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Gregory J. McGlinch

Stephen J. Jacquemin
Wright State University - Lake Campus, stephen.jacquemin@wright.edu

Laura E. Lindsey

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Evaluating winter malting barley grain yield with fractional green canopy cover

Gregory J. McGlinch[1] | Stephen J. Jacquemin[2] | Laura E. Lindsey[1]

[1] Horticulture and Crop Science, The Ohio State Univ., Columbus, OH 43210, USA

[2] Agriculture and Water Quality Education Center, Wright State Univ. – Lake Campus, Celina, OH 45822, USA

Correspondence
Gregory J. McGlinch, Horticulture and Crop Science, The Ohio State University, Columbus, OH 43210, USA
Email: mcglinch.2@osu.edu

Abstract

Because of growth in the craft brewing industry, farmers in the eastern United States are planting winter malting barley (*Hordeum vulgare* L.) to meet demands for locally sourced grain. However, given that barley is a relatively new crop in this region, basic agronomic information relating to stand assessment is needed. This is particularly relevant in this region, as climatic variability from extreme temperature fluctuations during the winter and spring can reduce a barley stand, creating the need for farmers to estimate grain yield potential. The objective of the research was to evaluate the relationship between spring stem counts, fractional green canopy cover (FGCC), and normalized difference vegetation index (NDVI) and barley grain yield. Trials were established at five site-years in Ohio, where seeding rate treatments of 0.75, 1.0, 1.5, 2.0 and 2.5 million seeds acre^{-1} were used to simulate a range of poor to excellent plant stands. All barley stand assessment methods were conducted in the spring at the Feekes 5 growth stage. Stem counts were correlated with FGCC and NDVI measurements (r = .76 and .74, respectively). Stem counts (R^2 = .67) and FGCC (R^2 = .65) measurements accounted for the greatest variability in barley grain yield. Specifically, FGCC ≤5% corresponded to yield between 27 and 39 bu acre^{-1}, whereas 5 to 10% corresponded to yield between 60 and 89 bu acre^{-1}. Fractional green canopy cover should be considered as a stand and yield assessment tool, as it reduces labor compared with stem counting techniques.

1 | PREVIOUS STUDIES ON STAND ASSESSMENT METHODS

Winter malting barley (*Hordeum vulgare* L.) acreage has been increasing in the eastern United States because of demand by the craft brewing industry for locally sourced grain (Hmielowski, 2017). In Ohio, just under 10,000 acres of winter malting barley were planted in 2019 compared with 3,994 acres in 2017 and acreage is predicted to increase (Bernot, 2020; USDA-NASS, 2020). As an added benefit, barley provides farming operations in the region an opportunity to increase crop diversity and profitability while also reducing environmental impact (Clark, 2012; Shrestha & Lindsey, 2019).

Winter malting barley is planted in the fall, allowing for vernalization, with green-up in the spring followed by harvest in early summer (Jacobs, 2016; Lindsey et al., 2020). Early fall plant establishment improves overwintering of the crop. However, saturated soils and heaving caused by freeze–thaw cycles can reduce barley stands (Dickson et al., 1979). This

Abbreviations: FGCC, fractional green canopy cover; NDVI, normalized difference vegetation index; OARDC, Ohio Agricultural Research and Development Center.

has been evident in recent years, as numerous examples of crop damage have been noted over the past several years as a result of weather. Most notably, over 50% of the 2014 barley crop in New York and the 2019 crop in Ohio were injured as a result of the polar vortex (Sonnenberg, 2019; Verbeten, Ganoe, O'Dea, Bergstrom, & Sorrells, 2014). Temperature fluctuations, reduced snow cover, and soil heaving during the winter and spring create challenges in the survival of winter malting barley, generating uncertainty among farmers regarding their crop's yield potential (Zhong, Wiersma, Sheaffer, Steffenson, & Smith, 2019).

