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Evaluation of Green, Red, and Near Infrared Bands for Predicting Winter Wheat Biomass, Nitrogen Uptake, and Final Grain Yield[#]

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ABSTRACT

Presently normalized difference vegetative indexes (NDVI) based on red (RNDVI) or green (GNDVI) reflectance are commonly used to evaluate plant health, biomass, and nutrient content. This study was conducted to determine which of these two indexes is more correlated with biomass, forage nitrogen (N) uptake, and final grain yield of winter wheat. Three experimental sites were established in Oklahoma in the fall of 2001 at Stillwater. Spectral reflectance measurements were taken at Feekes growth stage 4, 6, and 10.5 followed by winter

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wheat forage harvest. When evaluated at specific stages of growth, RNDVI was consistently more highly correlated with biomass than GNDVI. Green NDVI and RNDVI were more highly correlated with forage N uptake than with dry biomass at each stage of growth, but neither index appeared to have a comparative advantage over the other. Both indexes were highly correlated with final grain yield and grain N uptake across all locations. Neither index appeared to have a sizeable advantage over the other, suggesting that either will perform equally well when predicting forage N uptake, grain yield, and grain N uptake in winter wheat. Red NDVI does appear to be a better predictor of forage biomass, specifically at earlier stages of growth.

Key Words: NDVI; Biomass; Sensors; Yield protection; Wheat.

INTRODUCTION

Soil nutrient availability has traditionally been determined by soil sampling of crop fields. However, use of coarse resolutions encompassing large areas of land cannot provide reliable information about the inherent nutrient variability within the field. Wibawa et al.[1] in his evaluation of soil fertility variation using grid sampling for field maps indicated that variation in soil nitrate-N (NO_3-N) occurred over very short distances within a 15 m^2 grid. Solie et al.[2] showed that the optimum field element size could be less than 1 m^2, and variable rates should be adjusted to a resolution of 1 m^2 in order to optimize fertilizer inputs. They further defined field element size as the area, which provides the most precise measure of the available nutrients where the level of that nutrient changes with distance.

The potential of chemical soil analysis to address spatial variability at resolutions that have been identified as optimal is cost prohibitive. Nondestructive, indirect measures of crop health have been identified as possible alternatives to soil testing for making management decisions about agricultural inputs. Much research has been focused on the use of the normalized difference vegetative indices (NDVI) calculated using crop reflectance at differing wavelengths as a measure of plant health.

Reflectance measurements for predicting of forage biomass and N uptake is dependent on the growth stage, whether it is wheat (*Triticum durum* Desf. Var produra),[3] forage grasses,[4] and/or barley (*Hordeum vulgare* L.).[5] Research in barley showed that the relationship between fresh biomass and IR/red changed with time, indicating the ratio was dependent on growth stage.[5] Gausman et al.[6] reasoned that the impact

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of growth stage on reflectance reading of young plant tissue, had less air spaces within the mesophyll than did older leaves, and thus, showed decreased NIR spectral radiance. Sembiring et al.[7] reported that the amount of variability in total N uptake as explained by NDVI increased with advancing growth stages, which can be further evidence that NDVI is a reliable predictor of biomass and in-season N uptake. Taylor et al.[8] showed that red and green NDVI readings were significantly correlated with forage yield and N uptake of bermudagrass.

Previous work has shown that final grain yield can be predicted using an in-season estimate of yield (INSEY) which is calculated using RNDVI and growing degree days greater than zero.[9] It has been documented that using GNDVI is more highly correlated to final grain yield in corn than RNDVI at later stages of growth.[10] The objectives of this experiment were to determine the relationship between the RNDVI, GNDVI, forage biomass, and forage N uptake at various stages of growth, and to determine if GNDVI was a better predictor of forage biomass and/or forage N uptake than RNDVI, when vegetative coverage of the soil exceeds 50%.

MATERIALS AND METHODS

This experiment was conducted on four existing long-term fertility trials (222-Stillwater, 301-Efaw, AA-Efaw, and AA-Hennessey). Data were collected beginning in December extending through June 2002. Winter wheat cultivar ‘‘Custer’’ was planted at a seeding rate of 78 kg/ha at all sites. Planting dates ranged between October and November and sown with a spacing of 19 cm at Stillwater and 15 cm at Hennessey and Efaw. Treatments were laid out in a randomized complete block design with four replications at 222-Stillwater and three at 301-Efaw, AA-Efaw, and AA-Hennessey sites.

