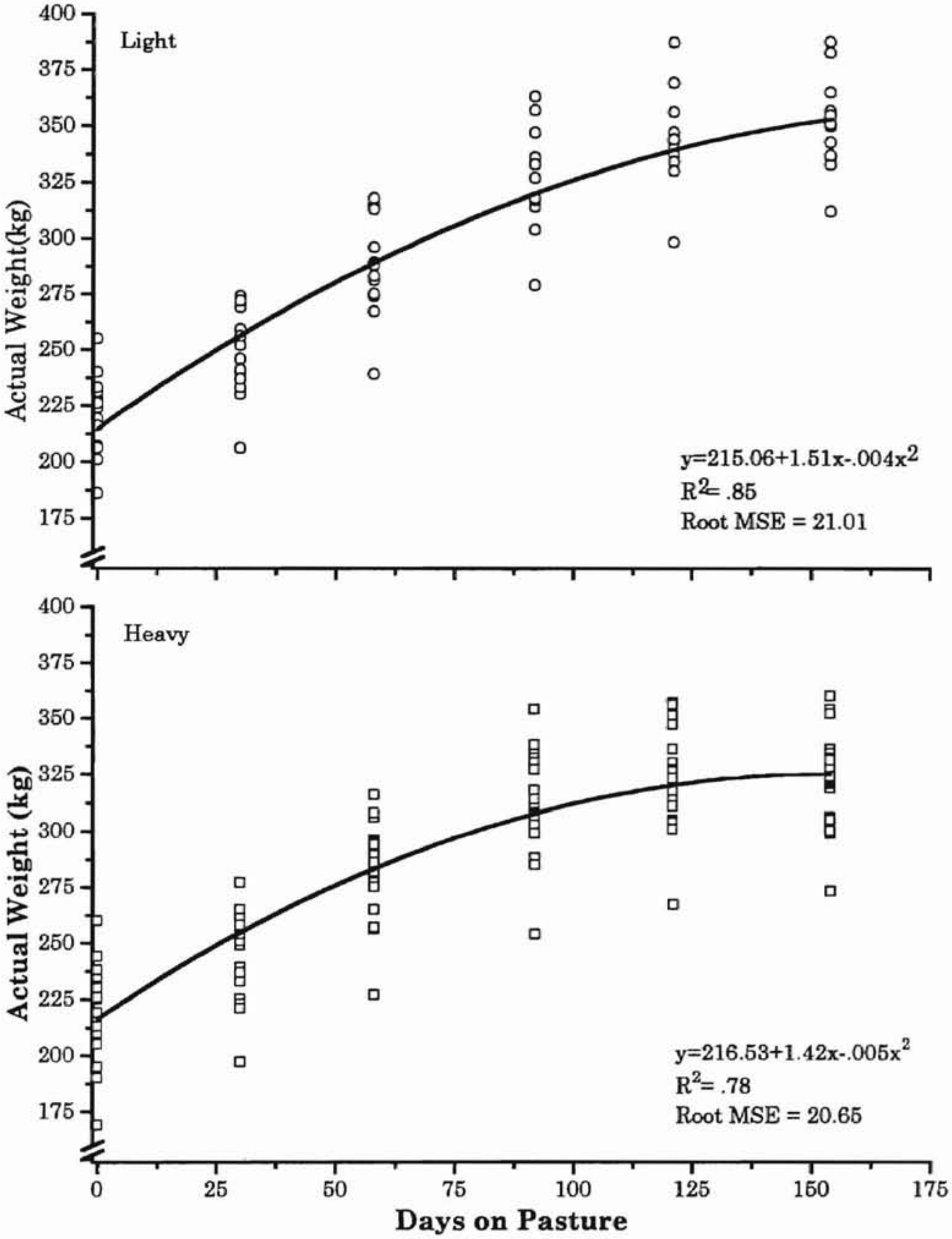


FIGURE 4-7. CUMULATIVE ACTUAL WEIGHTS OF STEERS GRAZING MIDGRASS PRAIRIE IN A LIGHT AND HEAVY STOCKED PASTURE FROM APRIL 6, 1994 TO SEPTEMBER 7, 1994. KLEMME RANGE RESEARCH STATION, BESSIE, OK.