Manual stem counts [counting the number of stems (main stem + tillers) in a given area] is the standard method used to estimate barley grain yield (USDA, 2015). However, while the traditional method of stem counts is highly accurate for yield predictions, it is also laborious and time-consuming, resulting in many farmers not assessing their small-grain stands (Goodwin, Lindsey, Harrison, & Paul, 2018). Alternatively, normalized difference vegetation index (NDVI) and fractional green canopy cover (FGCC) reduce the labor and time associated with stem count methods. Normalized difference vegetation index is calculated from reflectance measurements from the red and near-infrared regions of the spectra (Raun et al., 2001) and can be measured with sensors, either handheld or mounted to field equipment. Fractional green canopy cover can be measured with a free mobile phone application called Canopeo (Oklahoma State University) via the phone's camera. The Canopeo application analyzes pixels based on the red to green and blue to green color ratios and an excess green index (Patrignani & Ochsner, 2015).

The NDVI and FGCC methods have not been validated for estimating barley grain yield. In winter wheat (*Triticum aestivum* L.), FGCC and NDVI stand assessment methods at the Feekes 5 growth stage (leaf sheaths strongly erect) (Large, 1954) accounted for 49 and 45% of the variability in grain yield, respectively (Goodwin et al., 2018). One caveat to these alternatives to stem counts is that NDVI is traditionally not available to producers directly because of the cost and technical barriers, whereas FGCC methods are more universally available and easier to use. Thus, the research objective was to evaluate the relationship between spring stem counts, fractional green canopy cover (FGCC), and normalized difference vegetation index (NDVI) and barley grain yield.

Core Ideas

- Stem counts explained 67% of the variation in malting barley grain yield.
- Fractional green canopy cover explained 65% of the variation in barley grain yield.
- Fractional green canopy cover may be a useful tool for practitioners.

2 | METHODS USED TO MEASURE WINTER MALTING BARLEY STANDS

2.1 | Site information

Research trials were conducted over two growing seasons, 2017–2018 and 2018–2019, at the Western Agricultural Research Station in Clark County, OH (39°51′41.40″N, 83°40′30.36″W), and Ohio Agricultural Research and Development Center (OARDC) in Wayne County, OH (40°46′54.48″N, 81°50′45.24″W). A third location, Northwest Agricultural Research Station in Wood County, OH (41°13′6.6″N, 83°45′48.24″W), was used during the 2017–2018 growing season for a total of five site-years.

2.2 | Experimental design

The experimental design was a randomized complete block with four replications of the treatments. Five seeding rate treatments (0.75, 1.0, 1.5, 2.0 and 2.5 million seeds acre^{-1}) were used to simulate a range of poor to excellent plant stands. 'Puffin', a commercially grown two-row winter malting barley variety, was planted in rows 7.5 inches wide from late September to early October with soybean [*Glycine max* (L.) Merr.] as the previous crop. The entire study area was conventionally tilled using a disc, a field cultivator, and a cultimulcher. Plots were 6.25 ft wide and 19 ft long. Plots were planted with a custom-made planter, equipped with Great Plains 20 series row units and a Singulator-Plus precision seed meter. Fall nitrogen applications consisted of 21 lb N acre^{-1} at OARDC, 30 lb N acre^{-1} at Northwest Agricultural Research Station and 25 lb of N acre^{-1} at Western Agricultural Research Station. In the spring, the entire trial area received 80 lb N acre^{-1} topdressed by hand in the form of urea (46–0–0 N–P–K). Herbicides and insecticides were applied as needed in line with state guidelines (Lindsey et al., 2020). Prosaro (Bayer CropScience LP), prothioconazole [2-(2-[1-chlorocyclopropyl]−3-[2-chlorophenyl]−2-hydroxypropyl)−1,2-dihydro-3*H*-1,2,4-triazole-3-thione], and tebuconazole [α-(2-[4-chloropheny]ethyl)-alpha-(1, 1-dimethylethyl)−1*H*-1,2,4-triazole-1-ethanol] fungicide was applied at the Feekes 10.5 growth stage (50% of the heads completely emerged) at 8 oz acre^{-1} with a handheld carbon dioxide pressurized backpack sprayer. Plots were harvested in late June or early July, depending on the site-year, with a plot combine (Wintersteiger) equipped with a Harvest Master Classic GrainGage (Juniper Systems). Grain yield was adjusted to 13.5% moisture concentration.

