



# **Assessing Crop Performance Using Normalized Difference Vegetation Index 2024-2025**

Prepared by:



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## Introduction to NDVI

In 2024, On-Farm Applied Research and Monitoring (ONFARM) implemented drone multispectral imagery to evaluate the relationships between the normalized difference vegetation index (NDVI) and key factors, including field characteristics, soil health, crop development, and yield.

Drone flights provide extremely high-resolution imagery; for example, while satellite imagery typically offers a resolution of 3 m<sup>2</sup> per pixel, current drone technology can capture images at 3 cm<sup>2</sup> per pixel<sup>1</sup>. The captured drone images are multispectral, meaning they measure different wavelengths of light reflected from the landscape. This includes red, green, and blue light within the visible spectrum, as well as infrared wavelengths beyond human vision.

NDVI is a metric that is used to analyze multispectral imagery by measuring the greenness of vegetation by assessing the difference between near-infrared light (strongly reflected by healthy plants) and red light (absorbed by plants for photosynthesis). NDVI can detect variations in plant vigor, density (biomass), and chlorophyll content (photosynthetic activity) to help identify stressed or diseased vegetation, monitor crop growth stages, and assess spatial variability within fields (Al-Shammari et al., 2025). In some cases, it can also indicate underlying factors such as soil moisture (Khellouk et al., 2025) and nutrient availability (Cabrera-Bosquet et al., 2011), as healthier vegetation typically produces higher NDVI values.

NDVI is calculated using red and near-infrared (NIR) light reflectance and produces an index that ranges from -1 to 1:

$$NDVI = \frac{NIR - Red}{NIR + Red}$$

The red and near-infrared spectra are used because of their different interactions with chlorophyll, which is essential for photosynthesis. During photosynthesis, green plants absorb red and blue light while reflecting most green and NIR light. As a result, healthier, greener and more productive plants produce higher NDVI values, whereas stressed plants or bare ground produce lower NDVI values due to reduced red-light absorption. Typical NDVI values range from -1 to 0 for surface water, 0 to 0.3 for soil and plant residue, 0.3 to 0.6 for stressed crops, and above 0.6 for healthier crops.

Using geographic information system (GIS) tools, these images can be processed to calculate a variety of vegetation and landscape indices, each using specific wavelength combinations. These indices allow for more detailed interpretation of differences in field characteristics and plant health across multiple scales.

Through GIS platforms, NDVI values can be visualized and analyzed at multiple scales, allowing for statistical analysis across the field, at individual ONFARM treatment strips and ONFARM sampling locations. For example, **Figure 1** shows visible-spectrum imagery captured from ONFARM Soil Health trial Site 7, along with the processed NDVI map.

**Figure 2** shows a histogram of NDVI values for all pixels across the entire field at Site 7. Data points along the tail of the histogram (pixel values from 0 to 0.7) correspond to the light green, yellow, and orange areas

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<sup>1</sup> At 3 m<sup>2</sup> resolution, a single satellite pixel can capture several rows of crops. At 3 cm<sup>2</sup>, drone imagery can resolve individual plants, making it possible to detect within-row variability and early-stage growth differences.

shown in **Figure 1** (middle image). These areas indicate poorer crop establishment and growth-related stress compared to areas with NDVI values greater than 0.8.

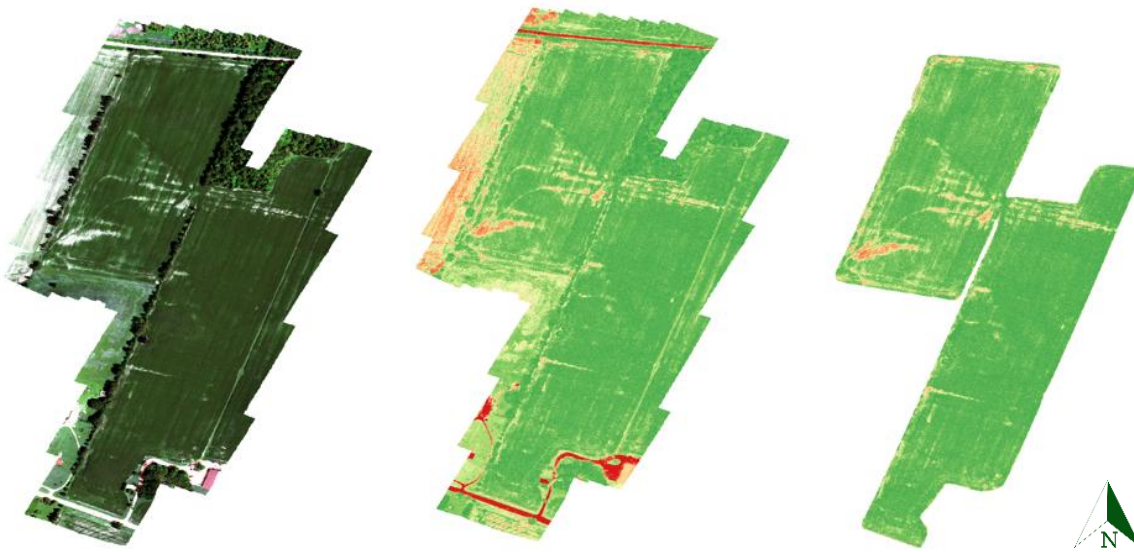


Figure 1. Drone imagery taken at Site 7 on July 28, 2024, showing the visible spectrum (left), NDVI with values of zero as red, values of yellow at 0.5, and values of one as green (middle), and the NDVI layer trimmed to the field boundary (right).

### ONFARM Monitoring Plan

Three ONFARM sites were selected for drone flights at regular intervals throughout the 2024 and 2025 growing season. The 2024-2025 sample consisted of two Soil Health trial sites in 2024, Site 7 and Site 15, and one Edge-of-Field (EOF) Water Monitoring site, Fairview, which was monitored in both years<sup>2</sup>. In 2024, monitoring began in June at Fairview and in July at Sites 7 and 15 and continued biweekly until crop harvest in late October.

