Predicting Diet Quality of White-Tailed Deer via NIRS Fecal Profiling

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Abstract

Near infrared reflectance spectroscopy (NIRS) of feces for the prediction of diet quality in several species of livestock and wildlife has been reported. The technique has not been reported in deer. This study was conducted to determine the ability of fecal NIRS to determine dietary crude protein (CP), digestible organic matter (DOM), and phosphorus (P) in white-tailed deer (*Odocoileus virginianus*). Seventy-six diet reference chemistry:fecal spectrum (D:F) pairs were created ranging from 6.00 to 18.95% CP, 26.64 to 76.08% DOM, and 0.08 to 0.48% P. Calibration results (R^2 and SE cross validation) were: 0.95 and 1.17, 0.88 and 3.62, 0.83 and 0.04 for CP, DOM, and P, respectively. These equations were used to predict a validation D:F set ($n = 11$). Results (R^2 and SE prediction) were: 0.79 and 1.53, 0.49 and 5.46, 0.67 and 0.03 for CP, DOM, and P, respectively. These two D:F sets were combined and calibrations reformulated. Results (R^2 and SE cross validation) were: 0.84 and 1.40, 0.89 and 3.55, 0.83 and 0.04 for CP, DOM, and P, respectively. These combined calibrations were used to predict diet quality characteristics using 11 fecal samples from wild deer. The diet quality characteristics were compared to NDVI greenness values for the study area in winter, spring and summer. High correlation ($R^2 > 0.7$) between fecal NIRS predicted diet quality and NDVI greenness was observed with the exception of P in summer ($R^2 = 0.25$). Fecal NIRS can be used to determine diet quality in white-tailed deer and thus become another tool to evaluate habitat suitability.

Resumen

La near infrared reflectance spectroscopy (NIRS) de excrementos para la predicción de la calidad de la dieta en varias especies de ganado y fauna es reportada en este estudio, la cual no ha sido reportada anteriormente en referencia al venado. Este estudio se realizó para determinar la habilidad de la NIRS fecal a determinar la proteína cruda dietética (CP), la materia orgánica digerible (DOM), y el fósforo (P) en el venado de cola blanca (*Odocoileus virginianus*). Setenta y seis dietas de referencia química: en el espectro fecal (D:F) los pares se crearon recorriendo de 6.00 a 18.95% CP, 26.64 a 76.08% DOM, y de 0.08 a 0.48% P. Los resultados de la calibración (R^2 y SE cruzan la validación) fueron: 0.95 y 1.17, 0.88 y 3.62, 0.83 y 0.04 para CP, para DOM, y para P, respectivamente. Estas ecuaciones se utilizaron para predecir una validación D:F fijo ($n = 11$). Los resultados (R^2 y la predicción SE) fueron: 0.79 y 1.53, 0.49 y 5.46, 0.67 y 0.03 para CP, para DOM, y para P respectivamente. Estos dos conjuntos D:F se combinaron y las calibraciones reinterpretadas. Los resultados (R^2 y SE cruzan la validación) fueron: 0.84 y 1.40, 0.89 y 3.55, 0.83 y 0.04 para CP, para DOM, y para P respectivamente. Estas calibraciones combinadas se utilizaron para predecir las características de la dieta de calidad, utilizando 11 muestras fecales del venado silvestre. Las características de la calidad de la dieta fueron comparadas con valores de NDVI verdes para el área del estudio durante el invierno, la primavera y el verano. La correlación alta ($R^2 > 0.7$) entre NIRS fecal predijo la calidad de la dieta y NDVI verdes se observaron a excepción de P en el verano ($R^2 = 0.25$). El NIRS fecal se puede utilizar para determinar la calidad de la dieta en el venado de cola blanca y así llegar a ser otro instrumento para evaluar la efectividad del hábitat.

Key Words: crude protein, digestible organic matter, feces, near infrared reflectance spectroscopy, *Odocoileus virginianus*, phosphorus

INTRODUCTION

Near infrared reflectance spectroscopy (NIRS) is a well established technique in the analysis of forage and feeds for livestock (see review by Roberts et al. 2004). The NIRS technique provides rapid information on feedstuffs to be used in ration formulation, or about forage on offer in a pasture. If however, information on the diet quality actually selected by free-ranging animals is the desired outcome, forage NIRS offers logistical, but no real analytical advantage over the reference method; it is just another means to determine the chemistry of samples

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acquired by the observer. The utility of such samples are thus subject to the observers' ability to "recreate" the diet of the particular grazing species.