TABLE 1 Pearson correlation coefficients (*r*) for stem count, fractional green canopy cover (FGCC), and normalized difference vegetation index (NDVI) measurements in winter malting barley at the Feekes 5 growth stage

	FGCC	NDVI
Stem count	.76	.74
	$p < .0001$	$p < .0001$
FGCC		.91
		$p < .0001$

2.3 | Measurements

In the spring, stem counts, FGCC, and NVDI measurements were collected on the same day at the Feekes 5 growth stage to ensure uniformity. As much as possible, measurements were collected on days with full sunlight in the early afternoon. Barley stem counts (main stem + tillers) were counted at the Feekes 5 growth stage, according to the methods developed by Goodwin et al. (2018). Stems were counted from a 12-inch length of row from three arbitrary selected locations within each plot and averaged. Stem counts were conducted before spring N fertilizer application. Fractional green canopy cover measurements were collected from three arbitrarily selected areas within each plot, approximately 3 ft above the plant canopy, to capture three rows of barley. Fractional green canopy cover was measured with the mobile phone application Canopeo (Oklahoma State University) (Goodwin et al., 2018; Patrignani & Ochsner, 2015). The stem count and FGCC measurements were collected from the same area within the plot, but with FGCC capturing a larger area (three rows of barley compared with one row of barley for manual stem counts). Normalized difference vegetation index measurements were taken with a handheld Greenseeker sensor (Trimble) at 3 ft above the barley canopy, walking the length of each plot twice per plot, similar to Goodwin et al. (2018).

Data were analyzed across all site-years with SAS Version 9.4 (SAS Institute, 2012). Proc Corr was used to determine the Pearson correlation coefficients for stem counts, NDVI, and FGCC. Proc Reg was used to analyze the linear and quadratic regressions to examine the relationships among NDVI, FGCC, stem counts, and yield. Prior to implementation of regression analysis, all associated statistical assumptions (e.g., linearity, homoscedasticity, etc.) were assessed and met. Significance was determined at $\alpha = .05$. The regression equations show the relationships among stem counts, NDVI, FGCC, and barley grain yield and are based on all measurements collected in the field (Table 1). Figure 1 to Figure 3 show the mean grain yield (and 95% confidence interval) for incremental ranges of stem counts, NDVI, and FGCC with the number of measurements shown under each respective range.

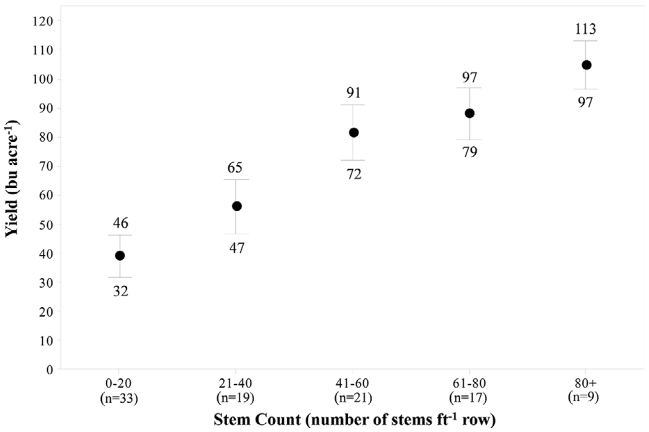

FIGURE 1 Winter malting barley grain yield based on the number of stems (main stem + tillers) ft^{-1} in a row. Closed circles represent the mean yield for each stem count range; the upper and lower bars represent the 95% confidence interval of the mean yield

This allows practitioners to easily see the mean grain yield and confidence interval associated with the stand assessment methods.

2.4 | Correlation between stand evaluation methods

All three winter malting barley stand evaluation methods were positively correlated with each other at the Feekes 5 growth stage (Table 1). Of these, NDVI and FGCC were most highly correlated ($r = .91$). This is consistent with studies conducted previously in winter wheat, where a high correlation ($r = .92$) between NDVI and FGCC was also detected (Lukina, Stone, & Raun, 1999). Fractional green canopy cover and NDVI both displayed a high correlation with barley stem counts ($r = .76$ and $r = .74$, respectively) (Table 1). Similar to winter malting barley, NDVI has also been found to be a predictor of tiller density in winter wheat (Goodwin et al., 2018; Phillips, Keahey, Warren, & Mullins, 2004).

