

# INTEGRATING NDVI AND PLANT TISSUE ANALYSIS AS DECISION SUPPORT TOOLS FOR NUTRIENT MANAGEMENT IN WINTER WHEAT

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## ABSTRACT

Efficient nitrogen (N) management is critical for improving winter wheat grain yield and protein content while minimizing production costs and environmental risks. Remote sensing indices, such as the Normalized Difference Vegetation Index (NDVI), and physiological indicators, such as flag leaf N concentration, have been proposed as predictors of crop performance to support in-season N management decisions. This study aimed to evaluate the relationships between NDVI measured at early (Feekes 7–8) and late (Feekes 10.1–10.5.3) growth phases, flag leaf N at flowering, final grain yield, and protein content.

A randomized complete block design with four replications was established across nine locations in Kansas. Treatments consisted of seven N rates (0 to 180 lb N ac<sup>-1</sup>) applied as broadcast urea at Feekes 6. NDVI data were collected using a handheld crop sensor, and grain protein was measured with an NIR spectrometer.

Results showed that NDVI was most strongly associated with grain yield at early growth stages (marginal  $R^2$  ( $R_m^2$ ) = 0.71), whereas the relationship at later stages was weaker. In contrast, NDVI showed limited predictive power for protein. Flag leaf N concentration was weakly related to both yield ( $R_m^2$  = 0.02) and protein ( $R_m^2$  = 0.15) across locations. These findings suggest that NDVI, particularly at early stages, can provide valuable insights for improving in-season nitrogen management decisions in winter wheat.

## INTRODUCTION

Efficient nutrient management, particularly nitrogen (N) management, is essential for maintaining winter wheat productivity while reducing production costs and minimizing environmental losses. Winter wheat (*Triticum aestivum* L.) is one of the most important cereal crops in Kansas, representing approximately 20% of U.S. wheat production (Kansas Department of Agriculture, 2023). Therefore, inadequate N management strategies can lead to over- or under-application, resulting in reduced yield potential, economic losses, and increased risks of environmental pollution.

Nitrogen management in cropping systems is challenging because conventional approaches often fail to account for spatial and temporal variability in N soil supply, crop uptake, and environmental conditions (Raun *et al.*, 2002). Therefore, in-season diagnostic tools that reflect N status are needed to improve N use efficiency and guide more adaptive management decisions.

Remote sensing indices, such as the Normalized Difference Vegetation Index (NDVI), have been widely used to estimate the physiological status of plants, which is often correlated with N status (Wang *et al.*, 2012). Similarly, the N concentration in plant

leaves has been shown to correlate with yield potential (Dordas, 2009). However, while both NDVI and flag leaf N concentration can indicate crop N status, limited research has directly compared their effectiveness for predicting yield and protein across multiple growth stages and environments.

The objectives of this study were to:

- I. Evaluate the relationship between NDVI measured at early and late growth stages and grain yield and grain protein content.
- II. Evaluate the relationship between flag leaf N concentration and grain yield and grain protein content.
- III. Compare the predictive ability of NDVI and flag leaf N for supporting in-season N management decisions in winter wheat.

## **MATERIALS AND METHODS**

The experiment was conducted across nine locations in Kansas during the 2023-24 and 2024-25 growing seasons, using a randomized complete block design with four replications. Treatment consisted of seven N rates ranging from 0 to 180 lb N ac<sup>-1</sup>, applied as broadcast urea at Feekes 6. Each experimental plot measured 7 x 40ft and was managed according to local agronomic practices.

NDVI measurements were obtained using the RapidSCAN CS-45 handheld crop sensor (Holland Scientific) at early (Feekes 7-8) and late (Feekes 10.1-10.5.3) growth stages. Flag leaf samples were collected at flowering (Feekes 10.5) and analyzed for total N concentration using the dry combustion method. Grain yield was measured at harvest using a small-plot combine, and grain protein was determined with an NIR spectrometer (NIR DS3, Foss Inc.).

Data were analyzed using linear mixed models in R (lme4 package), with N rate as a fixed effect and location and replication as random effects. Relationships between NDVI, flag leaf N, yield, and protein were evaluated by calculating marginal and conditional R<sup>2</sup> values (MuMIn package).

