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RESEARCH LETTER

Post-harvest drone flights to measure weed growth and yield associations

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Abstract

Drone flights are often only performed during the growing season, with no data collected once harvest has been completed, although they could be used to measure winter annual weed growth. Using a drone mounted with a multispectral sensor, we flew small plot corn (*Zea mays* L.) fertility, cover crop, and population studies at black layer and 0–14 d after harvest (DAH). Yields had positive correlations to normalized difference vegetation index (NDVI) at black layer but often had negative correlations to corn yields 0–14 DAH. After harvest, NDVI could be associated with weed growth, and negative correlations to yield could point to reduced corn canopy allowing light to reach late-season weeds. In fertility studies, excess nitrogen appears to increase weed biomass after harvest, which can be easily identified through drone imagery. Flights should be performed after corn harvest as weed growth may provide additional insight into management decisions.

1 | INTRODUCTION

A principle of weed management is to prevent weed growth during the critical period of weed control (Gantoli et al., 2013; Lui et al., 2009), after which the crop canopy has developed enough to limit adequate sunlight for weed growth (Page et al., 2009; Tollenaar et al., 1994). Often overlooked in summer grain crops is the effect the crop canopy has on winter annual weed emergence. For instance, any factor (biotic or abiotic) that reduces shading or leaf area index (LAI) could result in the growth of weeds later in the season (Tollenaar et al., 1994). While winter annual weeds do not affect yields or harvest efficiency, they can compete with fall-planted crops or cover crops (Youngerman et al., 2018), and research beyond a growing season may uncover more of the dynamics of weed emergence and growth.

An effective way of measuring LAI and other plant characteristics is through drone imagery, which has already been used to predict corn (*Zea mays* L.) yield (Meresma et al., 2020), derive variable rate nitrogen (N) recommendations (Thompson & Puntel, 2020), and detect in-season weed growth (Singh et al., 2020). While many studies have measured in-season weed growth with drones, they may overlook post-harvest data collection, even though weed biomass can be physically measured in harvested fields (Youngerman et al., 2018). Drone flights performed after harvest would be useful to measure full-season efficacy of weed control, correlate late-season crop damage to weed presence, provide researchers with insights to factors that contribute to early establishment and growth of winter annual weeds, or for farmers to provide maps of winter annual weeds to help inform fall management of fields.

Abbreviations: DAH, days after harvest; LAI, leaf area index; NDVI, normalized difference vegetation index.

2 | MATERIALS AND METHODS

Corn research studies spanning a variety of agronomic research trials were flown during black layer (R6) and approximately 1–2 wk after harvest at the Carvel Research and Education Center in Georgetown, DE, during the 2018–2021 field seasons (Table 1). Although none of the studies were evaluating weed control tactics, herbicide use was uniform for all trials within a given year. Individual plot size was 3-m wide by 8-to-10-m long. In 2018, fields were flown with a Parrot Disco Pro Ag fixed wing drone equipped with a Parrot Sequoia multispectral camera. The 2019–2021 field trials were flown with a DJI Matrice V210 rotary drone equipped with a Micasense Altum multispectral sensor. All flights were performed at 76 m above ground level with 75% side and frontal overlap. Ground control points were georeferenced for each study using an EMLID Reach receiver and RTK correction through a base at the research station. Orthomosaics for each camera spectral band were stitched together with Pix4D software using the default multispectral camera settings. The Pix4D software was also used to produce normalized difference vegetation index (NDVI) mosaics of each field for analyses in ArcGIS software. Reflectance corrections were performed by Pix4D using a photograph of a Micasense calibration panel taken before every flight at each field location.

Plot borders were drawn using the AutoCAD Civil 3D array function described in Miller and Adkins (2020) and used to extract average NDVI values using the Zonal Statistics as Table tool in ArcGIS. Corn yields were measured by plot combine, adjusted to 15.5% moisture, and correlated to NDVI by Proc CORR in SAS statistical software.

After harvest in the 2020 cover crop termination study, weed biomass was collected using a 0.25-m^2 quadrat and dried to determine total biomass and any correlations to drone derived NDVI. In the other nine studies, variable winter weed growth was observed (not rated) across the study, but weed biomass was not recorded. Yield, weed biomass, and NDVI were tested for normality using Proc Univariate and then correlated with Spearman's rank using Proc Corr in SAS 9.4 software. Treatments in this study were evaluated with Proc Glimmix as a randomized complete block design with means separation using Tukey's test. Corn growing degree days were calculated from the closest Delaware Environmental Observing System (DEOS) weather stations.