Spectral reflectance was measured using an Oklahoma State University designed sensor that included three upward directed photodiode sensors, and that received incident light through cosine correlated Teflon® windows fitted with red (671 ± 6 nm), near-infrared (NIR) (780 ± 6 nm), and green (550 ± 12.5 nm) interference filters. The instrument also included three down-looking photodiode sensors that received light through collimation and interference filters identical to the up-looking sensors. The instrument used a 16bit A/D converter to simultaneously capture and convert the signals from the four photodiode sensors. Collimation was used to constrain the view of the down looking sensors to a 0.80 m^2 circular area at the plant surface. Stability of

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the sensor was maintained across time by dividing spectral readings by day and time-specific spectral white plate (100% reflectance) readings (barium sulfate coated aluminum plate). The reflectance of the barium sulfate coating was assumed to be 1.0 for all three spectral bands investigated. Reflectance values (the ratio of incident and reflected values) were used in the calculation of NDVI to minimize the error associated with cloud cover shadows and sun angle. Reflectance based NDVI was calculated using the following equations:

$$\text{NDVIred} = \left[\frac{\text{NIRref}}{\text{NIRinc}} - \frac{\text{REDref}}{\text{REDinc}}\right] \Big/ \left[\frac{\text{NIRref}}{\text{NIRinc}} + \frac{\text{REDref}}{\text{REDinc}}\right]$$

$$\text{NDVIgreen} = \left[\frac{\text{NIRref}}{\text{NIRinc}} - \frac{\text{GREENref}}{\text{GREENinc}}\right] \Big/ \left[\frac{\text{NIRref}}{\text{NIRinc}} + \frac{\text{GREENref}}{\text{GREENinc}}\right]$$

where, NIRref, REDref, and GREENref = magnitude of reflected light, and NIRinc, REDinc, and GREENinc = magnitude of incident light.

The dates where readings were collected ranged between Feekes growth stage 4 (leaf sheaths beginning to lengthen), 6 (first node of stem visible), and 10 (flowering).[11] For all experiments, individual 1 m^2 plots were hand clipped (immediately following sensor readings) and weighed prior to being dried in a forced-air oven at 60°C. Once dry, samples were ground to pass a 0.125-mm (120-mesh) sieve and analyzed for total N using a Carlo-Erba (Milan, Italy) NA-1500 dry combustion analyzer.[12] Early-season plant N uptake was determined by multiplying dry matter yield by the total N concentration determined from dry combustion. Nitrogen uptake and forage biomass were correlated with GNDVI and RNDVI values to determine their relationship at different wheat growth stages. Statistical analysis was performed using SAS statistical package.[13]

RESULTS AND DISCUSSION

Forage Biomass

At the first sensing date (December 2001, Feekes growth stage 4), both GNDVI ($r^2 = 0.62$) and RNDVI ($r^2 = 0.78$) readings were highly correlated with forage biomass of winter wheat (Figs. 1 and 2). At the second sensing date (March, 2002, Feekes 6), both GNDVI ($r^2 = 0.69$) and RNDVI ($r^2 = 0.55$) were still highly correlated with biomass (Table 1). For both of the Feekes 4 and Feekes 6 sampling dates, there

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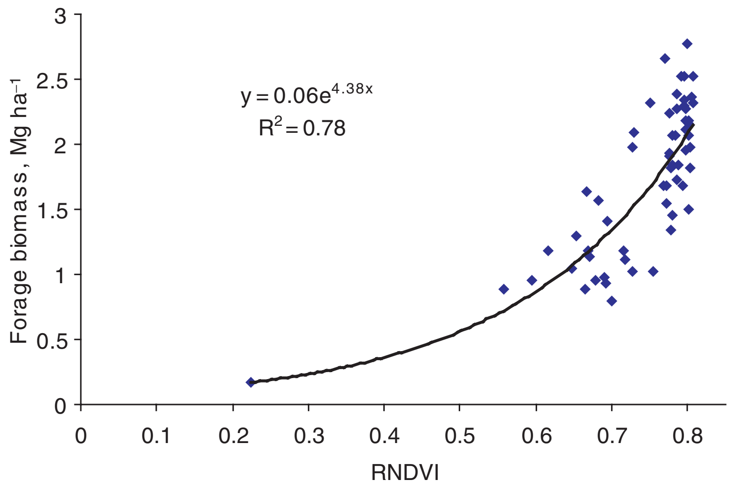