Analysis of feces, thus allowing the animal to "sample" its own diet, is an alternate method of determining diet composition (Smith et al. 1998; Saint-Andrieux et al. 2000), or inferring nutrient density (Hodgeman et al. 1996; Kucera 1997; Osborn et al. 1997; Osborn and Jenks 1998; Osborn and Ginnett 2001). Given the hypothesis that the physico-chemical properties of feces from two animals consuming different diets are different, it seems reasonable then to apply NIRS in the analysis of feces from free-ranging animals to determine diet quality. This application of the technology has in fact been reported for domestic livestock (*Bos* spp.: Lyons and Stuth 1992; Ksiksi et al. 2000; Gibbs 2002; Boval et al. 2004; Garnsworthy et al. 2004; *Capra hircus*: Waelput et al. 1990; Leite and Stuth 1995; Landau et al. 2004; *Ovis aries*: Krachounov et al. 2000; Decruyenaere et al. 2002), as well as elk (*Cervus elaphus*: Brooks et al. 1984), and roan antelope (*Hippotragus equinus*: Dorgeloh et al. 1998). Detection of diet antiquality components such as tannins (Tolleson et al. 2000) and intake of various forb and browse species have also been reported (*Pinus ponderosa* P.& C. Lawson: Kronberg et al. 1998, *Euphorbia esula* L.: Walker et al. 1998, *Artemisia tridentata* Nutt.,) using the fecal NIRS technique. Foley et al. (1998) and Woolnough and Foley (2002) present a compelling argument for the use of NIRS in wildlife ecology. While their comments refer specifically to NIRS on forage, the same could be made for fecal NIRS as well.

A key difference exists when using fecal NIRS to predict diet characteristics compared to using NIRS to predict forage quality. In the latter, calibrations for quality characteristics (e.g., crude protein) are developed by performing both NIRS and reference chemistry on the same material (i.e., the feed or forage in question). In contrast, with fecal NIRS, reference chemistry is performed on one material (diet) and spectra are obtained from another, albeit biochemically linked, material (feces). While the indirect prediction of diet quality via fecal NIRS is a novel application of the technology, it is by no means completely so. In the pulp and paper industry for instance, viscosity and percent lignin of sulphite pulp can be predicted by NIRS of the cooking liquor (Henriksen et al. 2004). This procedure would be somewhat analogous to predicting fecal characteristics via NIRS of rumen fluid. Still other examples include utilization of spectra obtained from yeast extracts to predict fermentation cell mass and specific product yields (Kasprow et al. 1998) and prediction of baking characteristics of flour via spectral properties of individual whole wheat grains (Guttieri et al. 2001). These three examples are all forward process predictions; NIRS is performed on a raw or intermediate substance and used to develop calibrations to predict characteristics on a subsequent or processed material. Fecal NIRS to determine diet quality is thus a reverse process prediction and not unlike the discrimination between treatment diets by NIRS of chicken breast meat (Berzaghi et al. 2005).

In light of the above accomplishments with indirect NIRS and the abundant population and economic value of white-tailed deer (*Odocoileus virginianus*) in the US, the assessment of dietary nutrient status of free-ranging deer would seem a logical next step for this technology and could provide a critical link between habitat quality, management, and animal well-being. The objective of this study was to determine the ability of fecal NIRS to predict dietary crude protein (CP), digestible organic matter (DOM), and phosphorus (P) in white-tailed deer.

