The Evaluation of NDVI Response Index Consistency Using Proximal Sensors and Satellites

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Abstract.

The Response Index NDVI (RI_{NDVI}) is described as the response of crops to additional nitrogen (N) fertilizer. It is calculated by dividing the NDVI of the high-N plot (N-rich strip) by the NDVI of the zero-N plot or farmer's practice where less pre-plant N was applied (Arnall et al., 2016). RI values are used to predict yield and monitor top dress N fertilization. Many research has been carried out to determine the difference between NDVI values using different Precision Agriculture (PA) tools, including proximal sensors and satellite imageries. The aim of this study is to determine if the RI_{NDVI} ratio is also fluctuating using different PA tools or stays consistent. To do that, we collected from wheat and soybean fields NDVI values of reference strips and check-plot using the Greenseeker and satellite imageries, and we compared the results.

Keywords*: Response Index, NDVI, Greenseeker, Reference strip, satellite imageries.*

Introduction:

The requirements of N fertilizer differ from season to season and from field to field. Therefore, farmers are always looking for innovative technologies to save input costs and increase fertilizer use efficiency (Butchee et al., 2011). Traditional N fertilizer application strategies fail to account for field variability or changing N needs over time. Over- or under-application of N may be economically and environmentally damaging, resulting in N leaching or lower yields and grain quality. The N recommendation is usually based on the yield goal, i.e., the current Oklahoma State University (OSU) wheat yield goal recommendation is 2 Ibs of N per bushel expected to be produced. However, Arnall et al. (2008) pointed out the fluctuation of the N required for maximum yield, showing the unpredictable response of yield to N application, especially during pre-planting. For this reason, OSU created the concept of a reference strip to consider the annual variation of N needs (Arnall et al., 2014). A reference strip, often referred to as an 'N-rich strip' supplied with a non-limiting amount of N, is the most common way to estimate field and season-specific N response (Colaço et al., 2018). The reference strip is used to calculate the response index (RI): the responsiveness to additional topdressing N applications to determine the N rate recommended in season. The objective of this study is to evaluate RI_{NDVI} consistency using different remote sensing (RS) techniques to see if it is possible to substitute the measure in the field using the Greenseeker with satellite imagery. Studies have been carried out to determine the difference between NDVI values using different PA tools, including proximal sensors and satellite imageries (Anastasiou et al., 2018; Kasimati et al., 2023). However, no research has studied whether the RI_{NDVI} ratio also fluctuates using different PA tools or stays consistent. The result of this study will help to demonstrate if the RI_{NDVI} measured using the Greenseeker for N recommendation can be replaced by RI_{NDVI} calculated using satellite imageries.

Methodology:

1. Field of the study:

This research was conducted on farmer's lands across various regions of Oklahoma over two growing seasons, from 2022 to 2024. The study involved soybean and wheat crops. For wheat, reference strips were established based on nitrogen (N) as a non-limiting factor. However, for soybean fields, the reference strips utilized potassium (K) as a non-limiting factor. Soybean trials were included to examine how RI values varied with RS methods under varying climatic conditions (winter and summer) and across different types of crops.

2. **Precision Agriculture tools used:**

NDVI measurements were conducted at various growth stages of wheat and soybean using the Greenseeker Handheld sensor, manufactured by N-Tech Industries and marketed by Trimble. The measurements for wheat were recorded from the Feekes 4 to Feekes 6 stages. In soybean fields, data collection spanned from the V3 to the R6 stage. The geographic coordinates of the fields were captured using Emlid Flow 360.

Additionally, NDVI maps for studied fields were obtained from satellite imagery; Sentinel-2 images were sourced from Satshot (https://satshot.com), and Dove imagery from Planet labs (https://www.planet.com). Owing to the inherent temporal acquisition constraints associated with satellite imagery, we maintained an interval up to 10 days between the on-field NDVI measurements and the satellite data acquisition.

