Estimating Wheat Yield with Normalized Difference Vegetation Index and Fractional Green Canopy Cover

Allen W. Goodwin, Laura E. Lindsey,* Steven K. Harrison, and Pierce A. Paul

Abstract
Producers are interested in methods for estimating wheat grain yield at earlier growth stages. Ability to estimate wheat yield early in the growing season could provide producers with the flexibility needed to decide whether to terminate their wheat crop to plant a more profitable alternative crop, such as soybean. The traditional assessment method, counting plants and tillers, is tedious and time consuming. There is a need to create easier methods to estimate wheat yield, such as normalized difference vegetative index (NDVI) or fractional green canopy cover (FGCC). The objective of this study was to compare NDVI, FGCC, and stem count measurements at multiple wheat growth stages to estimate winter wheat grain yield. Trials were established during the 2015–2016 and 2016–2017 growing seasons at two locations in Ohio. Treatment included wheat seeding rates of 0.75, 1.0, 1.5, 2.0, and 2.5 million seeds/acre to mimic a poor to excellent wheat stand. Wheat stand assessment methods of NDVI, FGCC, and stem counts were conducted at Feekes 1 (emergence), Feekes 5 (leaf sheaths strongly erect), and Feekes 6 (first node visible) growth stages. Regression models were used to estimate wheat yield. Normalized difference vegetation index ($R^2 = 0.49$) and FGCC ($R^2 = 0.45$) best estimated wheat grain yield while stem count measurements accounted for 29% of the variability in yield. However, NDVI and FGCC measurements are time sensitive and should be conducted prior to Feekes 6 growth stage, and for FGCC, camera height should be adjusted to capture three rows of wheat in the image.

History of Wheat Stand Assessment
Between planting in the fall and Feekes 4 growth stage (beginning of erect growth) in the spring, winter wheat is vulnerable to environmental stress such as freezing temperatures with limited snow cover, saturated soils, and freeze–thaw cycles that cause soil heaving (Dickin and Wright, 2008; Fowler and Gusta, 1979); all of which may lead to substantial stand reduction, and consequently, low grain yield. In Ohio, due to poor stands in the spring, an average of 5% of the winter wheat acres are destroyed annually and planted to an alternative crop such as corn or soybean, and as much as 12% of the wheat acres were destroyed in 2014 (USDA-NASS, 2017).

However, a stand that looks thin in the spring does not always correspond to lower grain yield, as the relationship between stand at a
given growth stage and yield is not always linear. New tillers may still develop, and wheat may compensate for stand loss by producing more and larger kernels per spike (Lafond, 1994; Porter and Khalilian, 1995). Rather than relying on a visual stand assessment, producers are encouraged to estimate the yield potential of their winter wheat crop by counting plants or tillers (Weisz et al., 2001) before deciding whether a field should be destroyed and planted to corn or soybean. In Illinois, a minimum of 25 to 31 tillers per foot of row by Feekes 6 growth stage is recommended to maximize yield while 9 to 13 plants per foot of row is the minimum suggested population to maintain production (Nafziger, 2009). In Kentucky, tiller counts are suggested at Feekes 3 growth stage (end of tillering), and 43 to 62 tillers per foot of row is considered sufficient (Lee et al., 2009). Despite these recommendations, many producers do not count wheat plants or tillers in the spring because the measurement is tedious and time consuming (Ohio Small Grains Marketing Program, unpublished survey, 2015).

Two alternative methods to evaluate wheat stand include normalized difference vegetation index (NDVI) and fractional green canopy cover (FGCC). Normalized difference vegetation index, calculated using near-infrared (NIR) and red (R) wavelengths, was strongly and consistently correlated with wheat tiller density in the absence of weeds (Flowers et al., 2001; Phillips et al., 2004). However, NDVI may not be reliable when the leaf area index is greater than 3, which may impact recommendations based on NDVI at Feekes 5 growth stage or later (Serrano et al., 2000).

Fractional green canopy cover can be used to measure the canopy surface area using automatic pixel classification. Casadesús et al. (2007) found a strong correlation between FGCC and durum wheat biomass and grain yield. Fractional green canopy cover can be calculated using the mobile device application, Canopeo (Oklahoma State University, Stillwater, OK), which automatically classifies pixels as green or not green (Patrignani and Ochsner, 2015). Canopeo correctly classified 100% and 90% of pixels in images of winter wheat produced under conventional tillage and no-tillage, respectively (Patrignani and Ochsner, 2015).

In addition to NDVI and FGCC, there are more than 40 other indices that estimate biomass, chlorophyll concentration, and yield of crops, including green normalized difference vegetation index and dark green color index (Bannari et al., 1995; Candiago et al., 2015; Abdelaziz et al., 2018). However, these other indices may require a multispectral camera and specialized software to process images (Candiago et al., 2015; Patrignani and Ochsner, 2015). In this study, NDVI and FGCC were selected because of the commercial availability of the GreenSeeker sensor (Trimble Inc., Sunnyvale, CA) for measuring NDVI and the Canopeo application for measuring FGCC. Wheat stand assessment methods have been used independently to estimate wheat grain yield; however, non-traditional stand assessment methods of NDVI and FGCC have not been directly compared to the plant or tiller count measurements in soft red winter wheat. Therefore, the objective of this study was to compare NDVI, FGCC, and stem count measurements at multiple wheat growth stages to estimate soft red winter wheat yield.