Figure 1. Relationship between RNDVI and forage biomass at Feekes growth stage 4 across all locations, 2001–2002. *(View image in color online.)*

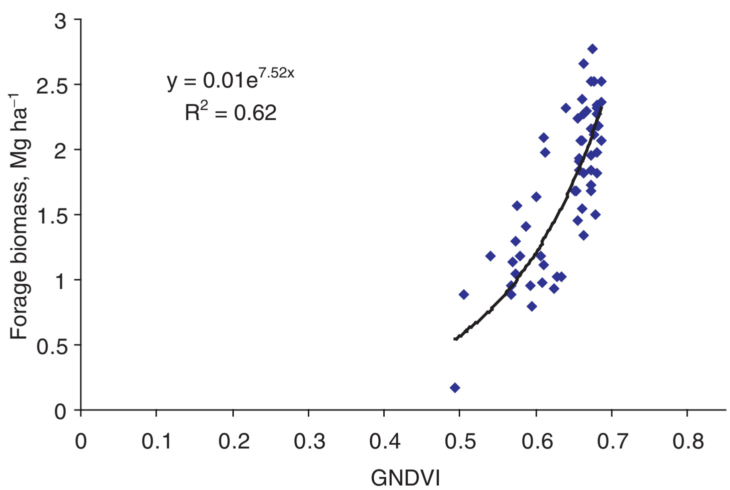

Figure 2. Relationship between GNDVI and forage biomass at Feekes growth stage 4 across all locations, 2001–2002. *(View image in color online.)*

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Table 1. Coefficient of determination (r^2) values for NDVI and forage biomass from Feekes 4 to Feekes 10.

	RNDVI[a]			GNDVI[b]		
Variable	Feekes 4	Feekes 6	Feekes 10	Feekes 4	Feekes 6	Feekes 10
Forage biomass	0.78[c]	0.69[c]	0.60[c]	0.62[c]	0.55[c]	0.54[c]

[a]Red NDVI.
[b]Green NDVI.
[c]Significant at $p < 0.01$.

was a tendency for the RNDVI readings to have a broader and more robust range (GNDVI), evidenced in the smaller slope components. At the final sensing date (April, 2002), approximately Feekes 10, both indexes showed decreased correlation with biomass (Table 1). The correlation between forage biomass and RNDVI or GNDVI tended to decrease with increasing stage of growth. The by cutting RNDVI readings tended to show improved correlation with biomass when compared to GNDVI.

Forage Nitrogen Uptake

At Feekes 4, RNDVI and GNDVI were highly correlated with forage N uptake ($r^2 = 0.78$ and 0.77, respectively). Similarly, at Feekes 6 RNDVI and GNDVI were highly correlated with forage N uptake ($r^2 = 0.91$ and 0.90, respectively) (Figs. 3 and 4). Red and green NDVI were still highly correlated with forage N uptake at Feekes 10 ($r^2 = 0.86$ and 0.88, respectively). Red and green NDVI were more highly correlated with forage N uptake than biomass, which is consistent with previous studies.[14] There appeared to be only small differences between the correlation between RNDVI and GNDVI and forage N uptake at the various stages of growth evaluated here.

Grain Yield

Spectral measurements taken at Feekes 5 were used to determine whether RNDVI or GNDVI was more highly correlated with final grain yield. Both indexes had a strong correlation with final grain yield across

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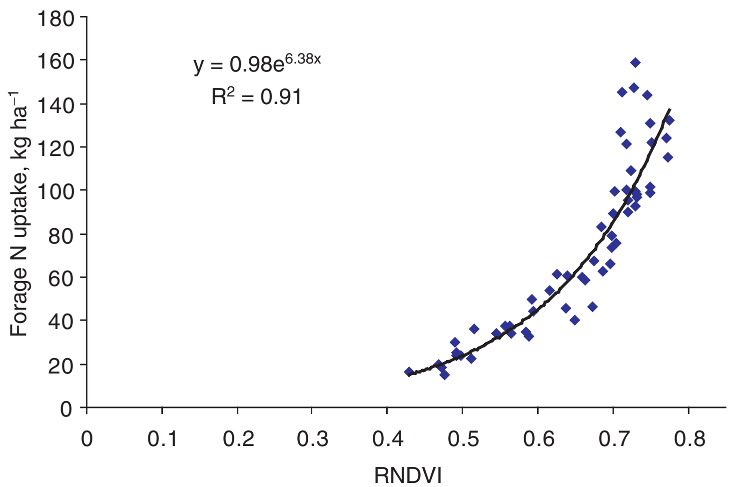