Core Ideas

- Corn yields can be correlated to post-harvest weed biomass by using NDVI.
- Drone flights efficiently mapped weeds and made correlations to yield and management.
- Fall weed control can be prioritized using drone mapping.

3 | RESULTS AND DISCUSSION

All of the studies presented here had positive relationships between corn yield and NDVI values collected at black layer (R6) stage, with Spearman correlation coefficients ranging from 0.46 to 0.87 (Table 2), similar to previously reported studies (Maresma et al., 2020; Thomason et al., 2007; Tagarakis & Ketterings, 2017).

When flights were performed shortly after harvest (0–14 d after harvest [DAH]), we observed that the relationship between yield and plot NDVI was often reversed (Table 2). Of the 10 site years presented in Table 2, 7 had negative relationships between yield and NDVI post-harvest. As NDVI is measuring LAI or greenness, this could represent weed

TABLE 1 Characteristics of each corn research study

Study	Research question	Year	Soil type[a]	Hybrid	Planting date	Harvest date
1	Potassium	2020	PLS	Axis 62A28RIB	14 May 2020	5 Oct. 2020
2	Poultry litter rates	2021	PLS	DKC 62-08RIB	14 May 2021	7 Oct. 2021
3	N rate	2021	PLS	H6219RCSS	20 May 2021	8 Oct. 2021
4	N rate II	2021	HLS/RLS	64B28RIB	30 Apr. 2021	14 Sept. 2021
5	Corn population	2021	HLS/RLS	64B28RIB	30 Apr. 2021	14 Sept. 2021
6	Cover crop termination	2019	RLS	Hubner 6429RCSS	2 May 2019	10 Sept. 2019
7	Cover crop termination	2020	RLS	Axis 62A28RIB	22 Apr. 2020	28 Sept. 2020
8	Cover crop termination	2021	RLS	Pioneer1506AM	27 Apr. 2021	14 Sept. 2021
9	Rye +/− N rate	2018	RLS	DynaGro D48SS38RIB	1 June 2018	4 Oct. 2018
10	Clover +/− N rate	2021	RLS	Pioneer1506AM	28 Apr. 2021	27 Sept. 2021

[a]PLS = Pepperbox loamy sand (loamy, mixed, semiactive, mesic Aquic Arenic Paleudults), HLS = Henlopen loamy sand (sandy, siliceous, mesic Lamellic Paleudults), RLS = Rosedale loamy sand (loamy, siliceous, semiactive, mesic Arenic Hapludults).

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TABLE 2 Growing degree days (GDD), days after harvest (DAH), and Spearman rank correlation coefficients (*r*) for yield vs. normalized difference vegetation index (NDVI) at black layer and after corn harvest

Study	Yield vs. black layer NDVI			Yield vs. post-harvest NDVI		
	GDD	Pr < *r*	*p* value	DAH	Pr < *r*	*p* value
				d		
1	2,674	.57	.0006	9	−.33	.0612
2	2,579	.57	.0001	12	.38	.0242
3	2,525	.61	.0001	11	.70	.0002
4	2,771	.87	.0003	10	.01	.9799
5	2,354	.72	.0004	15	−.50	.0235
6	2,869	.71	.0026	13	−.39	.027
7	2,718	.51	.0084	3	−.64	.0001
8	2,846	.46	.0022	5	−.52	.0027
9	2,293	.53	.0001	0	−.29	.0014
10	2,822	.66	.0001	2	−.59	.0001

TABLE 3 Normalized difference vegetation index (NDVI) (black layer and post-harvest) and weed biomass estimates from Study 7 (cover crop–termination timing)

Cover crop–termination timing	Black layer NDVI	Post-harvest NDVI	Post-harvest weed biomass[a] kg
None–early	0.894 bc[c]	0.263 a	75.0
None–late	0.890 c	0.243 a	60.9
Rye–early	0.897 abc	0.182 b	–[b]
Rye–late	0.910 a	0.173 b	–
Rye/vetch–early	0.896 bc	0.202 b	17.3
Rye/vetch–late	0.900 abc	0.165 b	–
Rye/clover–early	0.901 abc	0.169 b	–
Rye/clover–late	0.904 ab	0.165 b	–
p value	0.10	0.06	

