Influence of timing and vegetation index selection on the determination of in-season nitrogen recommendations rates for corn based on satellite imagery

A. Morales-Ona[a]*; K. Mizuta[b]; L. Lacerda[b]; Y. Miao[b]; D. Quinn[a]; R. Nielsen[a]; J. Camberato[a]; D. Cammarano[c]

[a]Agronomy Department, Purdue University - West Lafayette, IN, USA
[b]Precision Agriculture Center, University of Minnesota - Saint Paul, MN, USA
[c]Department of Agronomy - Climate and Water, Aarhus University - Tjele, Denmark

INTRODUCTION

NRCS ON-FARM PRECISION NITROGEN MANAGEMENT TRIAL

- **Improper management of nitrogen (N)** fertilizers in the cropping systems of the United States Midwest has resulted in **economic losses and significant N leaching and pollution**.
- A remote sensing and calibration strip-based precision management N **(RS-CS-PNM) strategy has been developed** by the Precision Agriculture Center at the University of Minnesota to **provide in-season N recommendation rates based on satellite imagery**.
- The project "On-farm Precision Nitrogen Management Trial", funded by the Natural Resources Conservation Service (NRCS), aims to **improve corn N management** at the farm level and significantly reduce N losses using the RS-CS-PNM strategy.
- **The RS-CS-PNM strategy is being tested under diverse on-farm conditions in Minnesota and Indiana**. Thirteen field trials were conducted in 2021 and sixteen are being conducted in 2022, with a total of twenty-nine field trials across both states.
- Currently, the RS-CS-PNM strategy uses the Normalized difference vegetation index **(NDVI) derived from satellite imagery at growth stage** V8 for the determination of in-season N recommendation rates.

OBJECTIVES

1. **Define what is the optimum growth stage and vegetation index (VI) to calculate sidedress N rates using the RS-CS-PNM strategy.***
2. Identify additional parameters to be considered to optimize the calculation of sidedress N rates using the RS-CS-PNM strategy.
3. Quantify the agronomic, economic, and environmental benefits of the RS-CS-PNM strategy compared to the current farmer's practice.
4. Assess effects of hybrid, agronomic management (tillage, planting date, seeding rate, preplant N form and application method), and weather on the calculation of sidedress N rates using the RS-CS-PNM strategy.