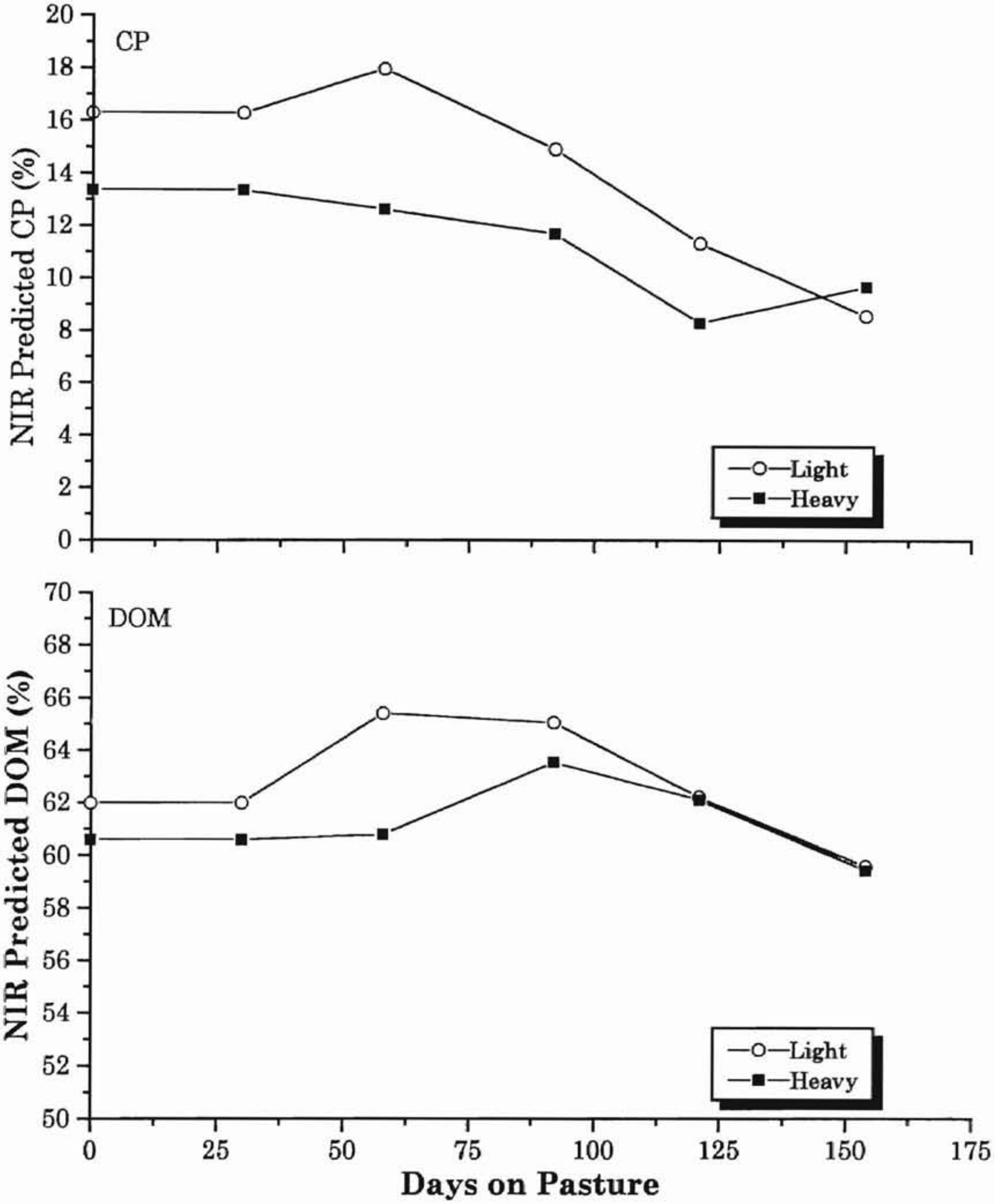


FIGURE 4-8. NIR PREDICTED CRUDE PROTEIN (CP) AND DIGESTIBLE ORGANIC MATTER (DOM) FROM FECAL ANALYSIS OF STEERS GRAZING MIDGRASS PRAIRIE IN A LIGHT AND HEAVY STOCKED PASTURE. KLEMME RANGE RESEARCH STATION, BESSIE, OK.