### Soil Health Site 7

Located in Brant County, Ontario, Site 7 focuses on implementing cover crops in corn, soybeans, and winter wheat rotation. The site is split across two farms (**Figure 1**). The eastern side has been under the cooperator's management for a longer period compared to the western side and has a strong history of best management practice (BMP) implementation (e.g., no till). The western side, which was acquired more recently, has a history of more conventional management. The site contains a range of soils across its hillslope with differing drainage conditions and has a slit clay loam soil type<sup>3</sup>. In 2024, the site grew grain

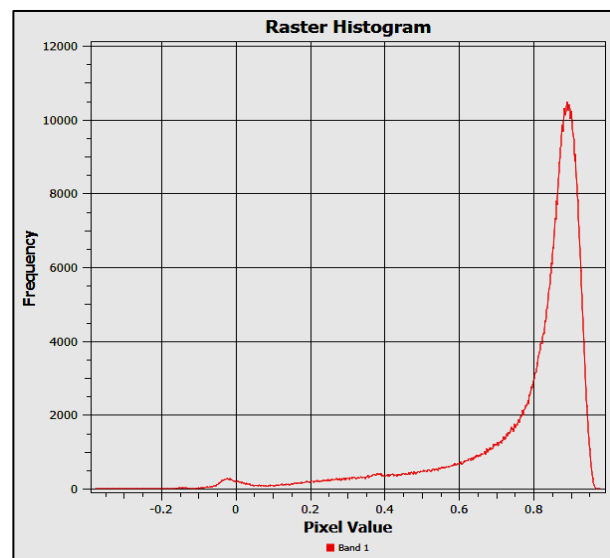


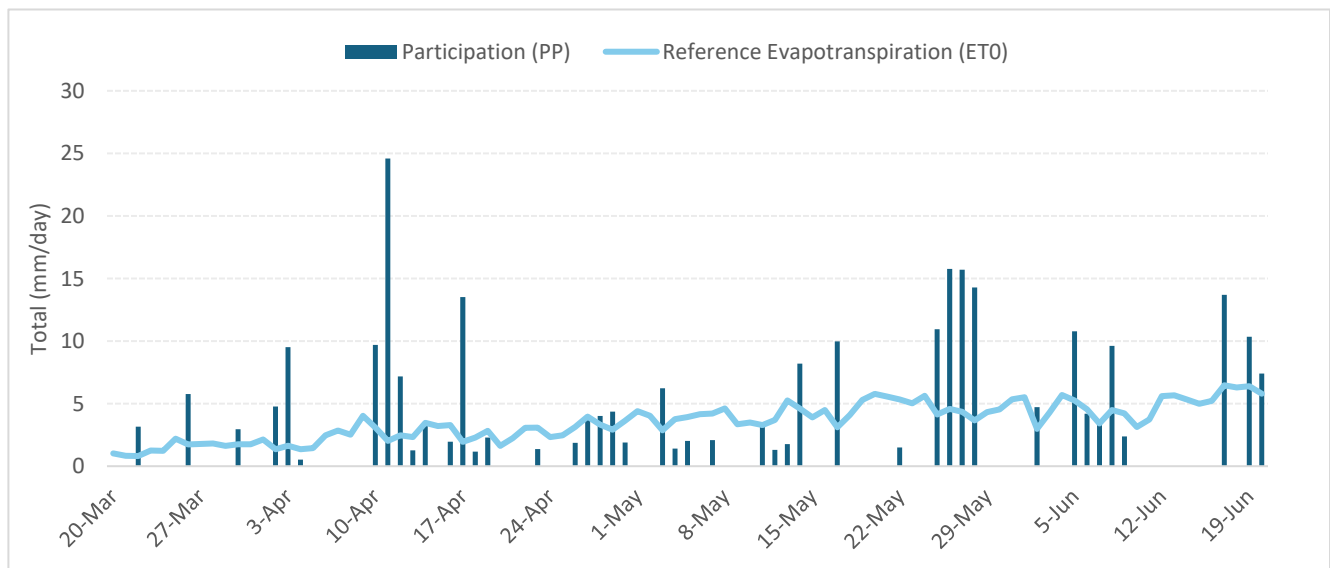
Figure 2. Histogram of pixel-level NDVI values for Site 7 on July 28, 2024.

<sup>2</sup> The EOF site at Fairview is not included in this report due to insufficient data.

<sup>3</sup> According to a baseline pedological assessment of the field conducted in 2020 by the Soil Research Group (SRG).

corn. Both sides of the field contained paired strips consisting of a cover crop treatment (strips 2 and 4) and a control where no cover crops were seeded (strips 1 and 3).

The spring of 2024 was characterized by consistent and heavy precipitation with an average spring water balance of -0.645, as measured by precipitation minus reference evapotranspiration ( $PP - ET_o$ ) (**Figure 3**). These factors, combined with other soil properties, such as soil type and soil structure, contributed to higher water retention and elevated soil moisture. The prolonged wet soil conditions in the spring delayed the timely planting of corn until June.



*Figure 3. Total daily precipitation (PP) and reference evapotranspiration ( $ET_o$ ) for spring 2024 at Site 7. Elevated levels of PP (>10 mm) correspond to major rainfall events.  $ET_o$  represents potential water loss from the soil.*

A DJI Phantom 4 Multispectral drone was used to collect imagery at an altitude of 328 ft, resulting in a ground sampling distance (GSD) of 5 cm per pixel. **Figure 4** shows the average (mean) NDVI values for each treatment strip from drone flights conducted biweekly throughout the summer of 2024. The range in NDVI values varied across strips over the season, with values increasing from early to mid-summer before declining toward the end of the season. The decline from mid-summer to late September is expected and reflects the natural progression of the crop toward maturity rather than crop stress. As the growing season progresses and frost-free days decrease, chlorophyll activity declines and photosynthesis slows, resulting in lower NDVI values (Wang et al., 2017; Richardson et al., 2017). Statistical analysis<sup>4</sup> indicated that NDVI values from July 28 to September 11 were significantly higher than those at the beginning and end of the season, with no significant difference between the beginning and end periods. Variability in NDVI was observed between treatments and strips on July 13 (**Figure 4**) which potentially reflected weaker plant establishment in poorly drained areas that experienced ponding earlier in the season. However, no statistically significant differences were found among treatments or strips throughout the growing season.