Figure 3. Relationship between RNDVI and forage N uptake at Feekes growth stage 6 across all locations, 2001–2002. *(View image in color online.)*

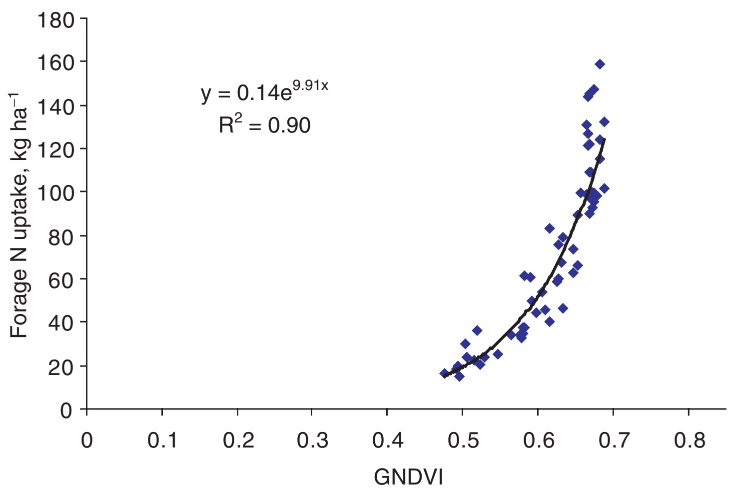

Figure 4. Relationship between GNDVI and forage N uptake at Feekes growth stage 6 across all locations, 2001–2002. *(View image in color online.)*

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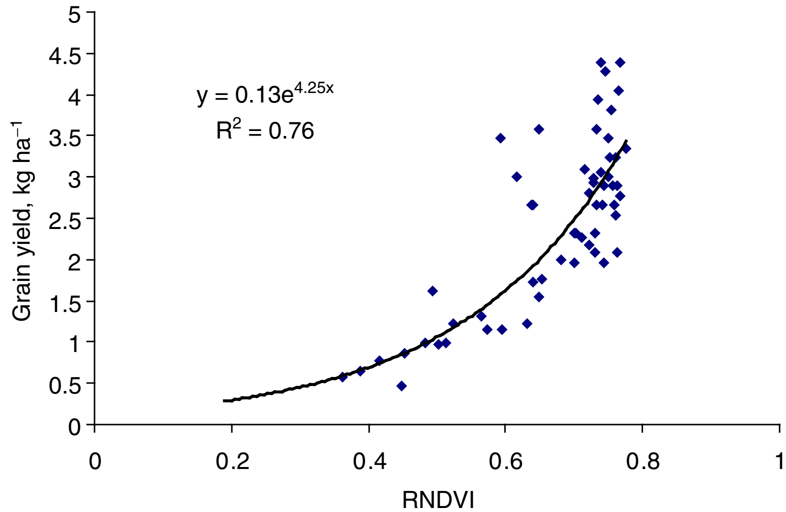

Figure 5. Relationship between RNDVI readings taken at Feekes growth stage 5 and grain yield across all locations, 2001–2002. *(View image in color online.)*

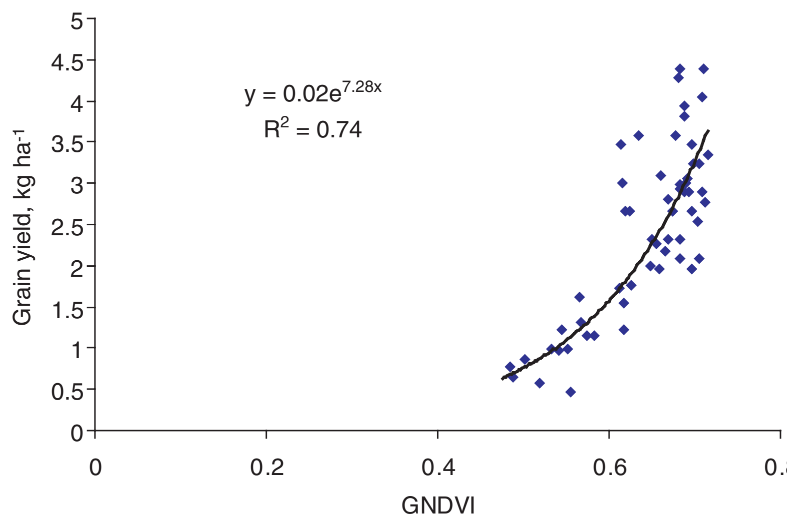

Figure 6. Relationship between GNDVI readings taken at Feekes growth stage 5 and grain yield across all locations, 2001–2002. *(View image in color online.)*