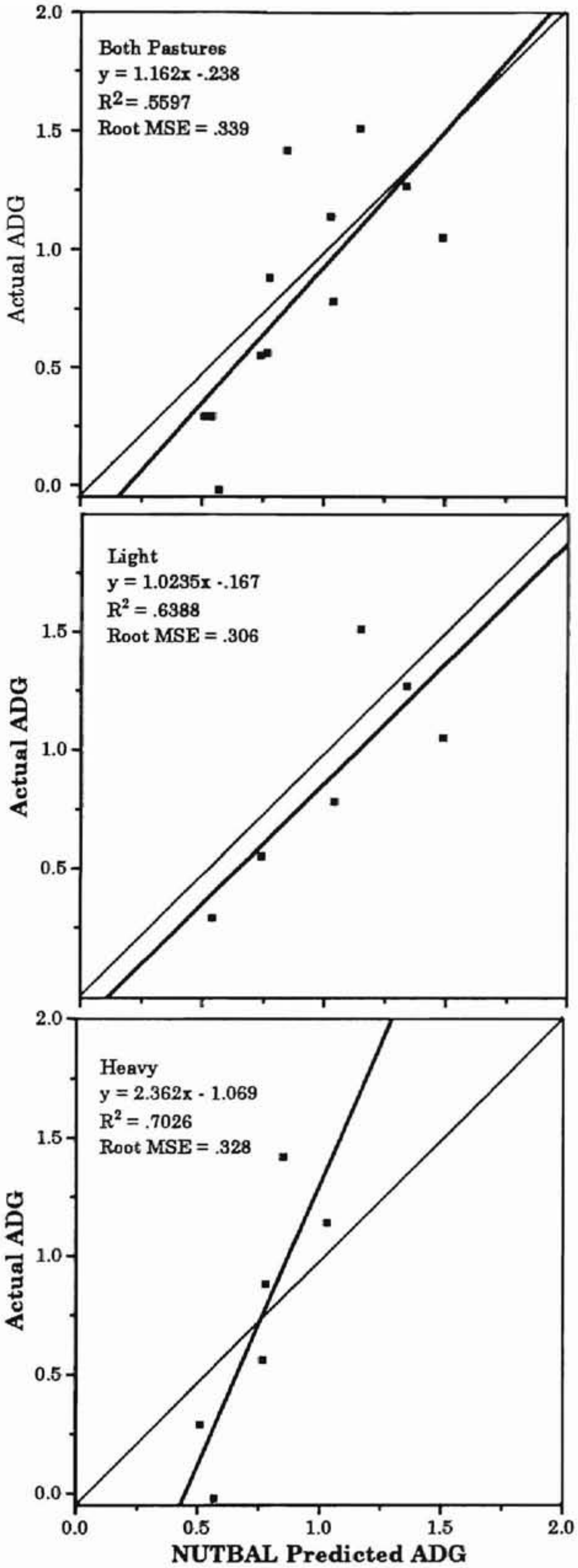


FIGURE 4-9. THE RELATIONSHIP BETWEEN ACTUAL AND NUTBAL PREDICTED AVERAGE DAILY GAIN (kg) OF STEERS GRAZING MIDGRASS PRAIRIE: BOTH PASTURES COMBINED, LIGHT, AND HEAVY.