* **FOCUS OF POSTER**

MATERIALS AND METHODS

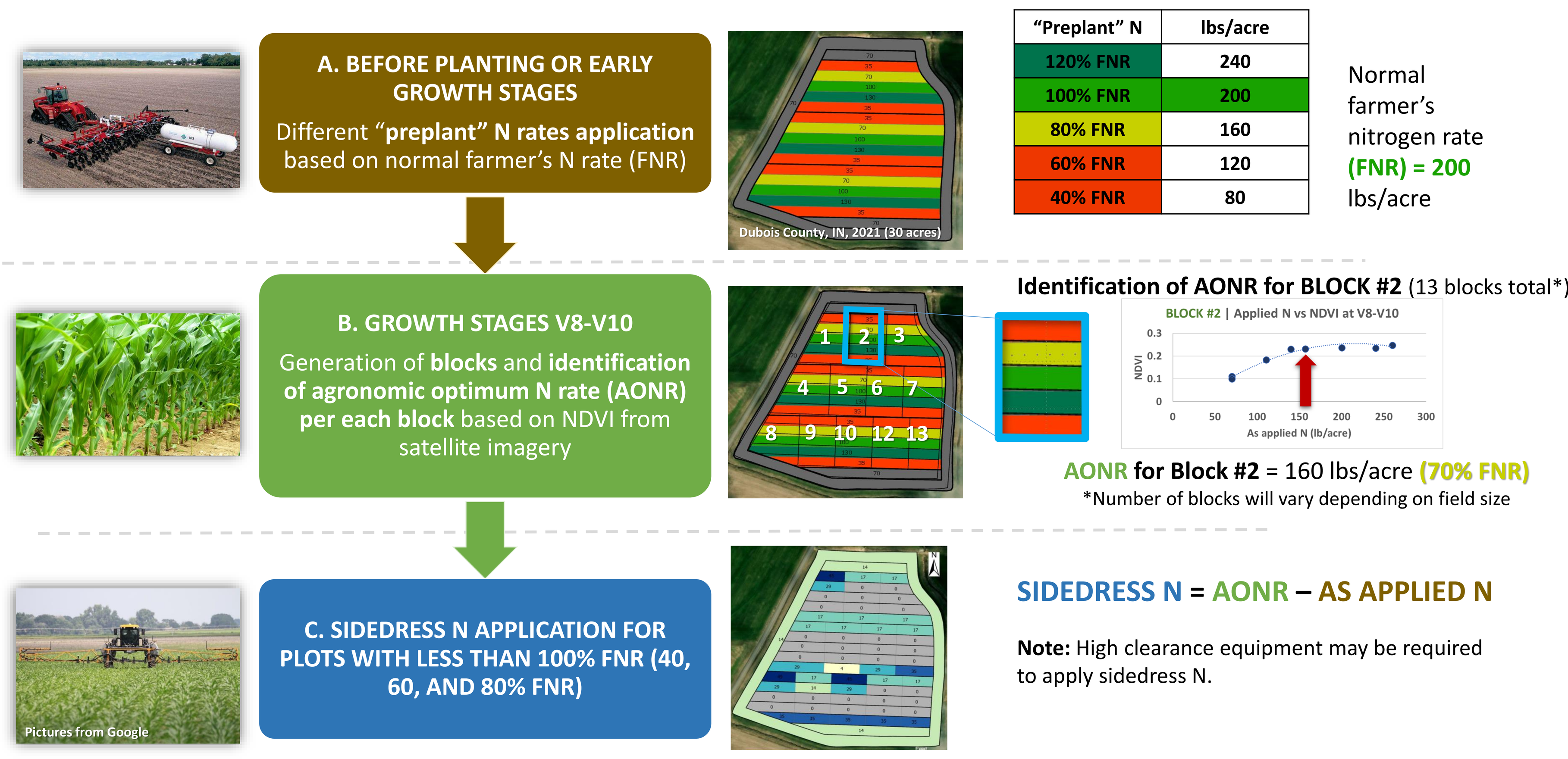

Figure 1. Remote Sensing and Calibration Strip-based Precision Management Nitrogen (RS-CS-PNM) Strategy 2022.

NITROGEN TRIAL INFORMATION

- Two rainfed on-farm fields located in White County, IN, in 2021 **(Table 1)**.
- Treatments: 50, 50, 70, 100, and 130% of farmer's N rate (FNR), replicated 4 times. Treatments changed for 2022 trials to 40, 60, 80, 100, and 120% FNR (Figure 1).
- Plot dimension was 24 rows (0.76 m each) wide by 370 (CC field) or 700 m (CS field) long.

Table 1. Agronomic management information for the two field trials evaluated.

Field ID	Area (ha)	Farmer's N rate (kg ha^{-1})	Soil type	Previous crop	Tillage	Planting date	Emergence	Hybrid	Seeding rate ($seeds^{-1}$)	Treatment application date	N form
CC	24	224	Silty clay loam Silt loam	Corn	Conventional	27-Apr	18-May	DKC 63-61	84000	5-Jun (V3)	NH3 (82-0-0)
CS	45	180	Silty clay loam Silt loam	Soybean	Conventional	22-May	26-May	DKC 62-51	86500	5-Jun (V2)	NH3 (82-0-0)

DATA ACQUISITION, PROCESSING, AND ANALYSIS

- Corn grain yield (GY) was harvested using a commercial combine equipped with a calibrated GPS-enabled yield monitor. Yield data was cleaned **(Figure 2)** prior to be analyzed.

Area of study → Heading (deviations from combine travel direction) → Moisture (range: 10-33 %) → Travel speed (range: 1.1-13.2 mph) → Speed change (15% faster or slower than the previous point) → Yield data between adjacent plots → Yield data converted to 15% moisture → 3 standard deviation (above and below treatment mean yield)

Figure 2. Parameters considered during yield data cleaning process.