METHODS

Feeding Trials

Calibration feeding trials were conducted from June through August 1996 at the Great Whitetail, Inc. urine collection and breeding facility, located 11 km west of Garrison, Texas (lat 31°47′N, long 94°35′W). Seventeen white-tailed deer (14 mature lactating does, 3 bucks) were utilized in 4 to 5 trials. Animals were housed in individual concrete-floored pens (6.5 m^2) enclosed by 2.5 m chain-link fencing. Water was provided ad libitum. Each animal was fed a unique ration during each feeding trial. Over 50 species of plants, assorted plant materials, and 3 supplemental feeds were utilized to create complete rations (Table 1) varying from 6.00 to 18.95% CP, 26.64 to 76.08% DOM, and 0.08 to 0.48% P on a dry matter basis. Vegetation was harvested by hand. Generally, new growth shoots and leaves were collected from mature browse and vines; in the case of young browse species and forbs, whole plants were collected. For detailed descriptions of rations fed, see Showers (1997). Rations were fed for 6 days with feces representing each diet collected on days 6 and 7 (i.e., day 1 of subsequent diet). In as much as it was possible, urine-free feces were collected, however some urine contamination was unavoidable. Seventy-six rations were fed successfully (some animals were removed for reasons of health or behavior). Feces were stored frozen (−40°C) until further processing. After thawing at room temperature, samples were dried at 60°C for 12 hours and ground to pass a 1 mm screen. Ground samples were redried at 60°C for 12 hours prior to analysis by NIRS. Near infrared spectra were collected on a Foss® 6500 scanning monochrometer in the 1 100 to 2 498 nm range.

Reference Chemistry

An aliquot of each diet was analyzed for CP and P content by micro-Kjeldahl procedures (AOAC 1975; Hach Co. 1987), and digestibility using a 48 hour fermentation (Tilley and Terry 1961) with the Ankom filter bag techniques (Komarek et al. 1994) followed by neutral detergent fiber analysis (Van Soest and Wine 1967) on the Ankom filter bags (Komarek et al. 1994). Rumen fluid was collected from cannulated steers grazing native pasture. Seven standards with known in vivo digestible dry matter (IVDDM) derived from deer (supplied by Dr Robert Cowan, retired, Pennsylvania State University, Palmer and Cowan 1980) were included in each in vitro run. These standards included ground commercial deer pellets (68.4% IVDDM), early cut alfalfa (*Medicago sativa* L., 62.1% IVDDM), crown vetch (*Coronilla varia* L. Lassen, 60.8% IVDDM), and red clover (*Trifolium pratense* L., 58.9% IVDDM), late cut alfalfa (52.2% IVDDM), white cedar (*Thuja occidentalis* L., 37.0% IVDDM), and fallen sugar maple leaves (*Acer saccharum* Marsh, 37.3% IVDDM). Digestibility values were determined for each standard at 12, 24, 30, 36, and 48 hours. From these, time in bath and in vivo correction factors were

Table 1. Vegetation and feedstuffs used in rations fed to white-tailed deer in order to establish diet reference chemistry:fecal spectrum calibration pairs.[1]

Browse	Forbs
American beautyberry (*Callicarpa Americana* L.)	Alfalfa (*Medicago sativa* L.)
American holly (*Ilex opaca* Ait.)	Bur-clover (*Medicago polymorpha* L.)
Big sage (*Artemisia tridentate* Nutt.)	Crimson clover (*Trifolium incarnatum* L.)
Bitter brush (*Purshia tridentate* [Pursh] DC.)	Engelmann daisy (*Engelmannia pinnatifida* Nutt.)
Blackjack oak (*Quercus marilandica* Muenchh.)	Giant ragweed (*Ambrosia trifida* L.)
Cedar (*Juniperus virginiana* L.)	Mexican hat (*Ratibida columnaris* [Sims] D. Don)
Coma (*Bumelia celastrina* H.B.K.)	Red clover (*Trifolium pretense* L.)
Dogwood (*Cornus florida* L.)	Vetch (*Vicia villosa* Roth)
Elm (*Ulmus* spp.)	Yellow sweetclover (*Melilotus officinalis* L.)
Farkleberry (*Vaccinium arboretum* Marsh.)	
Guayacan (*Guaiacum angustifolium* Engelm.)	Vines
Hacberry (*Celtis reticulate* Torr.)	Alabama supplejack (*Berchemia scandens* [Hill] K. Koch)
Huisache (*Acacia farnesiana* Gould)	Blackberry (*Rubus* spp.)
Live oak (*Quercus virginianan* Mill.)	Carolina jessamine (*Gelsemium sempervirens* [L.] Ait. f.)
Mulberry (*Morus rubra* L.)	Grape (*Vitis* spp.)
Pine (*Pinus* spp.)	Greenbriar (*Smilax* spp.)
Post oak (*Quercus stellata* Wang.)	Honeysuckle (*Lonicera japonica* Thunb.)
Red maple (*Acer rubrum* L.)	Peppervine (*Ampelopsis arborea* [L.] Koehne)
Red oak (*Quercus falcate* Michx.)	
Rusty blackhaw (*Viburnum rufidulum* Raf.)	Grasses
Sassafras (*Sassafras albidum* [Nutt.] Nees.)	Bahiagrass (*Paspalum notatum* Flugge)
Sweetgum (*Liquidambar styraciflua* L.)	Bermudagrass (*Cynodon dactylon* [L.] Pers.)
Water oak (*Quercus nigra* L.)	Rescuegrass (*Bromus unioloides* [Kunth] H.B.K.)
Wax myrtle (*Myrica cerifera* L.)	Ryegrass (*Lolium perenne* L.)
White oak (*Quercus alba* L.)	
Willow (*Salix nigra* Marsh.)	Cacti
Willow oak (*Quercus phellos* L.)	Texas prickly pear (*Opuntia lindheimeri* Engelm.)
Yaupon (*Ilex vomitoria* [Soland] Ait.)	
Acorns (*Quercus* spp.)	
Leaf litter	
Grains/supplemental feeds	
Corn	
Dairy Cow Milk Generator™	
Buck Chuck Deer Grower™	
CarMil Glo™	