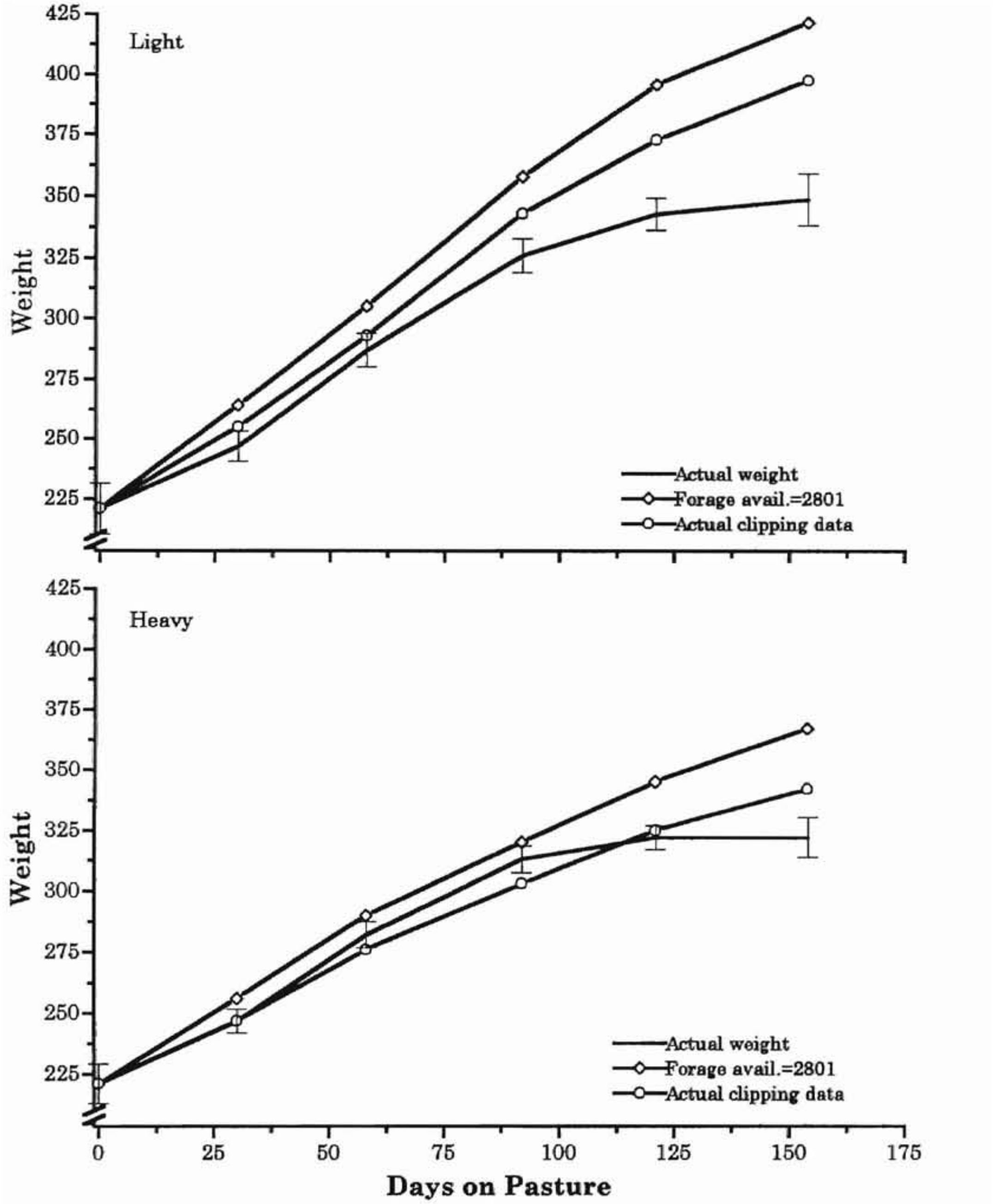


FIGURE 4-10. COMPARISON OF NUTBAL PREDICTED WEIGHT (kg) USING ACTUAL CLIPPING DATA OR UNLIMITED FORAGE AVAILABILITY (FORAGE AVAILABILITY=2801kg/ha) AND ACTUAL WEIGHT (kg) FROM THE LIGHT AND HEAVY STOCKED PASTURES ACROSS THE GRAZING SEASON. (ERROR BARS=95% CONFIDENCE INTERVAL)