<sup>4</sup> Statistical significance was determined using analysis of variance (ANOVA) to compare differences in NDVI across monitoring dates, and among treatments and strips for NDVI, soil nutrients, soil properties, and yield.

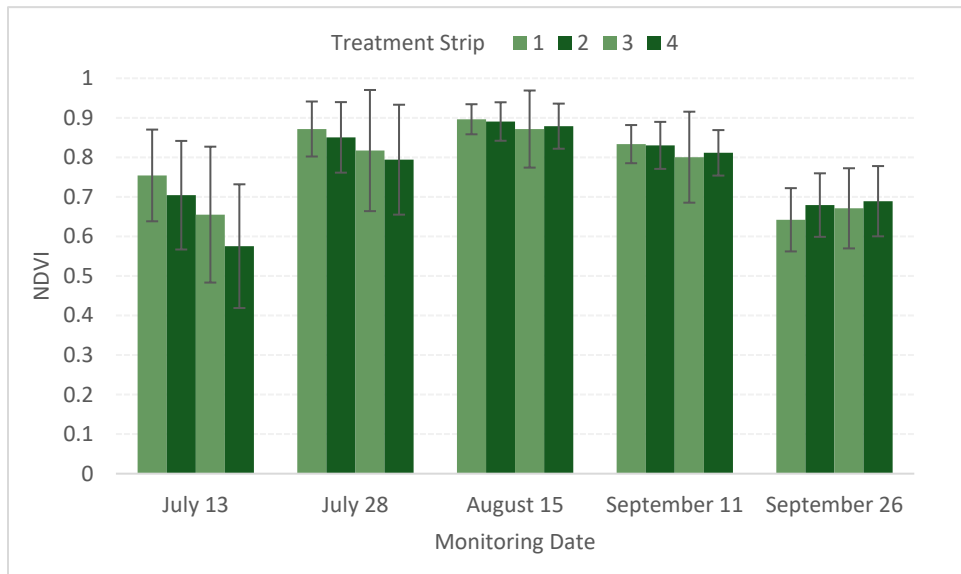


Figure 4. Mean NDVI values for cover crop treatment (strips 2 and 4) and control (strips 1 and 3) at Site 7 derived from monitoring flights conducted throughout the 2024 growing season. Error bars represent  $\pm$  one standard deviation.

Figure 5 shows the treatment strips and sampling points overlaid on the NDVI imagery, with translucent shading representing the average NDVI value for each strip and sampling points on a consistent scale. The darker the strip, the higher the average NDVI value. Site 7 exhibits differences in drainage capacities, with soils ranging from moderately well-drained at the south end of the strips to poorly drained toward the north. This is primarily due to random installation of tile drainage throughout the field. The eastern portion of the field has at least six uniformly spaced drainage tiles, whereas the western portion has only three tiles placed at varying orientations. The average slope is similar between strips 1 and 4, however the slope length was greater in strip 4 (116.7 m) compared to strip 1 (88.3 m), indicating a higher potential for water accumulation in strip 4. Higher NDVI values in the eastern field appear to reflect improved drainage, uniform tile placement, and long-term management differences, which likely contributed to stronger plant growth in strips 1 and 2 compared to strips 3 and 4 throughout July. However, both fields exhibited similar declines in NDVI for cover cropping strips relative to the control (no cover cropping), suggesting a potential short-term negative impact on corn growth following cover crop termination. No statistically significant differences were observed between treatments on July 13, 2024.

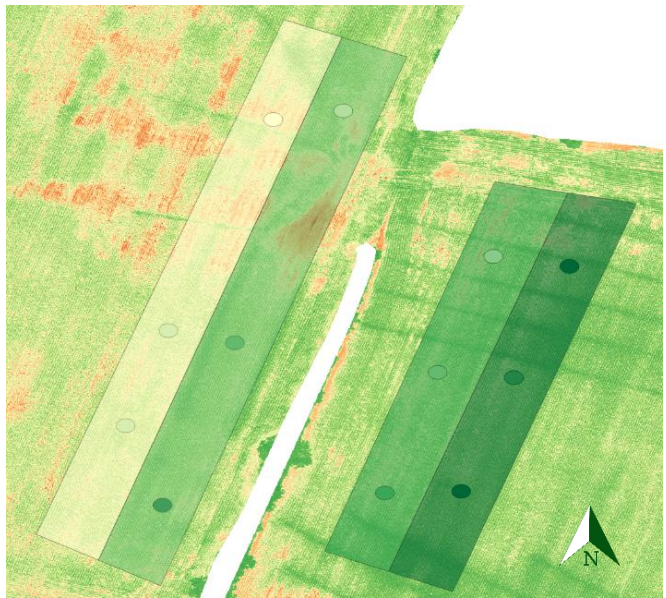


Figure 5. Mean NDVI values for cover crop treatment strips 2 (middle right) and 4 (left) and control strips 1 (right) and 3 (middle left) at Site 7 on July 13, 2024.