[1]Scientific names conform to those provided in Franklin and Dyrness (1973) and Hatch et al. (1990).

calculated. Corrected IVDDM values were individually converted to DOM by multiplying IVDDM by percent organic matter. Orts were analyzed using the same procedures to account for selective consumption of diet components.

Chemometrics

Calibration models were developed with the diet reference chemistry:fecal spectrum pairs using partial least squares regression (Martens and Naes 1987) in Win ISI II® version 1.50 software (Infrasoft International LLP, Port Matilda, PA). Two types of calibration outliers were identified. Spectral outliers were those greater than 8.0 Mahalanobis distance (H) units from the centroid of the calibration spectra (Mahalonobis 1930). Briefly, this statistic is the calculated euclidian distance between two points in multidimensional space; in this case, between the centroid and any given spectrum. The greater the distance between the 2, the more dissimilar they are. Reference method outliers were those with a "t" value greater than 2.5 (Shenk and Westerhaus 1993). Scatter correction (standard normal variate and detrend) was applied to spectra prior to regression (Duckworth 2004). Calibration equations were developed with either a first or second derivative using a gap and smooth (Duckworth 2004) of 4.0, and evaluated for performance. Cross validation in which each sample was individually predicted by a calibration consisting of the remaining ($n - 1$) samples was employed (Stone 1974). Minimum criteria to evaluate how well the calibration data were fit include: 1) coefficient of determination greater than 0.80 and 2) SE of calibration less than 2× the SE of differences for duplicate samples analyzed by the applicable laboratory reference method (Westerhaus 1989). The SE for laboratory

Table 2. Fecal NIRS diet quality equation results for white-tailed deer: original calibration dataset.

Diet constituent	Math[1]	*N*[2]	RSQ[3]	SEC[4]	1-VR[5]	SECV[6]
Crude protein	1,4,4	70	0.95	0.95	0.85	1.17
Digestible organic matter	1,4,4	72	0.88	2.81	0.77	3.62
Phosphorus	1,4,4	73	0.83	0.03	0.81	0.04

[1]Derivative, gap, smooth.
[2]Calibration outliers = 76 − N, criteria to select outliers: t = 2.5, H = 8.0.
[3]Coefficient of determination.
[4]Standard error of calibration.
[5]One minus variance ratio.
[6]Standard error of cross validation.

Table 4. Fecal NIRS diet quality equation results for white-tailed deer: original calibration plus validation datasets.

Diet constituent	Math[1]	*N*[2]	RSQ[3]	SEC[4]	1-VR[5]	SECV[6]
Crude protein	1,4,4	86	0.84	1.19	0.79	1.40
Digestible organic matter	1,4,4	84	0.89	2.63	0.80	3.55
Phosphorus	1,4,4	85	0.83	0.03	0.76	0.04

[1]Derivative, gap, smooth.
[2]Calibration outliers = 88 − N, criteria to select outliers: t = 2.5, H = 8.0.
[3]Coefficient of determination.
[4]Standard error of calibration.
[5]One minus variance ratio.
[6]Standard error of cross validation.

reference values were 0.50, 1.82, and 0.01% for CP, DOM and P, respectively.