3. **Statistical analysis:**

The data were analyzed using Python, utilizing libraries such as Pandas, Seaborn, and Statsmodels, to study the variations in the RI_{NDVI} measurements from different RS methods. Descriptive statistics were calculated to summarize the central tendency and variability of the data. Additionally, scatter plots with regression lines were generated to visualize the relationships between the sensors. A correlation map was also produced to examine the strength and direction of relationships between the different sensors' measurements.

Results and discussion:

1. **Descriptive statistics of the RI_{NDVI} for wheat and soybean using RS technologies:**

The descriptive statistics for wheat indicate that the RI GS (Greenseeker) sensor has a mean value of 1.51 with higher variability (SD=0.26) compared to the RI Sentinel-2 and RI Planet-lab, which have mean values of 1.17 and 1.16 with lower variability (SD=0.17 and SD=0.19, respectively). For soybean, the RI GS sensor also shows higher variability (SD=0.17) with a mean value of 1.37, compared to the RI Sentinel-2 and RI Planet-lab, which have lower variability (SD=0.08 and SD=0.06) with mean values of 1.14 and 1.10, respectively.

The RI calculated using the greenseeker showed higher standard deviation compared to the RI measured using satellite imageries because of its ability to detect more crop variability compared to the satellites.

Descriptive Statistics for Wheat (2023 & 2024):

	RI GS	RI SENTINEL-2	RI PLANET_LAB
count	34.000000	34.000000	34.000000
mean	1.512574	1.174165	1.156264
std	0.255502	0.174791	0.191590
min	1.119816	0.986583	0.978726
25%	1.336319	1.046552	1.043002
50%	1.499948	1.127640	1.105561
75%	1.731275	1.233322	1.191699
max	2.019928	1.832373	1.908625

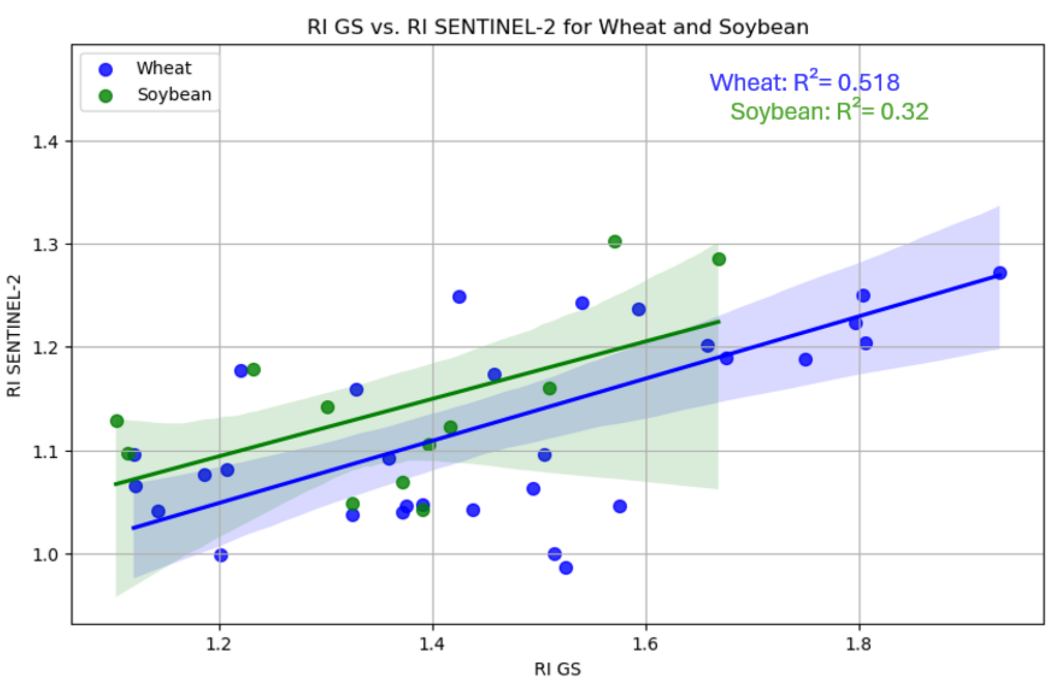
Descriptive Statistics for Soybean (2023):