[a]Total kg weed biomass from all treatment plots estimated from 0.25-m^2 quadrat samples.
[b]No weight indicates plot weed growth below visual detection.
[c]Values followed by different letters within a column are significant at $\alpha = 0.1$

growth with an inverse relationship to yields (Gantoli et al., 2013; Page et al, 2012). While weeds can be the cause of decreased yields (Ghosheh et al., 1996), it is also likely that reduced canopy shading (caused by other biotic or abiotic factors) allowed for more late-season weeds to proliferate (Tollenaar et al., 1994).

An example of a negative relationship between yield and post-harvest NDVI can be observed in Study 7, where corn was grown in plots with and without cover crops (Table 3). The corn NDVI at black layer was significantly higher in the late-terminated (at-planting) cover crop plots (0.910) and lowest in the late-terminated no-cover plots (0.890). This relationship was reversed after harvest, where no-cover plots had the significantly higher NDVI (0.243–0.265) compared with any plots with cover crops (0.165–0.202). Besides an early-terminated rye (*Secale cereale* L.)/hairy vetch (*Vicia villosa* Roth) plot, only the no-cover plots had any measurable weed biomass (Table 3), which coincided with the higher NDVI measurements (0.202). The lower NDVI measured at black layer in the no-cover crop plots may indicate canopy shading that allowed for weeds germination prior to harvest (Tollenaar et al., 1994).

The remaining three studies were either not significant or had positive relationships between post-harvest NDVI and yield, which includes the N rate studies, Studies 2, 3, and 4 (Table 2). For the two studies that had positive relationships between yield and post-harvest NDVI, the excessive N rates probably provided winter annual weeds with the fertility necessary to proliferate (Blackshaw et al., 2017; Gholamohosenini et al., 2013). Results from increasing manure application rates (Study 2) resulted in greater visually observed weed growth between the rows, leading to higher NDVI post-harvest, which resembled a fertilizer response curve (Figure 1).

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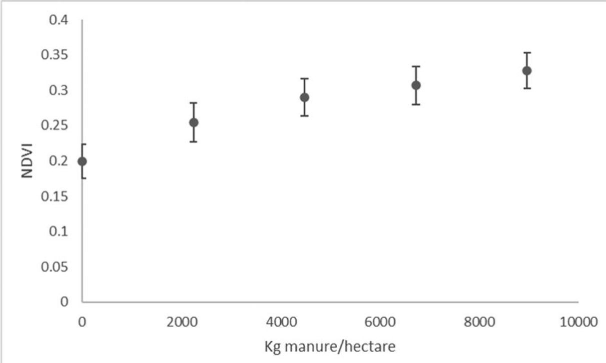

FIGURE 1 Post-harvest normalized difference vegetation index (NDVI) measurements of manure rate treatments (kg manure ha^{-1}) with visual weed growth

All of the studies presented here had different goals, which affected late-season and post-harvest weed growth, and this could successfully be measured by drone imagery.

4 | CONCLUSIONS

Drones are used to measure crop growth from emergence through reproductive stages, but flights often end with harvest. An additional flight following harvest may reveal additional information on weed growth patterns and factors that either increased weed growth (excess fertility) or allowed them to grow unimpeded (reduced canopy shading). In either case, this does not necessarily mean that the weed growth reduced potential corn yield, as most weeds were winter annuals and their biomass was fairly low, but this is still valuable information for fall weed management decisions. Pairing drone flights with in-season data and projects designed to measure the effects of management practices on shading, weed production, or crop stresses may benefit from post-harvest flights.

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AUTHOR CONTRIBUTIONS

Jarrod O. Miller: Conceptualization; Data curation; Formal analysis; Funding acquisition; Investigation; Methodology; Project administration; Software; Writing – original draft; Writing – review & editing. Amy L. Shober: Funding acquisition; Resources; Writing – original draft. Mark J. VanGessel: Methodology; Supervision; Writing – review & editing.

CONFLICT OF INTEREST

The authors declare no conflict of interest.

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