Validation

Twelve additional feeding trials were conducted at the same facility, using the same procedures described for calibration, during January 1997. Six non-lactating does (6 months to 9 years) not previously used in the calibration procedure were utilized; each was fed a unique ration, also not utilized in the calibration procedure, although some individual ingredients were repeated from the original feeding trials. One animal stopped eating on day 5 of the feeding trial; data from this trial was thus removed from consideration. In addition to this pen-fed validation group, 17 fecal samples collected monthly (January to September 2001) in 2 pastures from free-ranging white-tailed deer in the Central Rolling Red Plains Major Land Resource Area (lat 33°50′N, long 100°34′W), provided a set of unknowns with which to test the NIRS calibration equations. Only 1 sample was collected in April. Corresponding Normalized Difference Vegetation Indices (NDVI) for greenness at 2 km^2 resolution were obtained for the study area. Thus in addition to cross validation within the calibration set, potential NIRS equation performance on unknown samples was evaluated using linear regression (Snedecor and Cochran 1989) by: 1) predicting diet quality for the 11 samples from which chemical reference method data had been obtained, and 2) comparison of predicted diet quality to NDVI greenness data.

RESULTS

Calibration

Calibration results are presented in Table 2. For each dietary constituent, R^2 was greater than 0.80 and, with the exception of P, SE of calibration was less than 2× the SE for laboratory reference values. Calibration equations for CP and DOM were thus deemed acceptable according to predefined criteria. Although SE of calibration for P was outside the acceptable criteria, this could be due to values for P being below the sensitivity of the NIRS method as applied in this study. The R^2 value for P indicates a relationship between fecal NIR spectra and dietary P. Fecal P has been previously determined (Reeves 2001; Smith et al. 2001); this report, however, represents the first use of fecal NIRS to predict dietary P.

Table 3. Pen-fed validation group results for fecal NIRS diet quality equations in white-tailed deer: original calibration dataset.

	NIRS validation results				Lab. reference values		
Diet constituent	RSQ[1]	SEP[2]	Slope	Bias	Mean	SE	Range
Crude protein	0.79	1.53	1.11	0.84	12.86	0.81	8.37
Digestible organic matter	0.49	5.46	0.53	2.72	50.38	1.55	13.30
Phosphorus	0.67	0.03	1.02	0.01	0.19	0.01	0.17

[1]Coefficient of determination.
[2]Standard error of prediction.

Validation

Cross validation results are also presented in Table 2. An acceptable degree of prediction accuracy was observed for CP and P as indicated by 1-variance ratio values greater than 0.80. For DOM, this value was 0.77, less than predefined criteria but still indicative of a relationship between fecal NIR spectra and measured digestibility of the diet. Acceptable accuracy and precision was also obtained for CP and DOM, as SE of cross validation was less than 2× the SE for the reference method for both constituents. As with the SE of calibration, the SE of cross validation was greater than 2× the SE of the reference method for dietary P.

Results of the pen-fed validation trial are found in Table 3. A mean H value of 1.26 ± 0.14 (mean ± SE) for this sample set indicates similar spectral characteristics to those of the calibration set. Dietary CP, and to a lesser degree P, were predicted with a moderate level of success as indicated by R^2 values of 0.79, 0.67, and a SE of prediction 2.5 to 3× the laboratory SE, respectively. The relationship between predicted and measured DOM was poor as indicated by low values for R^2 and slope, and high values for SE of calibration and bias.

Samples from the validation set were added to the original calibration set and equations recalculated as per the previously described methods. Calibration and cross validation results from this new combined calibration are given in Table 4. As in the original, equation performance criteria met minimum standards with the exception of SE of calibration greater than 2× the laboratory method SE for dietary P. Cross validation yielded an outcome similar to the original with 1-variance ratio values approximately 0.80, but SE of cross validation was greater than 2× the SE of the laboratory reference method for both CP and P. The SE of cross validation for DOM (2.63) was less than 1.5× the SE of the laboratory method for DOM (2.73).