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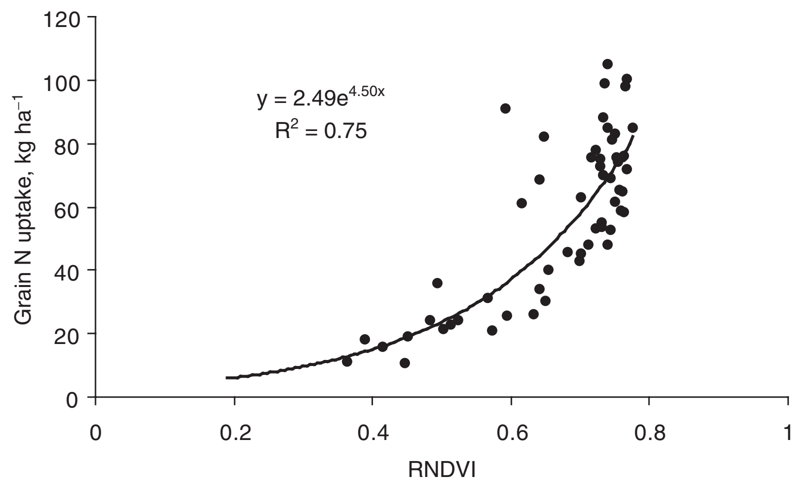

Figure 7. Relationship between RNDVI readings taken at Feekes growth stage 5 and grain N uptake across all locations, 2001–2002.

all locations (red, $r^2 = 0.76$ and green, $r^2 = 0.74$) (Figs. 5 and 6). The correlation between RNDVI and GNDVI and wheat grain yield was as good as the correlation between INSEY and wheat grain yield (data not shown).

Grain Nitrogen Uptake

As with grain yield, spectral measurements for correlation of grain N uptake and RNDVI and GNDVI were taken at Feekes 5. Both indexes were highly correlated with final grain N uptake across all locations (RED, $r^2 = 0.75$ and GREEN, $r^2 = 0.75$) (Figs. 7 and 8). Thus the correlations between grain N uptake and RNDVI and GNDVI were similar to the correlations between RNDVI and GNDVI and grain yield.

CONCLUSIONS

In these studies there did not appear to be an advantage of either index (RNDVI vs. GNDVI) over the other. Thus for the growth stages where data was collected in this work, the use of either RNDVI or GNDVI should be a reliable predictor of forage biomass, forage N

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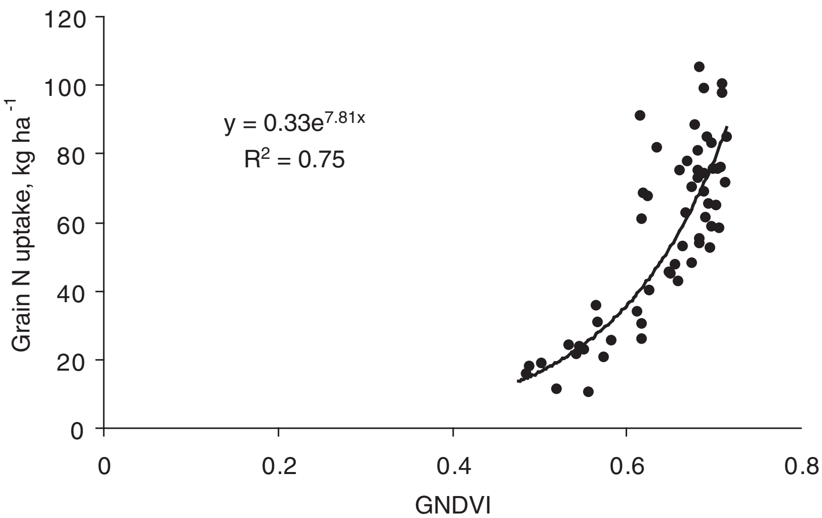

Figure 8. Relationship between GNDVI readings taken at Feekes growth stage 5 and grain N uptake across all locations, 2001–2002.

uptake, grain yield, or grain N uptake in winter wheat. There was a tendency for the RNDVI readings to be more robust (compared to GNDVI) and that provided a wider range in values where differences could be more easily partitioned.

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