- PlanetScope multispectral satellite images (3-m resolution) were used for the calculation of eight vegetation indices (VIs) **(Table 2)**. Selection of the satellite images was predicated on cloud-free images available from mid June to mid September: 17-June (CC only), 22-June, 3-July, 14-July, 30 July, 15-Aug, 14-Sept (CS only), 16-Sept (CC only), 25-Sept (CS only).
- Using ArcGIS Pro, plots were further delineated into smaller sections (grids) equal to the plot width by 60-m long. Adjacent grids (within the same replication) representing the range of all N rates are considered as a "block". Corn GY data and VI mean values per grid were extracted in RStudio ("raster" package).
- Linear regression analysis between corn GY (dependent variable) and VI (independent variable) was performed at the field level in RStudio ("stats" package). R^2 values were used to assess the ability of the VIs evaluated to predict GY at different growth stages across the growing season, particularly during the vegetative period when the calculation of in-season nitrogen recommendations rates is performed.

MATERIALS AND METHODS (continued)

Corn grain yield data cleaning (ArcGIS Pro and RStudio) → Satellite imagery retrieval (PlanetScope) → Vegetation indices calculation (RStudio) → Delineation of plots into smaller sections (plot width by 60-m long) (ArcGIS Pro) → Corn grain yield and VI data extraction (RStudio) → Statistic analysis Linear regressions (RStudio)

Figure 3. Data processing and analysis.

Table 2. Vegetation indices (VI) evaluated, their formulas, and the researchers who first developed each VI.

VI	Index full name	Formula	Reference
EXG	Excess Greenness Index	[2G-R-B]	Woebbecke et al. (1995)
EXR	Excess Red Index	[(1.4R)-B]	Meyer et al., (1999)
GNDVI	Green Normalized Difference Vegetation Index	[(NIR-G)/(NIR+G)]	Gitelson et al. (1996)
NDVI	Normalized Difference Vegetation Index	[(NIR-R)/(NIR+R)]	Rouse et al. (1973)
OSAVI	Optimized Soil-Adjusted Vegetation Index	[(NIR-R)/(NIR+R+0.16)]	Baret et al. (1993)
PPBR	Plant Pigment Ratio	[(G-B)/(G+B)]	Metternicht (2003)
VARI	Visible Atmospherically Resistant Index	[(G-R)/(G+R-B)]	Gitelson et al. (2002)
VDVI	Visible-band Difference Vegetation Index	[(2G-B-R)/(2G+B+R)]	Wang Xiaoqin et al. (2015)