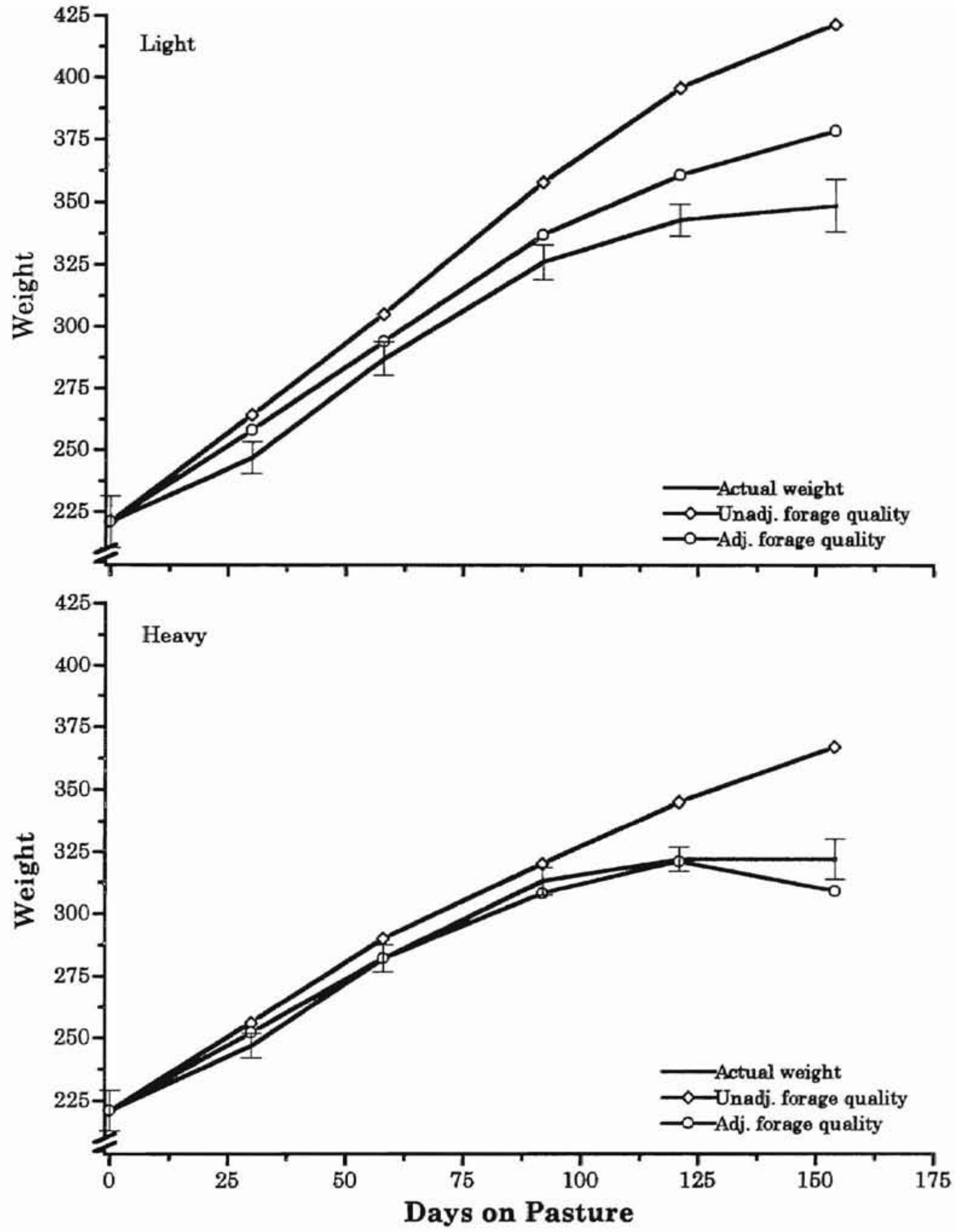
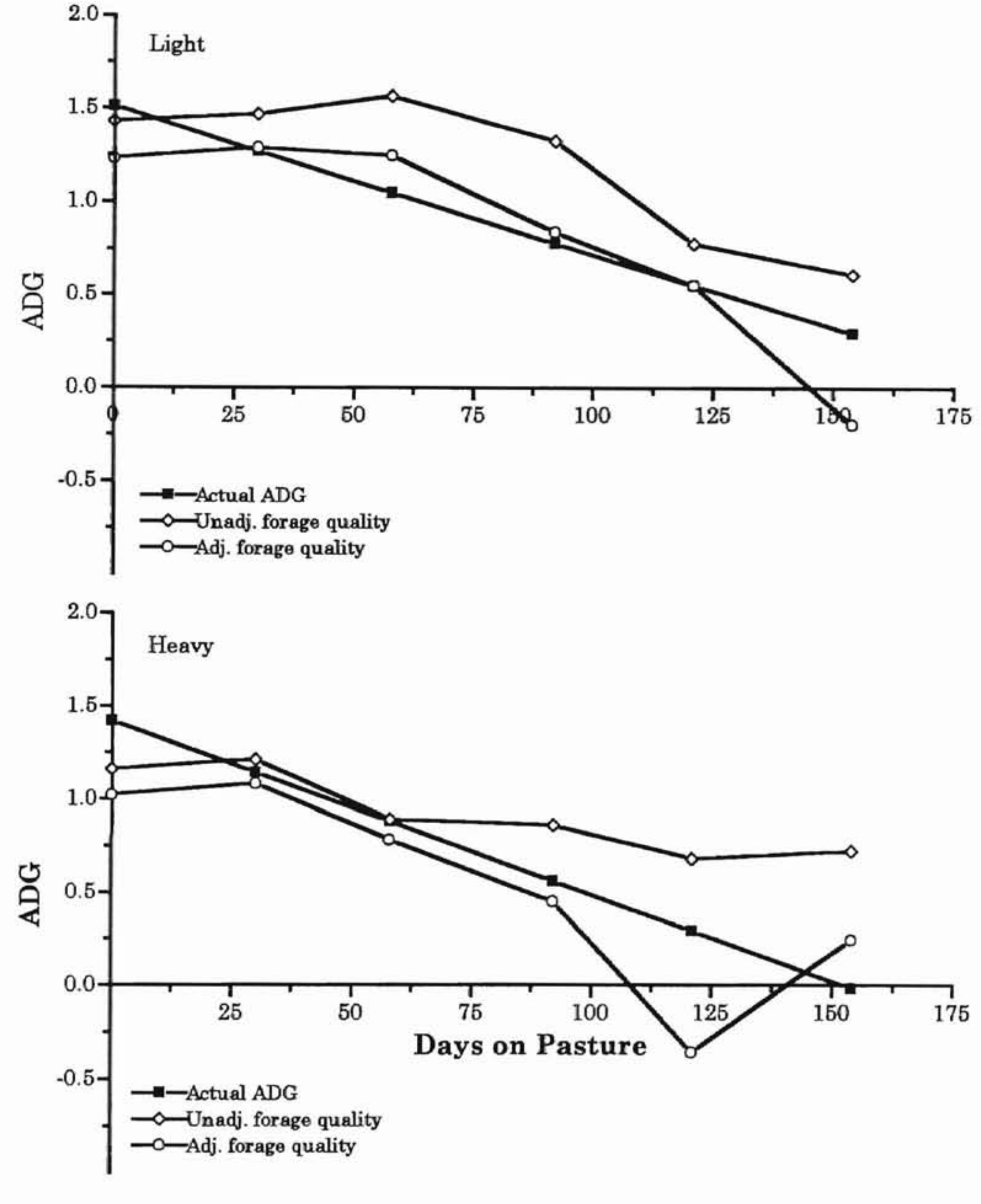