Fecal samples (H = 11.11 ± 1.77) from free-ranging deer in northwest Texas were predicted with both the original and the

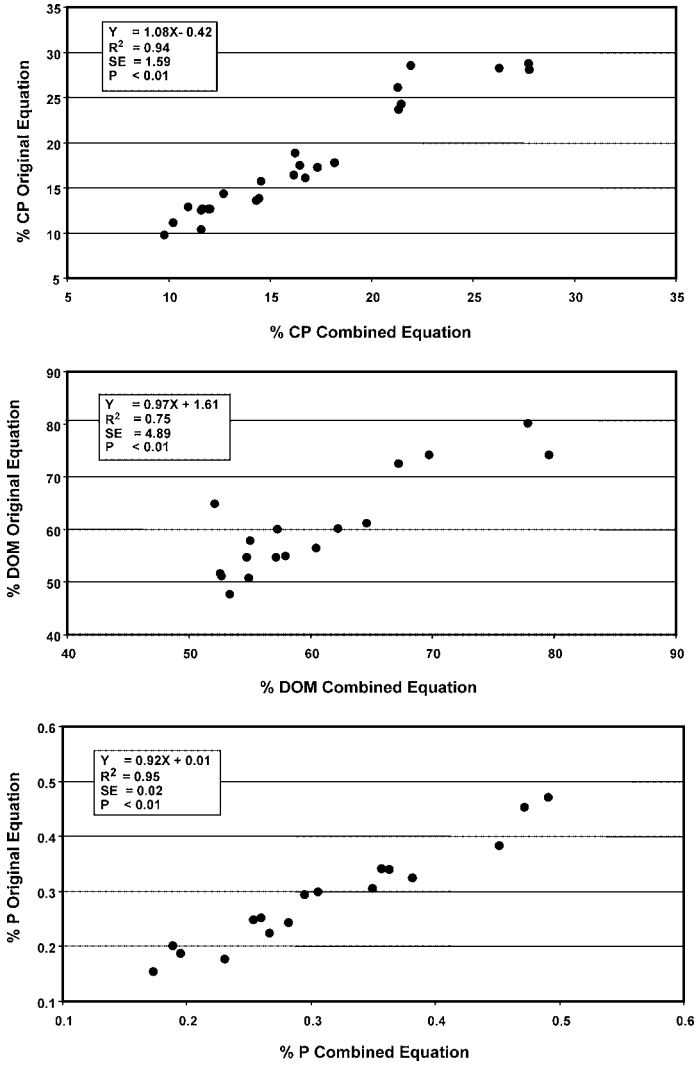

Figure 1. Fecal NIRS predicted diet quality in white-tailed deer: Original versus Original plus Validation (Combined) calibrations.

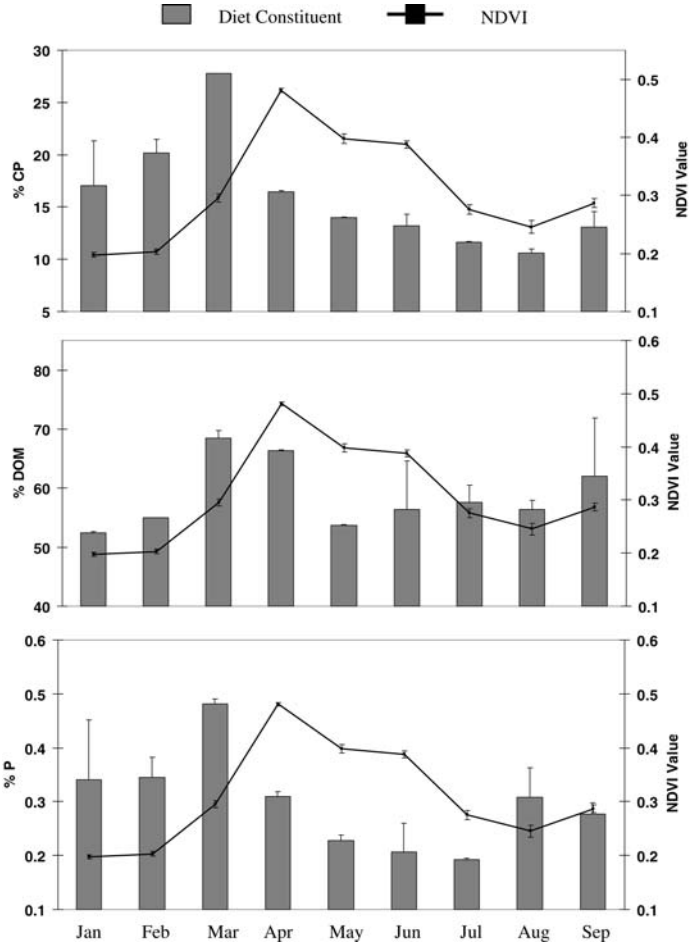

Figure 2. Fecal NIRS predicted diet quality (mean ± SE, $N = 2$ pastures) in free-ranging white-tailed deer and NDVI greenness index values (mean ± SE, $N = 9$ pixels) for the sampling area in northwest Texas.