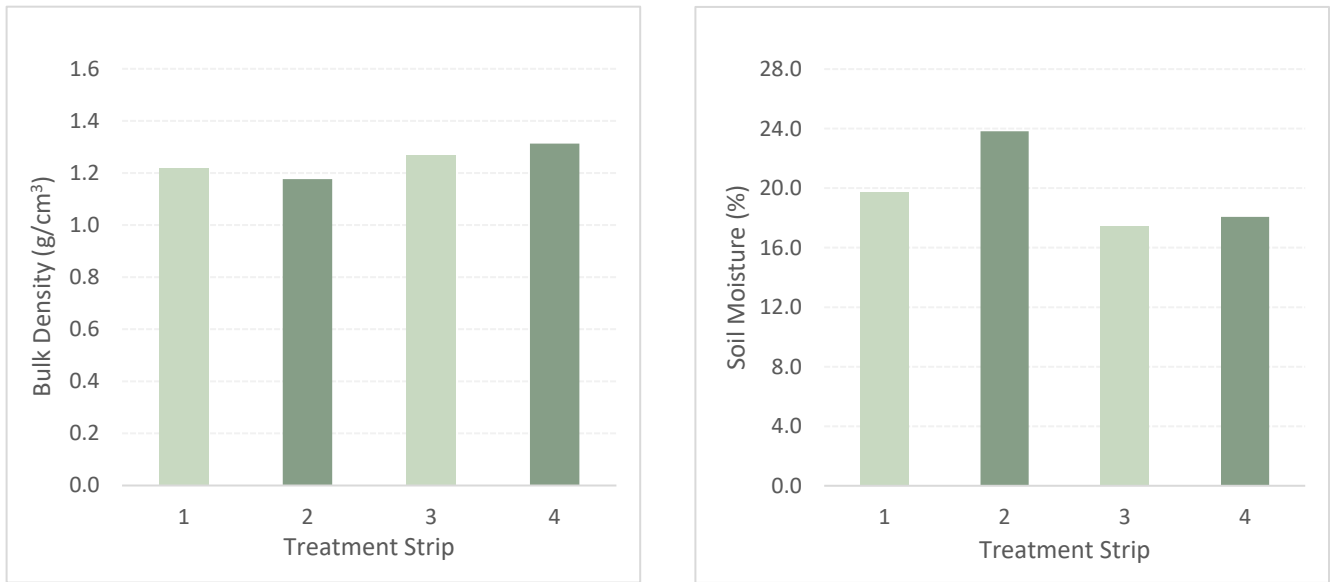


Figure 6. Mean bulk density and soil moisture for cover crop treatment (strips 2 and 4) and control (strips 1 and 3) at Site 7 on June 18, 2024

Soil samples were collected on June 18, 2024. The results provide evidence of NDVI’s ability to capture soil properties that are directly linked to water stress (Figure 6-Figure 7). Treatment strips with lower bulk density generally have higher soil moisture because looser soils provide more pore space for water infiltration and retention than compacted soils (Agriculture and Agrifood Canada, 2020; Barber, 1995). The drainage capacity of the field was influenced by both tile drain placement and soil bulk density, as these factors jointly control the water dynamics and water retention through the soil. Higher organic matter (OM) improves soil structure, water-holding capacity, and nutrient availability, which promotes better root development and more consistent crop growth (Agriculture and Agrifood Canada, 2020). This typically leads to greater biomass and chlorophyll content, resulting in higher NDVI values (Farias et al., 2023). July NDVI values appear to capture treatment-level variation in land conditions (i.e., tile drainage), soil physical and chemical properties. All soil properties showed significant differences between strips 1 and 2 compared to strips 3 and 4.

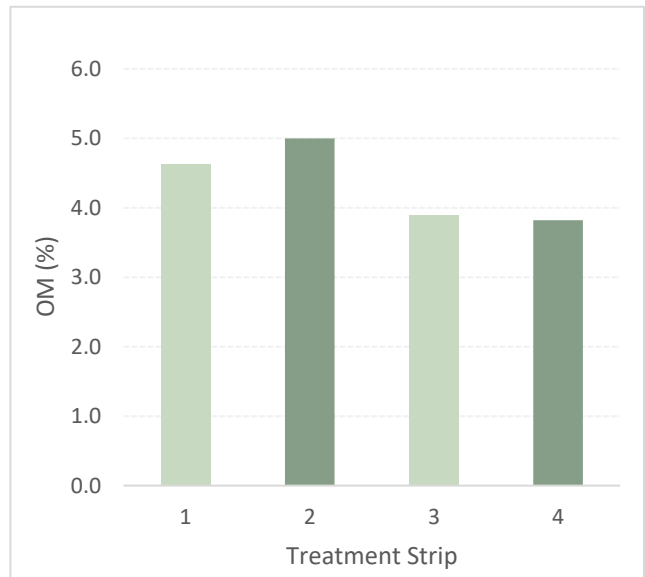


Figure 7. Mean organic matter (OM) for cover crop treatment (strips 2 and 4) and control (strips 1 and 3) at Site 7 on June 18, 2024 (right).

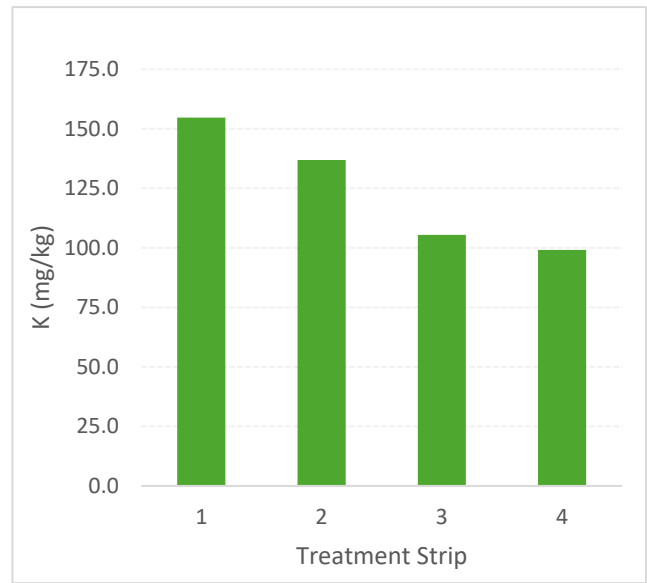
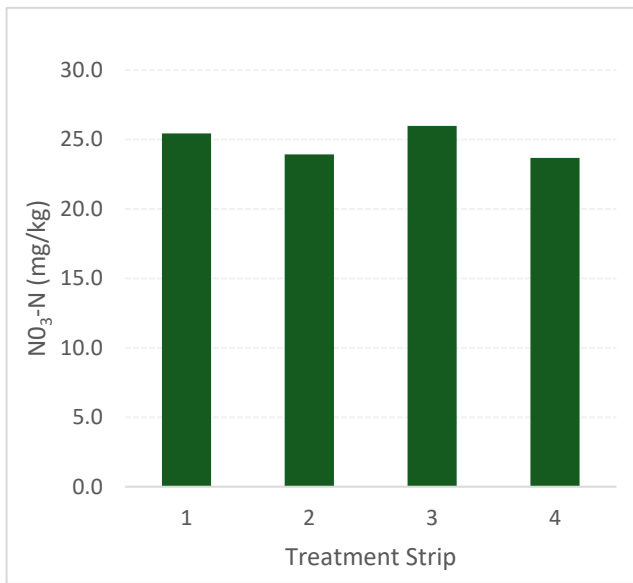


Figure 8. Mean P and K values for cover crop treatment (strips 2 and 4) and control (strips 1 and 3) at Site 7 on June 18, 2024. Green = medium, dark green = high (optimal).