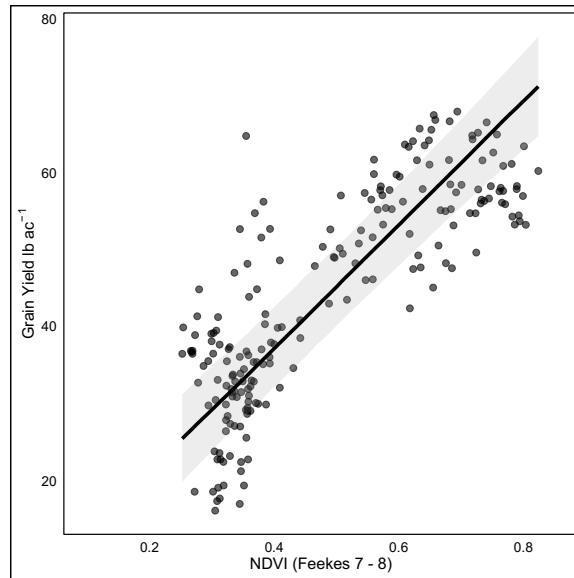
## **RESULTS AND DISCUSSION**

### **NDVI and grain yield relationships**

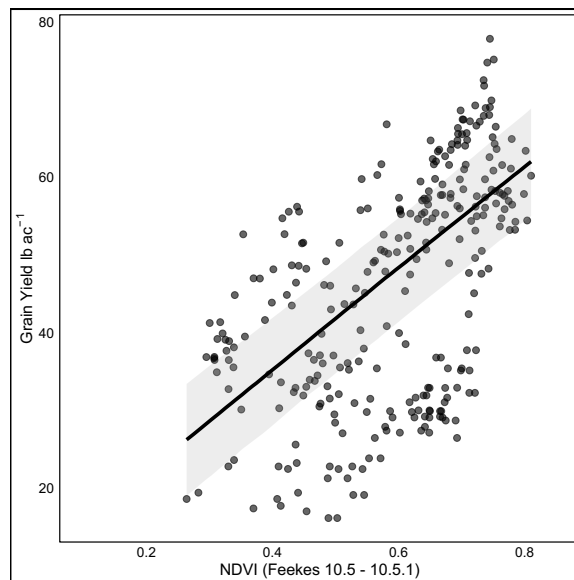
NDVI measured at early growth stages (Feekes 7 – 8) showed a strong positive relationship with grain yield across locations (Figure 1). It explained 71% of yield variability (marginal R<sup>2</sup> = 0.71), indicating a high potential for in-season yield prediction.

In contrast, NDVI measured at later stages (Feekes 10.1 – 10.5.3) explained only 37% of yield variability (Figure 2), suggesting it limits to predict yield.

These results align with previous findings, which show that early NDVI measurements capture canopy development and N uptake more efficiently than late-season measurements (Ali *et al.*, 2022).



**Figure 1.** Relationship between NDVI measured between Feekes 7 – 8 and grain yield across nine Kansas locations. Each point represents an individual plot. The solid line shows the fitted regression from a mixed model, and the shaded area indicates the 95% confidence interval. Early-season NDVI explained 71% of yield variability (marginal  $R^2 = 0.71$ ), indicating strong potential for in-season yield prediction.



**Figure 2.** Relationship between NDVI measured between Feekes 10.1 – 10.5.3 and grain yield across nine Kansas locations. NDVI at these later stages explained 37% of yield variability (marginal  $R^2 = 0.37$ ), suggesting reduced sensitivity due to canopy saturation at high biomass levels.

### Flag leaf N and NDVI relationships with protein

Both, NDVI and flag leaf concentration were weakly correlated with grain protein content ( $R^2_m \leq 0.15$ ; Table 1). The low predictive power indicates that canopy reflectance and flag leaf N status are not strong indicators of final grain protein accumulation, which is influenced by post-anthesis N remobilization and environmental factors (Sanchez-Bragado *et al.*, 2017). Similarly, flag leaf N concentration measured at flowering showed poor relationships with yield ( $R^2 = 0.02$ ).

**Table 1.** Marginal  $R^2$  values from mixed-effects models relating NDVI and flag leaf N concentration to grain yield and protein across nine Kansas locations.

Predictor	Growth stage	Response	$R^2_m$
NDVI	Feekes 7 – 8	Yield	0.71
NDVI	Feekes 10.1 – 10.5.3	Yield	0.37
Flag leaf	Feekes 10.5.3	Yield	0.02
NDVI	Feekes 7 – 8	Protein	0.02
NDVI	Feekes 10.1 – 10.5.3	Protein	0.11
Flag leaf	Feekes 10.5.3	Protein	0.15

### Comparative performance of predictors

Across all predictors, early NDVI provided the strongest association with yield, while late NDVI and flag leaf N were less effective (Table 1). These findings highlight a critical window during which remote sensing can support in-season nitrogen management decisions. Early NDVI offers farmers a valuable, non-destructive tool to guide N adjustment before yield potential is determined. The limited relationship between NDVI and protein reinforces the need for complementary tools to predict grain quality more accurately in advance.

### CONCLUSION

Early-season NDVI demonstrated strong potential for in-season yield prediction in winter wheat compared to flag leaf and later NDVI. These results support the use of proximal sensing as a decision-support tool to guide N management before critical growth stages. Early NDVI could be incorporated into N decision-support models for Kansas wheat. Continued research integrating multiple indicators may improve the prediction of grain protein and optimize N use efficiency across environments.

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