combined calibration equations (Fig. 1). Despite approximately 50% of the samples exhibiting H values greater than that specified to identify spectral outliers in the calibration process, a significant agreement ($P < 0.001$) in predicted diet quality between the 2 equations (original and combined) was observed for CP, DOM and P ($R^2 = 0.94$, 0.75, 0.95, respectively). Additionally, the NIRS predicted values were compared to NDVI greenness index values (bare soil: 0.0 to 0.1, dense vegetation: 0.5 to 0.7) for a 9 pixel (36 km^2) area (Fig. 2). For the entire period, correlation between fecal NIRS predicted diet quality and NDVI were poor ($R^2 < 0.20$). This poor correlation is due to differences in the magnitude of change in greenness observed at a landscape level versus changes in diet selected by individual animals. For instance, during the transition from winter to spring in the study area, dominant overstory plants such as honey mesquite (*Prosopis glandulosa* Torr.) would contribute to the proportionally large increase in NDVI values. Honey mesquite leaves are classified as "non-consumable" for white-tailed deer (Stuth 1991). There would thus be a disproportionate representation of these plants in overall greenness and in deer diets. So, while both greenness and diet quality were increasing, they were doing so at divergent rates. Based on this observation, we felt it prudent to make within season comparisons. Relationships between NIRS predicted diet quality attributes and NDVI greenness index by season are presented in Table 5. Within season, NIRS and NDVI values exhibit high levels of correlation ($R^2 > 0.70$) with the exception of P during summer ($R^2 = 0.25$).

Table 5. Relationship between fecal NIRS predicted diet quality in free-ranging white-tailed deer and NDVI greenness index values by season.

	Winter[1]			Spring[2]			Summer[3]		
Diet constituent	RSQ[4]	SE[5]	P[6]	RSQ[4]	SE[5]	P[6]	RSQ[4]	SE[5]	P[6]
Crude protein	0.95	1.82	0.15	0.98	0.32	0.08	0.88	0.61	0.22
Digestible organic matter	0.99	1.21	0.06	0.91	2.78	0.19	0.70	2.28	0.37
Phosphorus	0.99	0.01	0.02	0.99	0.01	0.06	0.25	0.07	0.67

[1]January to March.
[2]April to June.
[3]July to September.
[4]Coefficient of determination.
[5]Standard error.
[6]Probability value.

DISCUSSION

Crude Protein

The prediction of dietary CP in white-tailed deer can be accomplished via fecal NIRS. Equation performance statistics (R^2, SE of calibration) are similar to previous reports for cattle (0.92, 0.89: Lyons and Stuth 1992; 0.98, 0.33: Boval et al. 2004), goats (0.94, 1.12: Leite and Stuth 1995), and elk (0.99, 0.50: Brooks et al. 1984), respectively. Soper et al. (1993) in central Oklahoma observed seasonal patterns of white-tailed deer fecal N similar to the diet CP reported here. The degree of accuracy and precision obtained with fecal NIRS for the measurement of dietary CP in white-tailed deer indicates this technique could be employed to obtain near real-time assessments of both animal nutrient status and forage resource quality, depending on the goal of the observer. The relationship between NIRS predicted CP in a free-ranging herd, and NDVI greenness for their habitat is especially encouraging as these two tools could be linked at the landscape level for concurrent monitoring of animal and habitat health. Development of such has been reported by Awuma (2004) for livestock in West Africa.