2.5 | Relationship between stand assessment methods and yield

Stem count and FGCC measurements accounted for the most variability in winter malting barley grain yield, with R^2 values of .67 and .65, respectively, whereas NDVI accounted for the least variability in yield ($R^2 = .50$) (Table 2). Although stem count and FGCC measurements had similar R^2 values, FGCC is faster and requires less labor than stem count measurements (Goodwin et al., 2018). The Canopeo mobile phone application is free to download and easy to use, making it a cost- and time-effective option for estimating yield. However,

TABLE 2 Regression analysis for stand assessment methods and winter malting barley grain yield across five site-years and summary statistics for the independent variables (x) of stem count, fractional green canopy cover (FGCC), and normalized difference vegetation index (NDVI) measurements

Independent variable (x)	Equation	Adj R^2	p-value	Mean	Median	SE	Range
Stem count (per ft in a row)	$y^{a} = 0.83x + 34.08$	.67	<.0001	39	10	2.85	0–102
FGCC (%)	$y = -0.069x^2 + 4.42x + 26.89$	.65	<.0001	15	2.88	1.27	0.27–55.6
NDVI	$y = -666.05x^2 + 577.02x - 36.11$	.50	<.0001	0.30	0.18	0.01	0.12–0.60

[a]Winter malting barley grain yield (bu acre^{-1}): mean = 67, median = 67.4, SE = 2.9, and range = 12.5–115.2.

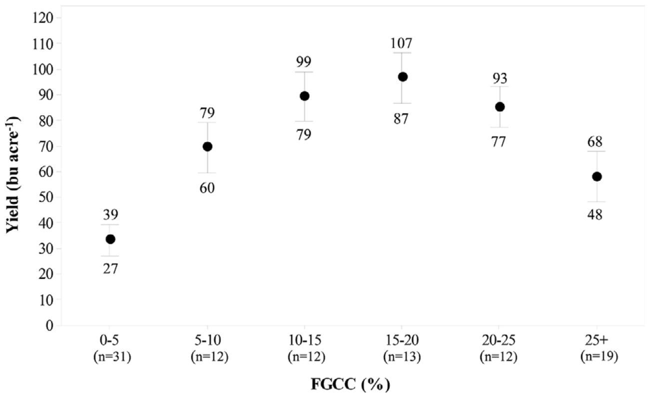

FIGURE 2 Winter malting barley grain yield based on fractional green canopy cover (FGCC) from three rows of barley at the Feekes 5 growth stage. Closed circles represent the mean yield for each FGCC range; the upper and lower bars represent the 95% confidence interval of the mean yield

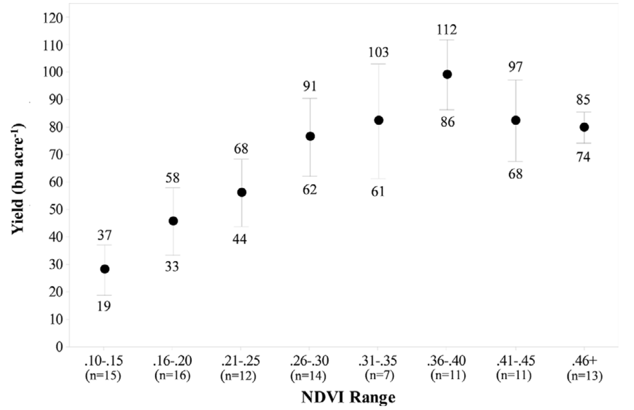

FIGURE 3 Winter malting barley grain yield based on normalized difference vegetation index (NDVI) values of barley at the Feekes 5 growth stage. Closed circles represent the mean yield for each NDVI range; the upper and lower bars represent the 95% confidence interval of the mean yield

both FGCC and NDVI measurements should only be used in a weed-free environment, as the Canopeo mobile phone application will include green weed biomass in the FGCC measurement.