RESULTS AND DISCUSSION

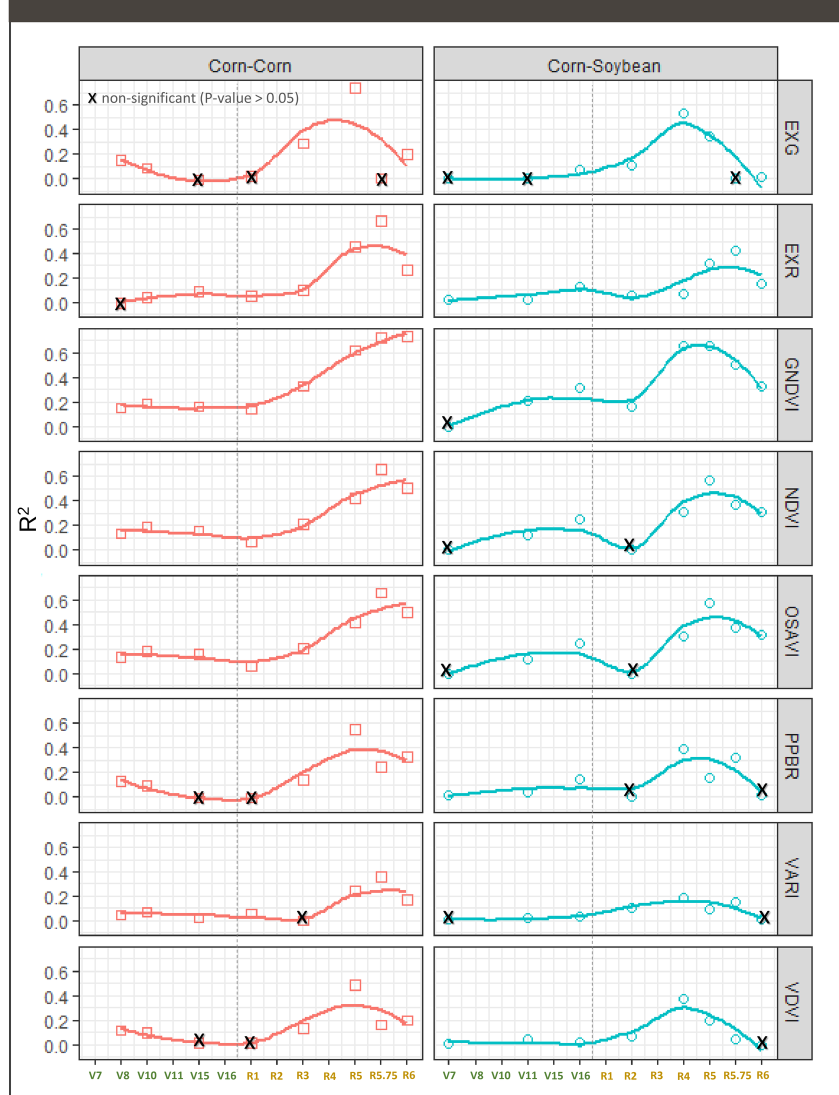

Figure 4. R^2 between corn grain yield and the VIs evaluated over time across the growing season.

Table 3. Coefficient of determination (R^2) results derived from linear regression analysis between corn grain yield and the VIs evaluated at both locations across the growing season.

Corn-Corn (CC)								
	V8 (17-June)	**V10** (22-June)	**V15** (3-July)	**R1** (14-July)	**R3** (30-July)	**R5** (15-Aug)	**R5.75** (31-Aug)	**R6** (16-Sep)
EXG	**0.15**	**0.09**	-0.01	0.02	**0.29**	**0.74**	0.00	**0.20**
EXR	-0.01	**0.04**	**0.09**	**0.05**	**0.10**	**0.45**	**0.66**	**0.27**
GNDVI	**0.15**	**0.18**	**0.16**	**0.14**	**0.33**	**0.62**	**0.72**	**0.73**
NDVI	**0.13**	**0.18**	**0.15**	**0.06**	**0.21**	**0.42**	**0.66**	**0.50**
OSAVI	**0.13**	**0.18**	**0.15**	**0.06**	**0.20**	**0.42**	**0.66**	**0.50**
PPBR	**0.13**	**0.09**	-0.01	-0.01	**0.14**	**0.56**	**0.25**	**0.33**
VARI	**0.05**	**0.07**	**0.02**	**0.06**	0.00	**0.24**	**0.36**	**0.17**
VDVI	**0.11**	**0.10**	0.01	0.01	**0.13**	**0.48**	**0.16**	**0.19**

Corn-Soybean (CS)								
	V7 (22-June)	**V11** (3-July)	**V16** (14-July)	**R1-R2** (30-July)	**R4** (15-Aug)	**R5** (31-Aug)	**R5.75** (14-Sept)	**R6** (25-Sept)
EXG	0.00	0.00	**0.08**	**0.11**	**0.54**	**0.35**	0.00	**0.01**
EXR	**0.02**	**0.02**	**0.13**	**0.06**	**0.07**	**0.32**	**0.42**	**0.15**
GNDVI	0.00	**0.21**	**0.31**	**0.16**	**0.65**	**0.65**	**0.50**	**0.32**
NDVI	0.00	**0.12**	**0.25**	0.00	**0.31**	**0.57**	**0.37**	**0.31**
OSAVI	0.00	**0.12**	**0.25**	0.00	**0.30**	**0.57**	**0.37**	**0.31**
PPBR	**0.01**	**0.04**	**0.15**	0.00	**0.39**	**0.16**	**0.32**	0.01
VARI	0.01	**0.02**	**0.03**	**0.10**	**0.19**	**0.09**	**0.15**	0.01
VDVI	**0.01**	**0.04**	**0.02**	**0.06**	**0.37**	**0.20**	**0.04**	0.00

Notes:
- R^2 values in bold indicate that regression between the VI and corn grain yield is statistically significant (P-value ≤ 0.05) .
- The darker the green, the greater R^2 value.
- Average corn grain yield was 12.59 Mg ha^{-1} for field CC and 14.72 Mg ha^{-1} for CS. Root mean square error (RMSE) from significant regressions ranged from 0.67 to 1.30 Mg ha^{-1} for field CC and from 0.01 to 0.65 Mg ha^{-1} for field CS.