Digestible Organic Matter

Determination of diet digestibility in deer can also be accomplished via fecal NIRS, although with less accuracy as compared to CP. This also agrees with previous reports from both wild and domestic ruminants as evidenced by the generally lower equation R^2 (0.80 to 0.94) values (Brooks et al. 1984; Lyons and Stuth 1992; Leite and Stuth 1995; Boval et al. 2004). Nitrogen content, and by default CP, is a chemical property of the diet and relatively easily measured. Digestibility, on the contrary is more difficult to determine, owing to the effects of the animal in question; it is not just a chemical component of the feedstuff. Thus it follows that the prediction of diet digestibility with fecal NIRS would be less successful than that of CP; the inherent error associated with quantifying diet digestibility being greater than that associated with diet nitrogen. The success of an NIRS prediction equation for any diet constituent will ultimately depend on the reliability of the chemical reference method. This will of course include all aspects of the process including sampling, not just the chemical technique in and of itself.

When compared to CP, the reported SE of calibration (1.51 to 2.20) values for digestibility are numerically greater and do reflect the inherent differences in laboratory error associated with each respective technique. However, if one evaluates the magnitude of SE of calibration as a proportion of the observed range of observed values for the respective constituents, they are in fact very similar. To illustrate, the range of CP we commonly observe in ungulate herbivore diets is approximately 20 units (5%–25%), and for DOM approximately 40 units (40%–80%). The SE of calibration for CP and DOM in our work and that reported by others is on the order of 1.0 and 2.0, respectively, thus both represent approximately 5% of the expected range.

Energy requirements of free-ranging deer can be affected by many factors including latitude and nutritional environment (Strickland et al. 2005). Reported maintenance requirements for white-tailed deer vary from 109 to 178 kcal DE $kg^{0.75-1}$ in fawns (Amman et al., 1973; Thompson et al. 1973; Holter et al. 1977, 1979), and from 192 to 219 kcal DE $kg^{0.75-1}$ in yearlings (Thompson et al. 1973; Holter et al. 1977, 1979). Growth in yearlings (309 to 329 kcal DE $kg^{0.75-1}$: Holter et al. 1979) and gestation in mature females (160 to 158 kcal DE $kg^{0.75-1}$: Ullrey et al. 1969, 1970) show similar variability. Determination of diet DOM via fecal NIRS as accomplished in this study should be sufficiently accurate and precise to provide both researchers and resource managers with timely, useful information on the energy status of free-ranging deer.

Phosphorus

Determination of dietary P for deer was accomplished in this study, although again, less successfully than that observed for CP. Perhaps a larger calibration with a greater range of values would yield both higher R^2 and lower SE of calibration for this diet constituent. Alternatively, the degree to which dietary P was predicted via fecal NIRS in this study may represent the level of success attainable for this constituent. Phosphorus metabolism in white-tailed deer has been observed to change with current needs (Wetzl 1968; Stephenson and Brown 1984; Brown 1990). This fact would obviously affect fecal chemistry irrespective of diet quality and as a result, complicate the use of fecal NIRS to predict P content in the diet. Grassman and Hellgren (1993) determined P requirements in white-tailed deer. In so doing they fed three levels of dietary P (0.14 to 0.19%, 0.24 to 0.27%, and 0.34 to 0.37%). The dietary P fecal NIRS equation reported herein ($R^2 = 0.83$, SE of calibration $= 0.03$) would be able to adequately distinguish between similar levels of dietary P content and thus provide a means of monitoring this important mineral. Additional work in this area may be required to determine if fecal NIRS predictions of dietary P can attain higher levels of accuracy and precision.

MANAGEMENT IMPLICATIONS

Cross validation, independent validation with pen-fed animals, and comparison to NDVI data in a wild herd, all indicate that fecal NIRS can be used to predict diet quality attributes at a level that one would find useful in making management decisions regarding a free-ranging population of white-tailed deer. Geo-referenced fecal NIRS predictions, collected at regular intervals in concert with forage availability measurements could provide baseline habitat and resource quality data, similar to what has been done with domestic livestock on native range and pastureland (Awuma 2004).

Our experience with predicting livestock diet quality using fecal NIRS has shown that incorporation of samples representing diversity in season, location, and vegetation improves the overall predictive performance of the calibration, even though this by necessity involves utilizing multiple laboratories, thus introducing greater error into the calibration procedure. While considerable effort was expended in the current study to create diverse diets and represent the range of quality wild deer might encounter, it is by no means a finished product. Fecal NIRS diet quality equations should always be a work in progress, expanded and improved as opportunity allows. The work

reported herein is thus an encouraging first step toward continuing development of nutritional and rangeland monitoring tools for this and related species.

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