In Figure 1 to Figure 3, we also show the stand assessment and grain yield data as mean grain yield (and 95% confidence intervals) for incremental ranges of stem counts, NDVI, and FGCC with the number of measurements shown under each respective range. Note that stem count ranges of 0 to 20, 21 to 40, 41 to 60, 61 to 80, and 80+ stems ft^{-1} row corresponded to grain yields of 32 to 46, 47 to 65, 72 to 91, 79 to 97, and 97 to 113 bu acre^{-1}, respectively (Figure 1). Based on these data, winter malting barley grain yield should not be extrapolated beyond 102 stems ft^{-1} row, as this was the greatest value measured in this study (Table 2).

With the Canopeo mobile phone application, FGCC ranges of 0 to 5, 5 to 10, 10 to 15, and 15 to 20% corresponded to grain yields of 27 to 39, 60 to 79, 79 to 99, and 87 to 107 bu acre^{-1}, respectively (Figure 2). Fractional green canopy cover values of >20% indicated a decrease in winter malting barley grain yield. Note that these high FGCC measurements do not necessarily correspond to a lower winter malting grain yield; rather, these are likely to indicate a limitation of the Canopeo mobile phone application to assess FGCC at high levels of plant biomass (Jáuregui, Delbino, Brance Bonvini, & Berhongaray, 2019). In five winter forage crop species, the Canopeo mobile phone application predicted canopy cover up to 80%, but at values of >80%, the area was saturated because of the increased plant biomass of grass shoots (Jáuregui et al., 2019). If the FGCC is >20%, stem count measurements should be used instead of FGCC.

Normalized difference vegetative index values of .10 to .15, .16 to .20, .21 to .25, .26 to .30, .31 to .35, and .36 to .40 corresponded to grain yields of 19 to 37, 33 to 58, 44 to 68, 62 to 91, 61 to 103, 86 to 112 bu acre^{-1}, respectively (Figure 3). Normalized difference vegetation values of >.40 indicated a decrease in grain yield. Similar to the inflection point seen in FGCC data, high NDVI values do not necessarily correspond to a lower winter malting barley grain yield but are likely to indicate a limitation of the NDVI assessment method. When the NDVI is >.40, it should not be used to assess barley stands because when the leaf area index is >3, there are only small increases in NDVI (Carlson & Ripley, 1997). In winter wheat, NDVI was also found to be a poor predicator at the Feekes 6 growth stage when the leaf area index was likely to be >3 (Goodwin et al., 2018).

2.6 | Management recommendations

Spring stand evaluation methods are an effective tool to estimate the yield potential of winter malting barley. Yield estimates in the early spring allow farmers to determine the feasibility of N and fungicide applications related to the crop's potential profitability. The Canopeo mobile phone application (used to measure FGCC) is an easy, cost-effective method compared with NDVI, which relies on specialized equipment. Stand evaluation methods can provide yield estimates for agronomic and management decisions. Barley grain yield ranges associated with the stand evaluation methods indicate the mean yield and 95% confidence interval (Figure 1– Figure 3). Although some of these ranges are wide, stand evaluation techniques can provide a reasonable assessment of yield potential compared with just visual inspection of the field. Ultimately, the decision to keep a barley field or plant to an alternative crop is up to the farmer, depending on the commodity prices and perceived risk. Our guidelines provide an additional tool to help farmers make that decision.

Maintaining a relatively weed-free environment and proper staging are important to assure consistent measurements of FGCC and NDVI. Furthermore, if yield-limiting conditions occur after stand assessment at the Feekes 5 growth stage, the yield may be lower than expected. For example, if there is dry weather during grain filling, yield could be reduced, even though there was an adequate number of stems at the Feekes 5 growth stage. In summary, FGCC and NDVI can provide a reliable method for providing easy and consistent results in yield assessment, reducing the potential error associated with manual stem counts and improving production through data-driven decision-making.

CONFLICT OF INTEREST

The authors declare no conflicts of interest.

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ORCID

Gregory J. McGlinch https://orcid.org/0000-0001-9902-5459
Laura E. Lindsey https://orcid.org/0000-0001-7026-0949

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