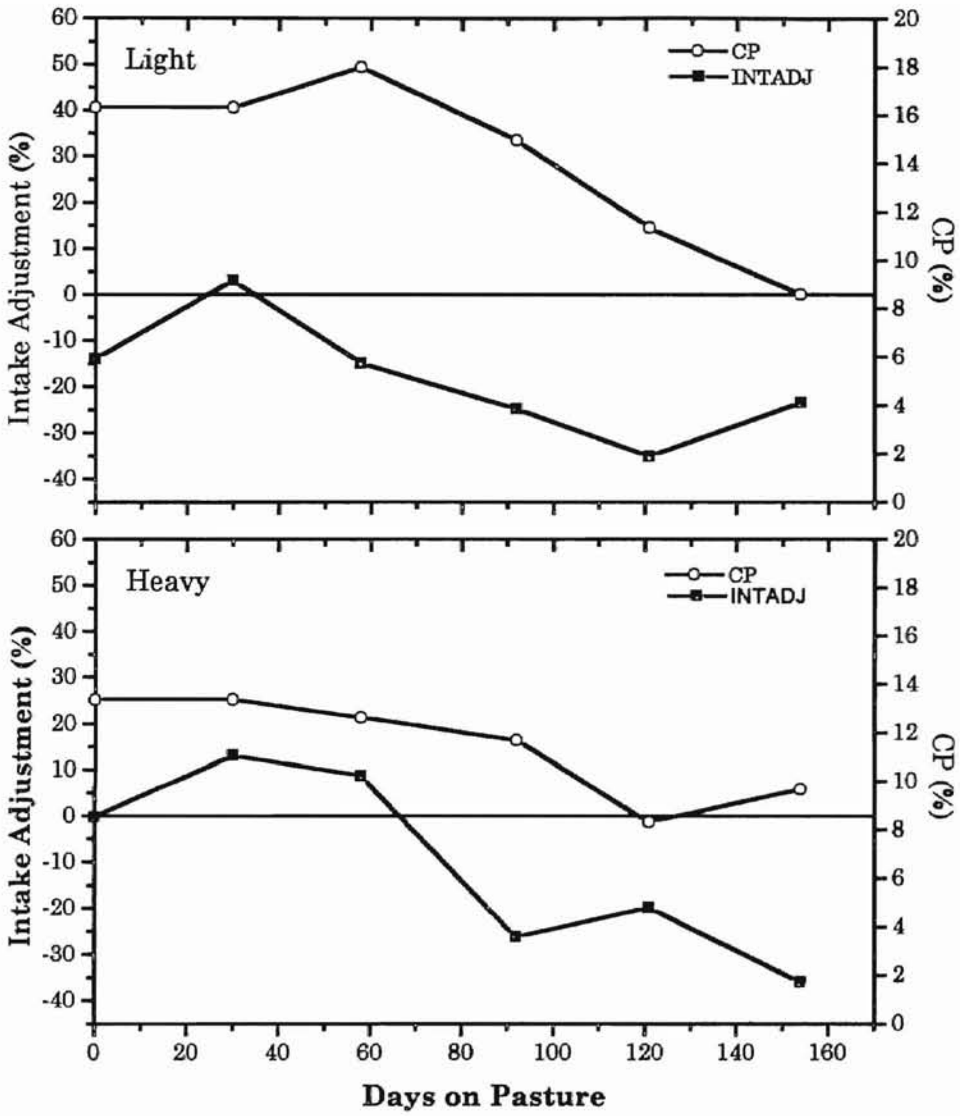