**Methods Used to Assess Spring Stand of Soft Red Winter Wheat**

The study was conducted during the 2015–2016 and 2016–2017 growing seasons at two on-farm locations in Pickaway County, Ohio (39°39’ 7.20′′N, 83°1’37.2′′W) and Crawford County, Ohio (40°46’ 39.72′′ N, 82°53’ 52.80′′ W) for a total of four site-years. At both locations, the trial was conducted in a different field each year.

The experiment was a randomized complete block design with four replications of treatments. Five seeding rate treatments (0.75, 1.0, 1.5, 2.0, and 2.5 million seeds/acre) were used to mimic a poor to good stand in the spring. At all site-years, the wheat variety ‘Pioneer 25R40’ was used, and the previous crop was soybean. Prior to planting, the Crawford County location was vertically tilled while the Pickaway County location was prepared by discing. Fall nitrogen application ranged from 18 to 35 lb N/acre, depending on the site-year, and 90–104 lb N/acre was applied in the spring. Herbicides, fungicides, and insecticides were applied as needed to minimize the effect of weeds, diseases, and insects. Plots were 5.5 ft wide and 19 to 34 ft long, depending on the site-year. Plots were planted with a custom-made planter, equipped with a Great Plains 20 series row unit, a Singulator-Plus precision seed meter, and high-rate wheat seed discs. Wheat was planted in a 7.5-inch row width. Plots were harvested with a Wintersteiger combine, equipped with a high-capacity grain gauge (Wintersteiger, Salt Lake City, UT). Grain yield was standardized to 13.5% moisture concentration.

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**Table A. Useful conversions.**

<table>
<thead>
<tr>
<th>To convert Column 1 to Column 2, multiply by</th>
<th>Column 1 Suggested Unit</th>
<th>Column 2 SI Unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.405</td>
<td>acre</td>
<td>hectare, ha</td>
</tr>
<tr>
<td>1.12</td>
<td>pound per acre, lb/acre</td>
<td>kilogram per hectare, kg/ha</td>
</tr>
<tr>
<td>67.19</td>
<td>60-lb bushel per acre, bu/acre</td>
<td>kilogram per hectare, kg/ha</td>
</tr>
<tr>
<td>2.54</td>
<td>inch</td>
<td>centimeter, cm (10–2 m)</td>
</tr>
<tr>
<td>0.304</td>
<td>foot, ft</td>
<td>meter, m</td>
</tr>
</tbody>
</table>
Wheat stems (main stem + tillers) were counted at Feekes 1, 5, and 6 growth stages from three arbitrarily selected linear feet of row within each plot. At Feekes 5 and later, additional tillers developed are not expected to impact grain yield; however, producers still have time to plant an alternative crop (Lindsey et al., 2017). All stems were counted regardless of height or leaf number. Normalized difference vegetation index measurements were taken at Feekes 5 and 6 growth stage with a GreenSeeker handheld crop sensor. The sensor was held parallel to the ground at a height of 3 ft above the soil surface and measured the average NDVI for the entire length of the plot at a width of 34 inches. Fractional green canopy cover was measured using the mobile device application, Canopeo, at Feekes 5 and 6 growth stages at two heights to capture one row of wheat (12-inch length of row) or three rows of wheat (camera height and length of row varied based on canopy height). One picture was collected per plot at each of the two camera heights.

Data were analyzed using SAS 9.3 (SAS Institute, Cary, NC). Analysis of variance was conducted to evaluate the effect of seeding rate on NDVI and FGCC using Proc Mixed. Seeding rate treatment was considered a fixed effect. Location and replication were treated as random effects. Means were separated with the LSD at α = 0.05. Proc Corr was used to determine Pearson’s correlation coefficient for NDVI, FGCC, and stem count measurements collected at the various growth stages. Linear and quadratic regression analyses were performed using Proc Reg to examine the relationship among NDVI, FGCC, and stem count measurements collected at the various growth stages and yield. Significance was determined at α = 0.05.

### Correlation between Stem Counts, NDVI, and FGCC

The wheat seeding rate treatment significantly influenced NDVI measured at Feekes 5 growth stage, FGCC measured from three rows of wheat at Feekes 5 growth stage, and FGCC measured from one row of wheat at Feekes 6 growth stage (data not shown). Normalized difference vegetative index and FGCC tended to be similar for seeding rates of 1.0 to 2.5 million seeds/acre. The lowest seeding rate, 0.75 million seeds/acre, resulted in significantly lower NDVI and FGCC values compared with rates of 1.0 million seeds/acre and greater.