Figure 8-Figure 9 show select soil nutrient levels across treatment strips, with the coloured bars indicating nutrient availability ratings based on cation exchange capacity (CEC)<sup>5</sup>. NDVI has been shown to reflect crop nutrient status, responding to nitrogen uptake and canopy development as well as physiological changes associated with phosphorus (P) potassium and (K) availability under different fertilization strategies (Farias et al., 2023). Areas with sufficient P and K typically exhibit denser, greener canopies, which NDVI captures as higher values. At Site 7, P and K availability closely reflect NDVI values in July, with higher P and K availability in strips 1 and 2 compared to strips 3 and 4 (Figure 8). All four treatment strips exhibited sufficient pre-side dress nitrate-nitrogen (NO<sub>3</sub>-N), suggesting that nitrogen was not a limiting factor and was unlikely to explain differences in plant growth (Figure 9). Statistically significant differences were observed for all soil nutrients between strips 1 and 2 compared to strips 3 and 4, except for NO<sub>3</sub>-N.

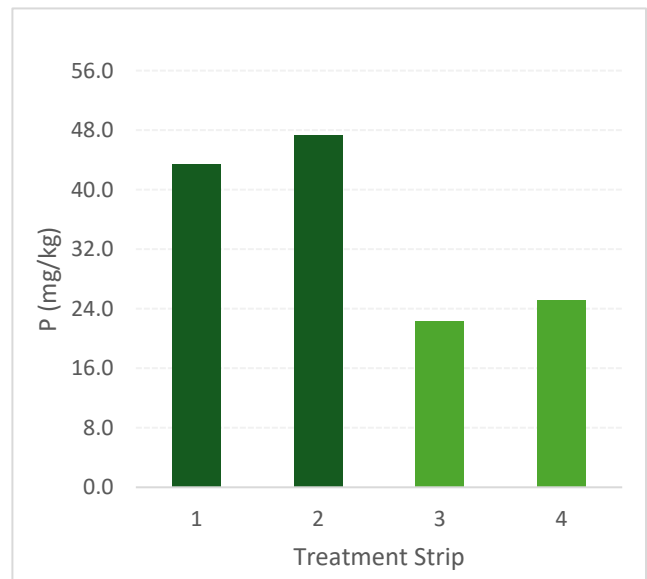


Figure 9. Mean NO<sub>3</sub>-N for cover crop treatment (strips 2 and 4) and control (strips 1 and 3) at Site 7 on June 18, 2024. All strips received a high (optimal) rating (right).

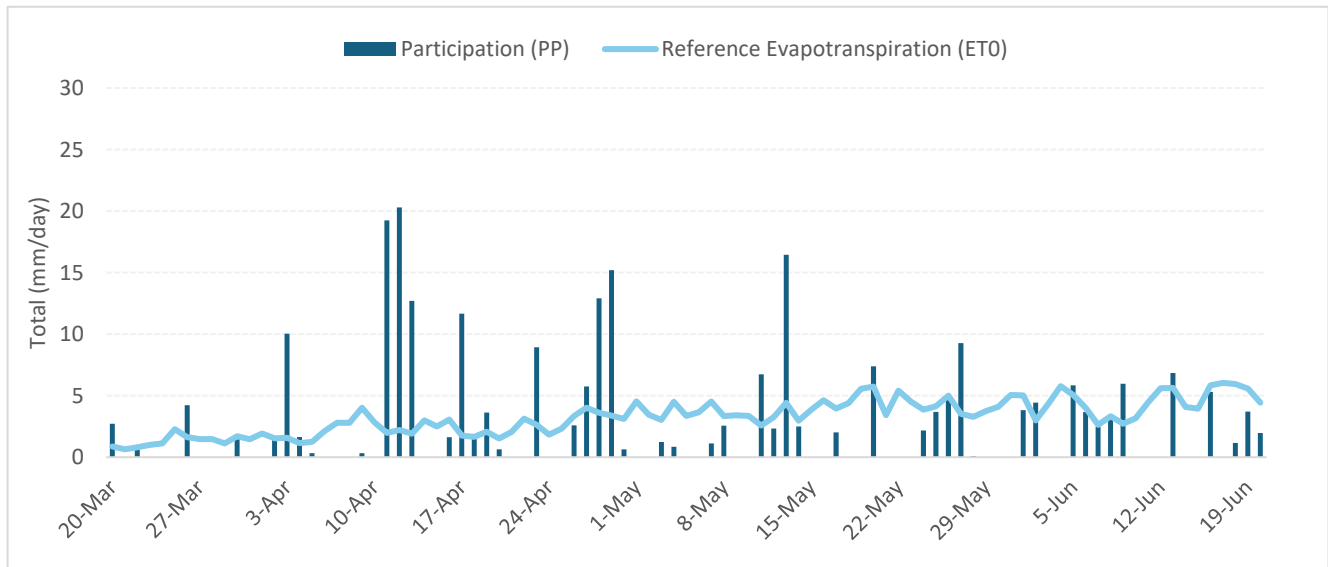
### Soil Health Site 15

Site 15 is a beef operation located in Bruce County, Ontario and is the second of the ONFARM Soil Health trial sites that conducted drone monitoring flights to capture NDVI imagery over the 2024 season. The site focuses on improving soil health using organic beef amendments and cover crops. It is characterized by a silt loam soil type and follows a wheat-corn-soybean rotation, with corn grown in 2024. The paired strips consisted of a cover crop treatment (strips 1 and 4) and

<sup>5</sup> Soil optimum levels based on CEC were provided by A&L Canada Laboratories, Inc.

a combination treatment of cover crop and organic beef amendments (strips 2 and 3). In contrast to Site 7, which experienced significant ponding and poor crop establishment in the western field, Site 15 exhibited uniform crop development despite experiencing similar precipitation events during the spring of 2024 (**Figure 10**). No statistically significant differences in NDVI were observed between strips, treatments or dates from July 13 to September 10.