FIGURE 4-11. COMPARISON OF NUTBAL PREDICTED WEIGHT (kg) USING NIR ESTIMATED FORAGE QUALITY (UNADJUSTED), NIR ESTIMATES ADJUSTED TO ESOPHAGEAL DATA AND ACTUAL WEIGHT (kg) FOR THE LIGHT AND HEAVY STOCKED PASTURES. (ERROR BARS=95% CONFIDENCE INTERVAL)



FIGRUE 4-12. COMPARISON OF NUTBAL PREDICTED AVERAGE DAILY GAIN (kg) USING NIR ESTIMATED FORAGE QUALITY (UNADJUSTED), NIR ESTIMATES ADJUSTED TO ESOPHAGEAL DATA AND ACTUAL AVERAGE DAILY GAIN (kg) FOR THE LIGHT AND HEAVY STOCKED PASTURES.



FIGRUE 4-13. MODEL INTAKE ADJUSTMENT (INTADJ) REQUIRED FOR NUTBAL TO PROJECT ACTUAL WEIGHT IN RELATIONSHIP TO NIR PREDICTED CRUDE PROTEIN (CP) FOR THE LIGHT AND HEAVY STOCKED PASTURES. THIS ASSUMES UNLIMITED FORAGE AVAILABILITY.

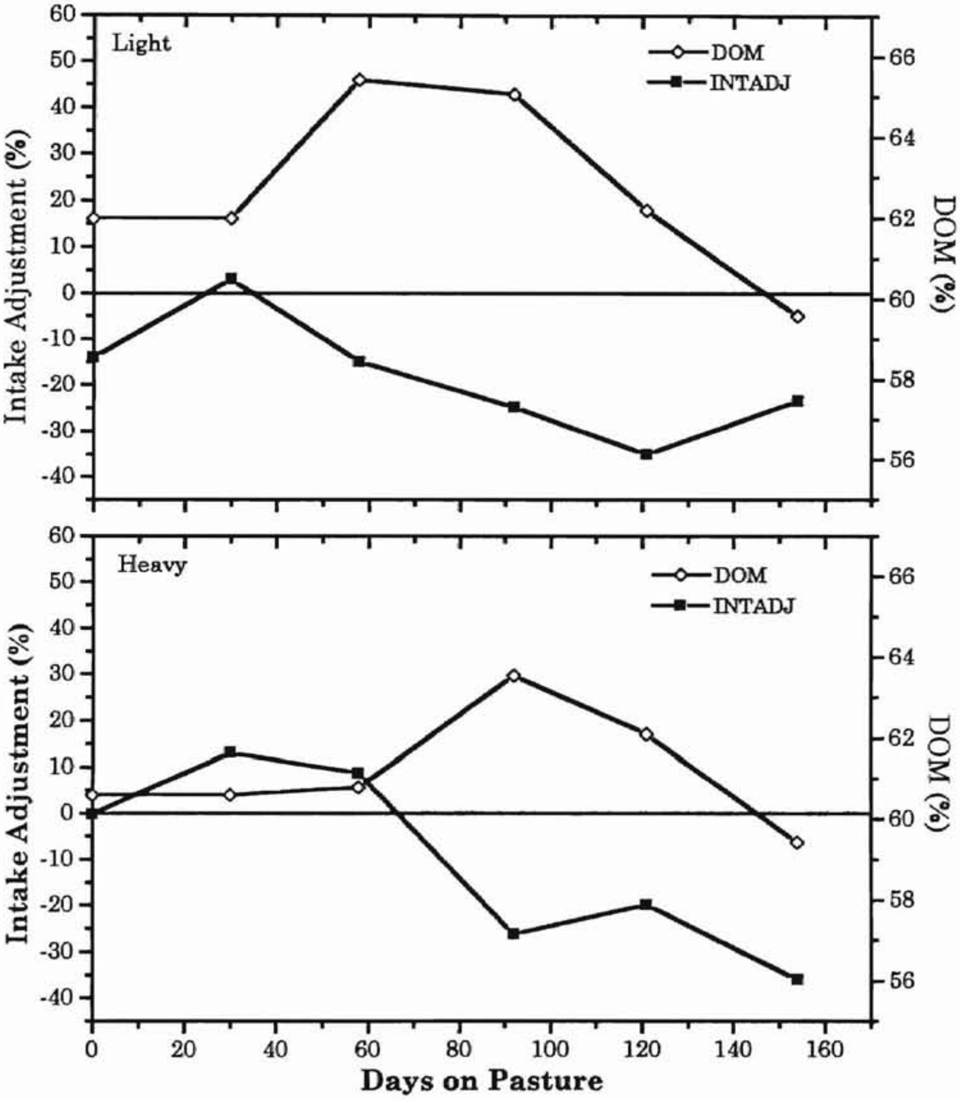


FIGURE 4-14. MODEL INTAKE ADJUSTMENT (INTADJ) REQUIRED FOR NUTBAL TO PROJECT ACTUAL WEIGHT IN RELATIONSHIP TO NIR PREDICTED DIGESTIBLE ORGANIC MATTER (DOM) FOR THE LIGHT AND HEAVY STOCKED PASTURES. THIS ASSUMES UNLIMITED FORAGE AVAILABILITY.

CHAPTER V

CONCLUSIONS

Simple well-defined methods to determine the quantity and quality of consumed forages have eluded researchers for many years. Near infrared reflectance spectroscopy (NIR) analysis of feces has been promoted as an accurate and precise method that rapidly and efficiently determines forage quality. There are few questions as to the speed and cost of NIR analysis, and the ease in which fecal samples can be obtained is a definite advantage over conventional procedures. However, the present research suggests that the general exceptance of NIR as a potential replacement of laboratory procedure should be questioned.

Based on the regression relationships between NIR predictions and actual laboratory values, NIR accounted for 61% and 51% of the variation in the lab values for CP and DOM, respectively. Accuracy of NIR estimates for CP and DOM was reduced as forage CP increased and DOM declined. However, the magnitude of the decreases in accuracy was not the same for CP and DOM. The regression relationships developed for each forage type at a given location indicate that the accuracy of NIR estimates is not the same for all locations within Oklahoma. The observations from this study suggest the calibration equations need to be modified by including a larger range of forages. The forages and conditions encountered during this study are not entirely represented by the calibration data set.