The correlation among stem counts, NDVI, and FGCC measurements collected at three growth stages is shown in Table 1. Stem count measurements were correlated with most of the NDVI and FGCC measurements, but Pearson correlation coefficient values were lower compared with the correlation between NDVI and FGCC measurements. Many of the correlations between NDVI and FGCC were high (r ≥ 0.70). At Feekes 5 growth stage, NDVI had a high correlation with FGCC measured at Feekes 5 growth stage from three rows of wheat (r = 0.87, p < 0.01), NDVI measured at Feekes 6 growth stage (r = 0.75, p < 0.01), and FGCC measured at Feekes 6 growth stage from three rows of wheat (r = 0.70, p < 0.01). At Feekes 6 growth stage, NDVI had a high correlation with FGCC measured at Feekes 5 growth stage from three rows of wheat (r = 0.73, p < 0.01) and FGCC measured at Feekes 6 growth stage from three rows of wheat (r = 0.95, p < 0.01). Additionally, FGCC collected from three rows of wheat at Feekes 5 and 6 growth stage had a high correlation (r = 0.95, p < 0.01). Carlson and Ripley (1997) found NDVI to be sensitive to changes in FGCC until full canopy closure was reached (Carlson and Ripley, 1997). In wheat,
Although other studies have found NDVI to reliably estimate wheat grain yield across four site-years and field conditions (Carlson and Ripley, 1997). At the Feekes 6 growth stage, leaf area index was likely greater than 3 (Ulaby et al., 1984), which may explain the low R² values at Feekes 6 growth stage compared with Feekes 5 growth stage.

Furthermore, in our trials, spring N application often occurred between Feekes 5 and 6 growth stage, which also increases leaf area index and greenness of plants (Nielsen and Halvorson, 1991).

At the Feekes 5 and 6 growth stages, FGCC capturing three rows of wheat in the image accounted for more variability in yield compared with FGCC capturing one row of wheat in the image. Determining FGCC for a larger area of the wheat stand likely improved the relationship between FGCC and yield. Furthermore, developers of Canopeo noted that the camera should be held at a height of approximately 2 ft above the crop canopy (Patrignani and Ochsner, 2015).

**Management Implications**

Estimates of wheat grain yield using stem count, NDVI, and FGCC (capturing three rows of wheat in the image) measurements at Feekes 5 are shown in Table 3. In our research trials, wheat grain yield ranged from 82 to 131 bu/acre, and regression analyses should not be extrapolated beyond that range. Due to the quadratic relationship between stem count measurements and grain yield, there was no increase in grain yield at stem counts greater than 100 stems/f. However, grain yield increased linearly with increasing NDVI and FGCC.

Although NDVI and FGCC are alternative methods to evaluate a winter wheat stand, it is important to note that our trials were under weed-free conditions. Using a hand-held sensor to measure NDVI and mobile device application to measure FGCC, wheat plants and weeds cannot be distinguished and will influence results (Scotford and Miller, 2005). In fields with weeds, stem count measurements should be conducted.
Normalized difference vegetation index and FGCC (capturing three rows of wheat in the image) measurements accounted for the most variability in yield. However, these measurements are time sensitive and should be conducted at Feekes 5 growth stage. At Feekes 5 growth stage (generally early to mid-April in Ohio), any additional tillers should not significantly contribute to grain yield; however, there is still time to terminate the wheat crop and plant an alternative crop if wheat grain yield potential is low (Lindsey et al., 2017).

Acknowledgments
We would like to thank the Ohio Small Grains Marketing Program for funding this project. Salary and research support provided in part by state and federal funds appropriated to The Ohio Agricultural Research and Development Center (OARDC) and The Ohio State University, manuscript number HCS18-06. Thanks are extended for field and technical assistance from Matthew Hankinson, other members of the lab, and farmer cooperators.

References


<table>
<thead>
<tr>
<th>Grain yield</th>
<th>Stem count †</th>
<th>NDVI‡</th>
<th>FGCC§</th>
</tr>
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<tbody>
<tr>
<td>bu/ac</td>
<td>number/foot of row</td>
<td></td>
<td></td>
</tr>
<tr>
<td>85</td>
<td>27</td>
<td>0.33</td>
<td>17</td>
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<tr>
<td>90</td>
<td>34</td>
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<td>51</td>
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<td>105</td>
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<td>0.51</td>
<td>41</td>
</tr>
<tr>
<td>110</td>
<td>80</td>
<td>0.55</td>
<td>47</td>
</tr>
<tr>
<td>115</td>
<td>100</td>
<td>0.60</td>
<td>53</td>
</tr>
<tr>
<td>120</td>
<td>–</td>
<td>0.64</td>
<td>59</td>
</tr>
<tr>
<td>125</td>
<td>–</td>
<td>0.69</td>
<td>65</td>
</tr>
<tr>
<td>130</td>
<td>–</td>
<td>0.73</td>
<td>71</td>
</tr>
</tbody>
</table>

† Calculated stem count (x) values required for predicted grain yields shown, based on the equation: \( y = -0.005x^2 + 1x + 62 \)
‡ Calculated NDVI (x) values for predicted grain yields shown, based on the equation: \( y = 112x + 48 \)
§ Calculated FGCC (x) values for predicted grain yields shown, based on the equation: \( y = 0.83x + 71 \)
¶ Due to the quadratic relationship, grain yield plateaus at 100 stems/ft of row.