The soil at Site 15 had a higher capacity to infiltrate and retain water, with 14% lower bulk density and 18% higher organic matter compared to Site 7. These characteristics, along with other factors such as soil type and drainage efficiency, contributed to reduced crop water stress and supported stable, consistent growth throughout the season.



*Figure 10. Total daily precipitation (PP) and reference evapotranspiration (ET<sub>0</sub>) for spring 2024 (Site 15). Both sites exhibited similar levels of average spring water balance (PP – ET<sub>0</sub>).*

**Figure 11** shows the average value and standard deviation of NDVI for each treatment strip measured biweekly from July to September 2024. By early July, average NDVI values exceeded 0.8, and remained consistently high throughout the summer. There was minimal to no variability in crop activity observed between the strips at this site.

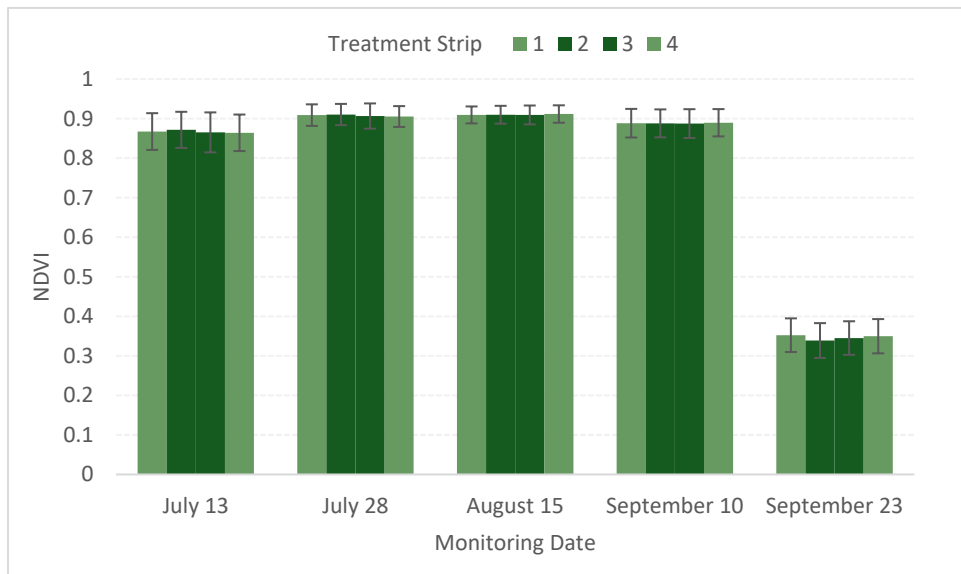


Figure 11. Mean NDVI values for cover crop (strips 1 and 4) and combination treatments (strips 2 and 3) at Site 15 derived from drone monitoring flights conducted throughout the 2024 growing season. Error bars represent  $\pm$  one standard deviation.

Figure 12 presents NDVI imagery for Site 15, with treatment strips and sampling points overlaid. The translucent shading illustrates the average NDVI values for each strip and sampling location, using a consistent scale across the field. Compared to Site 7, Site 15 shows uniform NDVI across treatment strips and similar values across sampling points, indicating low spatial variability across the trial area.

Similar to Site 7, Site 15's NDVI values showed the strongest relationship with soil properties that influence water availability, such as soil moisture, bulk density and OM (Figures 13). NDVI did not capture differences in nutrient status even when availability was below optimal levels (Figure 14). No statistically significant differences were found between strips or treatments for all soil properties and soil nutrients, except for  $\text{NO}_3\text{-N}$ . If a crop is experiencing adequate moisture and favourable weather conditions, plants can maintain growth at lower nutrient concentrations due to increased nutrient mobility in the soil solution and improved uptake efficiency, particularly under conditions that support active root growth and mass flow-driven nutrient transport (Marschner, 2012; Barber, 1995). Furthermore, NDVI becomes less responsive under conditions where crop growth is not strongly constrained and canopy conditions remain relatively uniform, due to saturation

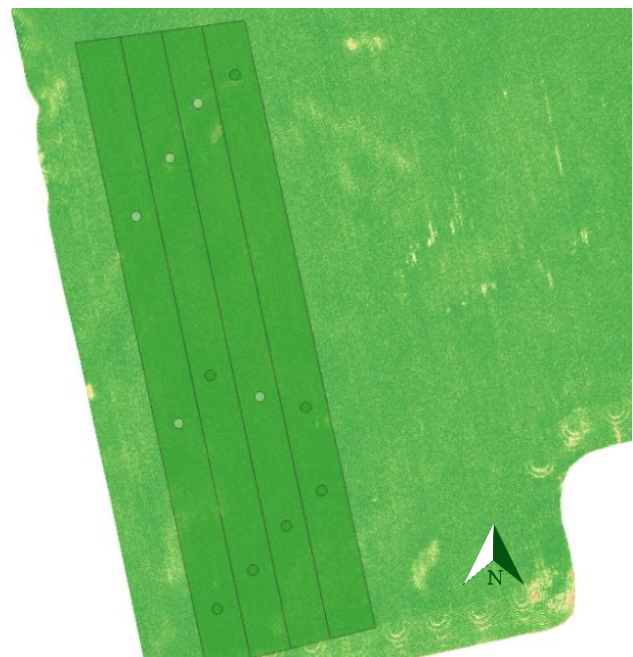
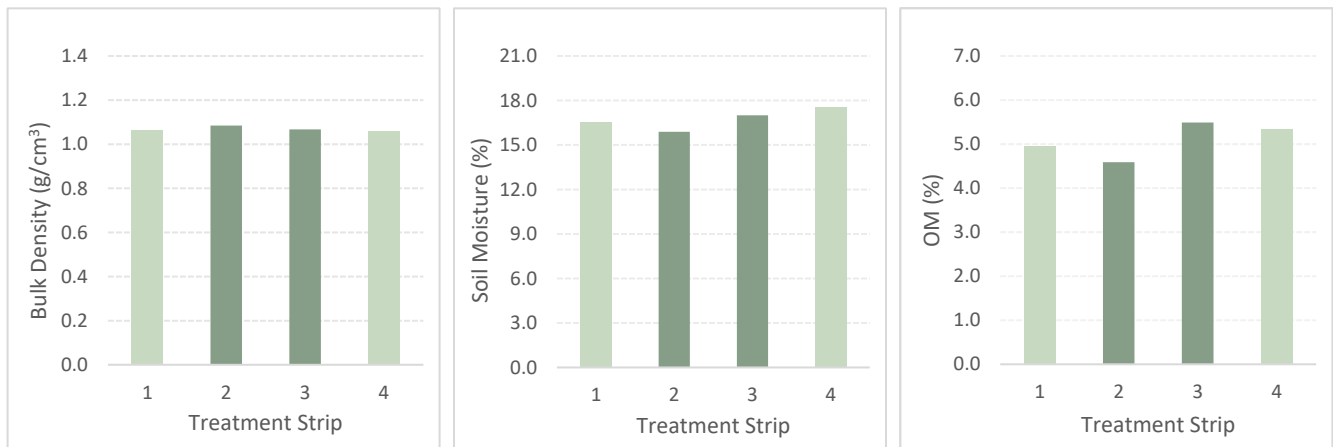