- During the vegetative period, when the sidedress N prescriptions are prepared, the greatest R^2 values from the linear regression between corn GY and the VIs were obtained at late vegetative growth stages, ranging from V10 to V16 across both locations **(Figure 4, Table 3)**.
- Although the greatest R^2 values were at V15-V16 during the vegetative period, the time frame from V16 to the beginning of the reproductive period may be too short and uncontrolled conditions (e.g., weather) might delay or avoid sidedress N application before flowering. Therefore, V10-V11 would be the optimal growth stage for the calculation of sidedress N rates using the RS-CS-PNM strategy.
- During the vegetative period, GNDVI, NDVI, and OSAVI had consistently greater R^2 values than the rest of VIs evaluated across both locations, with GNDVI having the greatest values **(Table 3)**.
- The response from specific VIs to N at the block level during the vegetative period was similar to the corn GY response for some blocks, but not consistently for all **(Figure 5)**. Further research is needed to identify which are the factors that drive the difference between the VI response to N among blocks during the vegetative period, so they can be considered in the calculation of sidedress N rates using the RS-CS-PNM strategy.

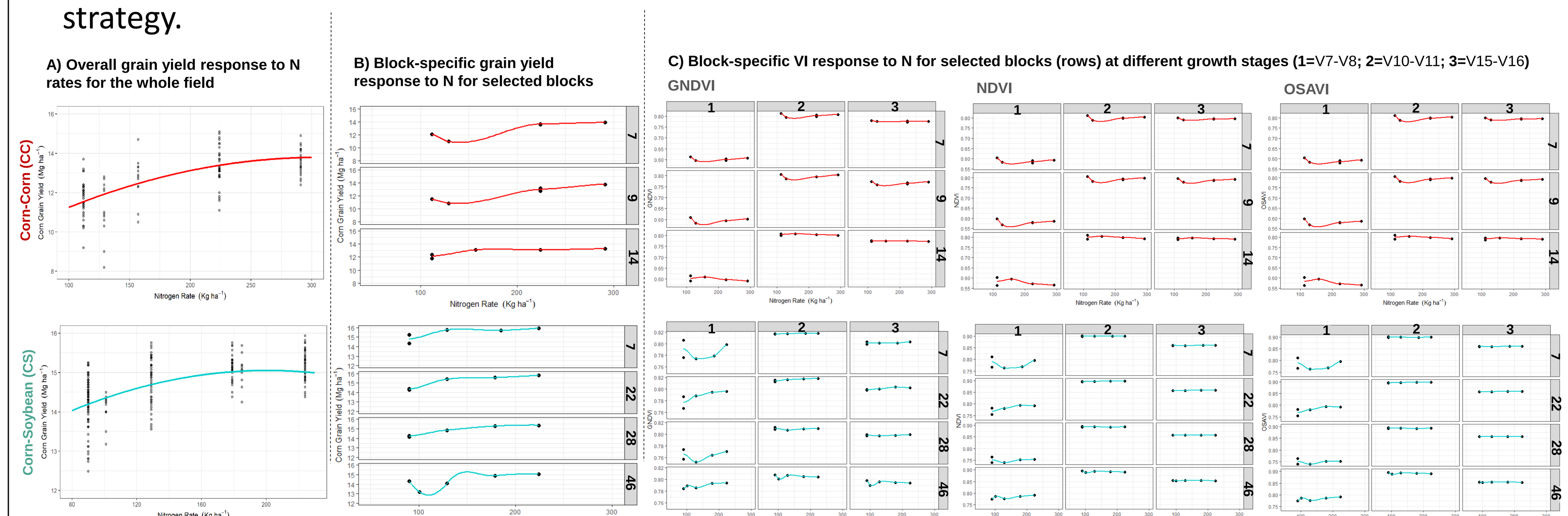

Figure 5. Corn grain yield and VI response during the vegetative period to N rates at the field and specific blocks level.

CONCLUSIONS

- The results from this study suggest that V0-V11 are the optimal growth stages to calculate sidedress N rates using the RS-CS-PNM strategy. However, further research is needed to identify which are the factors that drive the difference between the VI response to N among blocks during the vegetative period.
- GNDVI, NDVI, and OSAVI, had consistently greater R^2 values that the rest of the VIs evaluated.

Acknowledgments

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