	RI GS	RI SENTINEL-2	RI PLANET_LAB
count	12.000000	12.000000	12.000000
mean	1.366717	1.140314	1.100262
std	0.169158	0.082993	0.064635
min	1.103142	1.042373	1.007038
25%	1.283904	1.090486	1.061147
50%	1.381580	1.126079	1.086421
75%	1.440053	1.165055	1.128911
max	1.668571	1.302329	1.208367

Figure 1: The descriptive statistics of RI's measured with the Greenseeker and satellites for wheat and soybean

2. Regression analysis between the RI_{NDVI} Greenseeker and RI satellites:

The two scatter plots (Figure 2) illustrate the relationships between the Greenseeker RI and the RI calculated from Sentinel-2 and Planet Lab for wheat and soybean crops. For wheat, the correlations with the Planet Lab and Sentinel-2 RIs show moderate positive R^2 values of 0.59 and 0.52, respectively. In contrast, the soybean data exhibit a weaker relationship, with R^2 values of 0.32 for Sentinel-2 and 0.29 for Planet Lab. These results indicate a moderate relationship between the Greenseeker RI and satellite RIs in wheat compared to soybean.



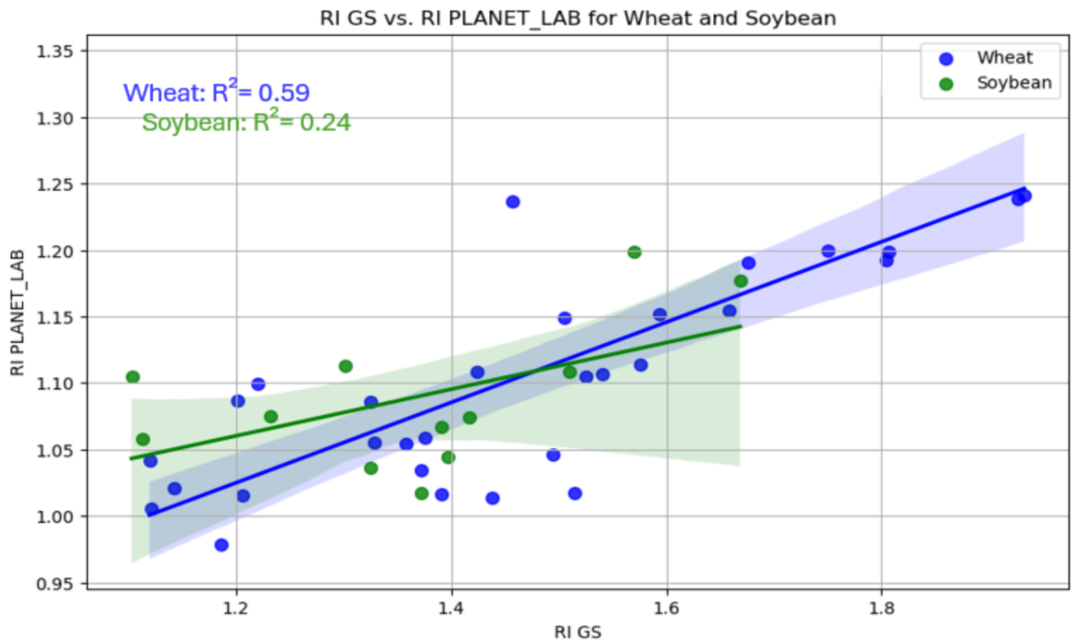


Figure 2: Scatter plots with regression lines and R-squared values illustrating the relationships between RI GS and RI satellites (RI Planet_lab and RI Sentinel-2) for wheat and soybean crops. The blue points and lines represent wheat, while the green points and lines represent soybeans.

1. **Correlation Analysis of RI_{NDVI} calculated using the Greenseeker and satellites for Wheat and Soybean:**

In our study, we analyzed correlation matrices for soybean and wheat to investigate the relationships between ground station (GS) data and satellite observations from Sentinel-2 and Planet Lab. For soybean in 2023, the correlations between GS and Sentinel-2 (r = 0.57) and GS and Planet Lab (r = 0.49) were moderate and positive, indicating that satellite observations moderately reflect ground-based measurements of soybean conditions. For wheat, however, the correlations differed more significantly: the correlation between GS and Sentinel-2 was strong (r = 0.72), whereas GS and Planet Lab demonstrated a slightly stronger correlation (r = 0.77), suggesting a closer alignment between GS and Planet Lab data for wheat.