Currently, the uncertainty of cattle prices and continuous pressures to increase efficiency of production increase the need for producers to be able to evaluate alternatives. The Texas A&M NUTBAL model was developed to help producers consider different production options. The model was designed to project the performance of grazing animals. NUTBAL allows users to enter information that pertains to an individual's own production situation. The model is currently being used by livestock managers without extensive field validations testing the animal performance projections. The present study was designed to evaluate the effects of supplementation and stocking rate on weight gain predictions.

Based on the regression equations developed between NUTBAL predicted and actual weight gains, the r^2 (.83 to .88) values suggest that NUTBAL can project animal performance with an acceptable level of accuracy. The predicted weight gains for the cattle supplemented with protein would support this conclusion, but NUTBAL overestimated the final weight for the control and energy supplemented groups by 20 and 29 kg, respectively. Based on the regression relationships, the overestimation in performance may appear to be insignificant, but the magnitude of the difference observed in this study may represent the profit potential of most producers. For example, considering the prices used in NUTBAL energy supplementation cost $8.78/hd for no improvement in weight gain, and $20.94/hd for the opportunity cost of giving up the potential added weight from protein supplementation. It is apparent that the model only considers the additional energy available when supplementation recommendations are made.

The relative differences between predicted and actual gains for the stocking rates were even more pronounced than for the supplement groups. Performance projections by NUTBAL were more accurate at heavier stocking rates. In both trials, adjusting forage quality improved the weight predictions, but none of the final weight projections were contained within the 95% confidence interval. In trial 2, using actual clipping data improved improved the performance of

NUTBAL, but final weight projections still fell outside the confidence interval. Based on the intake adjustments, it is clear that DOM highly influences the model. Therefore, using accurate diet quality information in NUTBAL is crucial if reliable weight predictions are to be obtained. Based on this research, caution is advised to the users of NUTBAL. In the current trial, the algorithm used by NUTBAL to recommend supplementation promoted unecessary or improper supplementation. Therefore, this mechanism needs refinement.

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VITA

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