Figure 12. Mean NDVI values for cover crop treatment strips 1 (right) and 4 (left) and combination treatment strips 2 (middle right) and 3 (middle left) at Site 15 on July 13, 2024.

effects at higher levels of vegetation development (Gao et al., 2023b).



Figures 13. Mean bulk density, soil moisture and organic matter (OM) for cover crop (strips 1 and 4) and combination treatments (strips 2 and 3) at Site 15 on June 4, 2024.

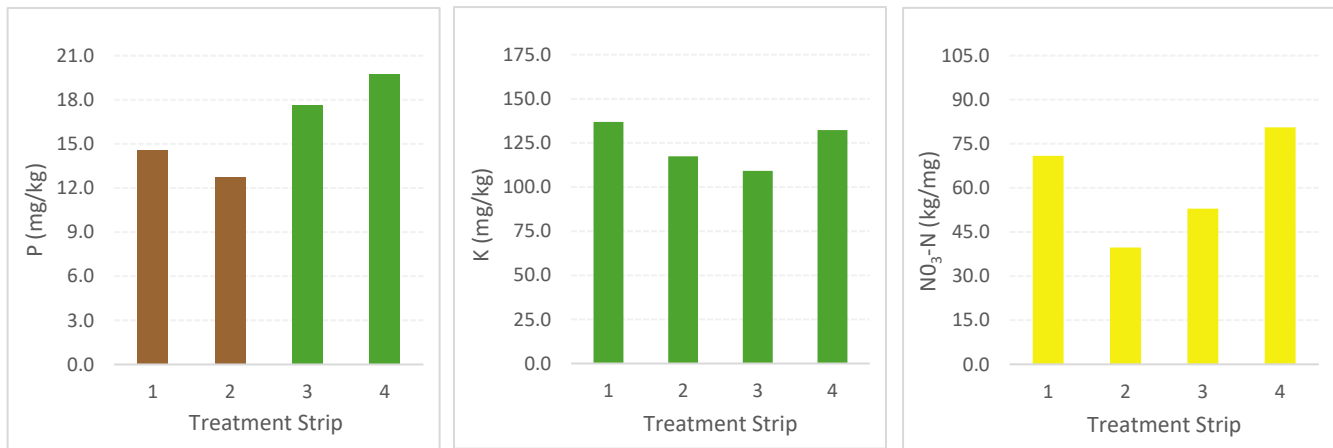


Figure 14. Mean P, K and NO<sub>3</sub>-N for cover crop (strips 1 and 4) and combination treatments (strips 2 and 3) at Site 15 on June 4, 2024. Brown = low, green = medium, dark green = high (optimal), yellow = very high.

## NDVI and Yield

To examine the relationship between NDVI and yield, a simple regression plot was constructed. **Figure 15** shows NDVI values across the growing season plotted against final yield, with differences in the coefficient of determination ( $R^2$ ) highlighting the period when NDVI exhibits the strongest correlation with yield at each site. For Site 7 the strongest correlation was observed on July 28, indicating that mid-season NDVI most closely reflected eventual yield. After this peak,  $R^2$  values gradually decreased, reflecting diminishing sensitivity of NDVI to yield as the crop reached maturity. Due to the limited variation in both NDVI values and hand yield, Site 15 showed a weak NDVI-yield relationship at each point throughout the growing season. This is consistent with the saturation effect of NDVI at high values, where the index becomes less sensitive to differences in biomass and canopy structure under dense, high-yielding conditions, thereby reducing its ability to detect variability in crop performance (Gao et al., 2023a; Gao et al., 2023b).

A regression model provides evidence of the predictive power of NDVI for yield while controlling for site-specific differences (**Table 1**). The inclusion of the site dummy variable in all models accounts for field-

specific differences, ensuring that observed patterns reflect NDVI’s predictive power rather than underlying site effects. The model results show that the relationship between NDVI and yield varies across the growing season. On July 28, NDVI exhibits a strong positive correlation with yield ( $R^2 = 0.850$ ,  $p < 0.01$ ). This finding supports evidence that NDVI–yield relationships are strongly dependent on the timing of image acquisition, with mid-season observations generally providing the most reliable yield estimates (Maresma et al., 2016). Overall, the results suggest that mid- to late-July NDVI values are the most informative for predicting yield.