These findings align with the conclusion drawn by Mezera et al. (2021), who also found a medium to strong positive correlation between VI calculated using a proximal sensor and VI using Sentinel-2 in wheat.

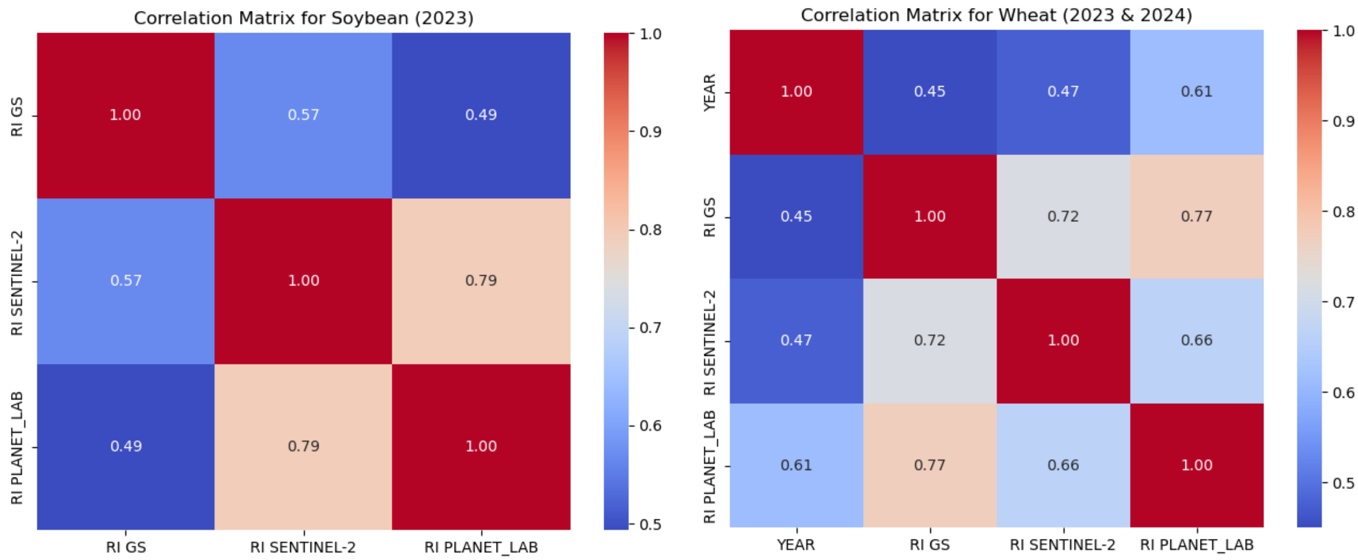


Figure 3: The correlation matrix between the RI measurements using the different RS methods.

PlanetPlanet Lab typically offers higher spatial resolution imagery compared to Sentinel-2, which means it can provide more detailed data at the plant level. This high-resolution detail allows for a more expression of the intra-field variability. Additionally, GreenSeeker is a proximal sensor that captures data at a closer range, resulting in high-resolution observations of field variability (Anastasiou et al., 2018). Consequently, the relationship analysis involving both GreenSeeker and Planet Lab shows a slightly higher correlation, which was the case for wheat. However, for soybeans, the relationship between the RI using the three RS techniques was less important.

In conclusion, our findings highlight the varying degrees of correlation and regression between ground-based and satellite data across different crop types and satellite platforms. For soybeans, both satellites provided weak accurate reflections of ground conditions. However, in the case of wheat, the good correlations indicate a high potential for both satellites in predicting the in-season N rate needed. The advantage of the use of planet-lab imageries compared to Sentinel-2 for wheat is that it offers a higher chance of obtaining imagery over consecutive days compared to Sentinel-2, ensuring continuous data even in cloudy conditions.

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