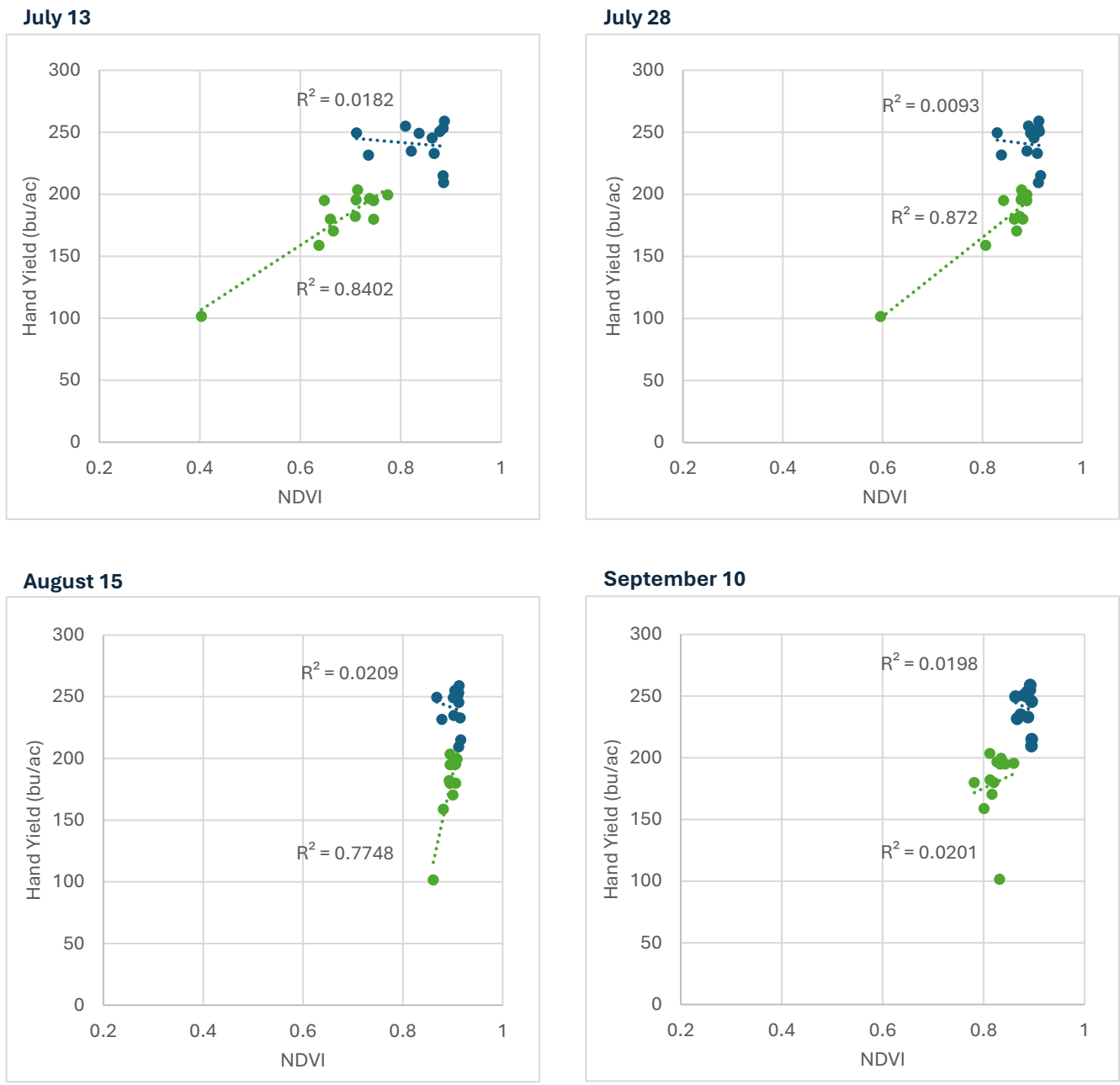


Figure 15. Temporal NDVI plotted against yield across the 2024 growing season for Site 7 (green) and Site 15 (blue). Yield was combined on October 18 and 22, 2024 for Sites 15 and 7, respectively.  $R^2$  shows the proportion of variance in yield explained by NDVI at each site.

Table 1. Temporal NDVI-yield regression results across 2024 growing season with site dummy included.

Variable	(1) July 13	(2) July 28	(3) August 15	(4) September 10
NDVI	181.346*** (10.436)	276.333*** (53.568)	716.048** (309.520)	102.431 (300.969)
Constant	88.331** (39.777)	-6.581 (48.090)	-406.585 (279.740)	149.791 (266.380)
Observations	24	24	24	24
R <sup>2</sup>	0.801	0.850	0.729	0.662
Site Dummy	YES	YES	YES	YES

Note: Coefficients represent the estimated change in yield (bu/ac) associated with a one-unit increase in NDVI. Standard errors are shown in parentheses. Significance levels are indicated as \*\*\*p < 0.01, \*\*p < 0.05, p < 0.1. 'Site Dummy' indicates whether a control variable for site was included in the model. R<sup>2</sup> shows the proportion of variance in yield explained by the model.

### Discussion and Next Steps

The findings in this report suggest that NDVI is more responsive to soil properties affecting water availability than to soil nutrient status when nutrients or other soil properties (e.g., moisture) are sufficiently available. NDVI reflects canopy greenness and biomass, which are strongly influenced by water stress and soil moisture dynamics, rather than soil nutrient availability. At Site 7, there was greater NDVI variability and nutrient differences were only reflected when availability likely limited plant growth. Where nutrient levels were sufficient for plant uptake, variability in nutrient levels did not correspond to changes in NDVI. When NDVI did not vary between strips, there was a saturation effect leading to a lack of relationship between NDVI, nutrient status and yield. The relationship between NDVI and yield was strongest during mid- to late-July, indicating that NDVI captured crop vigor most effectively during peak vegetative growth. Later in the season, NDVI became less predictive of final yield. The results suggest that temporal NDVI can be useful for identifying areas of potential water stress and estimating yield in the earlier stages of growth. Overall, no statistically significant differences in yield were observed among treatments at either site.

There are several directions for future research. First, integrating NDVI imagery with Light Detection and Ranging (LiDAR), an active remote sensing technology that generates high-resolution 3D representations of surface topography, along with the Soil and Water Assessment Tool (SWAT), could enhance spatial analysis of BMP treatment areas by linking crop performance with underlying landscape and water dynamics. Second, expanding the number of sites to include a wider range of soil types, crop management practices, and weather conditions would improve model robustness. Third, NDVI shows strong potential as a decision-support tool for BMP implementation. For example, temporal NDVI could be used to inform cover crop planting strategies or to guide targeted fertilization (e.g., organic amendments) and other interventions in areas where spatial variability indicates emerging stress. Together, these approaches could help bridge current ONFARM NDVI research with practical applications for future BMP recommendations.

To stay up to date on ONFARM activities and to view past reports, please visit the [OSCIA ONFARM Website](#).

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