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Research Article

Assessment of Corn (*Zea mays*) Emergence using High-Resolution Spatial UAV-Based Remote Sensing

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Abstract

Timing and uniformity of seedling emergence can affect corn growth and development through interplant competition. Assessing uniformity of emergence can be time consuming when done visually by researchers. Research was conducted to compare accuracy of a UAV platform used to estimate corn stand within the first five days of emergence compared with hand counting emerged seedlings. Analysis of UAV-derived estimates of emergence fit a linear regression model for seedlings emerging one (R = 0.45) and two (R = 0.75) days after the first seedlings were observed in a trial with multiple corn hybrids across multiple locations. By days 3 and 4 after initial seedling emergence, virtually all seedlings had emerged and no further improvements in the relationships between UAV vs hand counted measurements were found. These data suggest that UAV-derived data can be used to determine the uniformity of emergence of corn in a manner similar to collecting data using the traditional method of hand counting but with less time and therefore increases the likelihood that this important measurement for hybrid comparisons will be used.

Introduction

Variability in plant emergence can alter plant height, leaf area index, dry matter accumulation, and grain yield of corn *(Zea mays* L.*)* [1-5]. Heiniger & Boerema [6] reported that corn yield increased when plants emerge uniformly and grows rapidly from emergence to the growth stage vegetative V6 [7]. Defining uniformity of emergence of corn hybrids is an important characteristic measured in the North Carolina Official Variety Testing (NCOVT) [8]. Emergence uniformity analysis of popular corn varieties is essential to the identification and production of higher vigor, higher yielding corn hybrids. Along with uniformity of emergence and ear height the NCOVT program uses test weight, resistance to pests, and grain yield to recommend corn hybrids for farmers in North Carolina [8]. However, measuring uniformity of emergence requires multiple observations in a timely manner early in the season across multiple locations to develop an adequate database for these recommendations. A more efficient method of collecting uniformity of emergence is needed. Aerial imaging using UAVs has the potential to make data collection of corn emergence uniformity more efficient. In this paper, we present information on the reliability of using imaging collected by a UAV in corn emergence uniformity compared with manual collection of corn emergence.

Materials and Methods

The experiment was conducted at four locations over two years in North Carolina to determine accuracy of measuring the uniformity of corn emergence using an unmanned aerial vehicle (UAV) platform compared with manual data collection. The data we report here are part of a larger data set evaluating agronomic performance of the following corn hybrids: AgVenture '8915', AgVenture '9583', Augusta '4565', DeKalb 'DKC 64-35', DeKalb 'DKC 67-44', Dynagro '57RR51', Pioneer '1442', and Pioneer '1870'. In 2018, experiments were conducted on a farm in Camden County and the Tidewater Research Station in Washington County. In 2019, these experiments were conducted on Haslin Farm in Beaufort County and Gray Farms in Pasquotank County. The locations at the Tidewater Research Station and Beaufort County had similar soil types, Portsmouth silt loam, and used conventional tillage. Likewise, the locations in Camden and Pasquotank Counties were both on a Roanoke silt loam using conventional tillage. The experimental design for this study was a split plot with three replications.

Main Plot- Sampling Period (First four days after initial emergence)

Split Plot – Eight Hybrids: Pioneer 1442; Pioneer 1870; DKC 64-35; DKC 67-44; DG 57RR51; AV 9583; AV 8915; Augusta 4565

Individual plots were 4 rows wide (76-cm spacing) by 9.1 m long. Planting was done in Camden County on 17 Apr, at the Tidewater Research Station on 30 Apr, at the Haslin Farm on 2 May, and at the Gray Farm on 18 Apr. The seeding rate used at all four locations was 81 510 seeds ha-1. Standard fertility and preemergence weed control practices were used. Over the first four days after corn spikes were initially observed in growth stage vegetative emergence (VE) from the soil a DJI Matrice M210 UAV using a Real-Time Kematic Global Positioning System (RTK-GPS) (Dà-Jiāng Innovations, Shenzhen, China) was flown at a height of 30 m. The UAV was equipped with a Zenmuse X5S and X4S RGB sensor (Dà-Jiāng Innovations, Shenzhen, China) and a Sequoia Multispectral sensor (MicaSense Inc, Seattle, WA). The DJI Matrice M210 RTK produced around 400 photos per flight. On each flight, images were captured using Pix 4D Capture (Pix 4D S.A, Lousanne, Switzerland) with 70% forward and 60% horizontal overlapping. Each UAV campaign took about fifteen minutes to fly. Immediately after the UAV flight, emerged spikes in a 4.6-m section of one of the center rows of the four-row plots were marked manually with color-coded golf tees, coded to the specific day of emergence. This procedure was repeated every 24 hours. The number of plants in each plot on the first day of spike emergence and the ensuing spikes observed emerging 24, 48 and 72 hrs later were totaled and the spikes from each day were divided by a total stand count, to determine a fraction of emergence variable (FE).

Output photos from the red-edge and RGB images from each flight were processed and stitched together to create an orthomosaic image layer using photo stitching software, Pix 4D Mapper (Pix 4D S.A, Lousanne, Switzerland). Within Pix 4D a point cloud, orthomosaic image (.tif file) and a 3D model of the field were created for each flight. Orthomosaic TIFF files were uploaded to Arc GIS Pro (Environmental Systems Research Institute, Redlands, CA). Within Arc GIS, an image classification tool was used to identify pixel groupings of corresponding values to the identified emerging corn spikes using the golf tees as identification markers. The pixel groupings were counted and recorded counts were output to a Microsoft Excel table for each day and location and uploaded to SAS (SAS Inst., Cary, NC.) for comparison to manual counts. A simple linear regression in SAS was used to compare manual and orthomosaic emerged corn spike counts. To illustrate the value of measuring the uniformity of corn emergence in identifying differences in seedling vigor, the GLIMMIX procedure in SAS (SAS Institute, Cary, NC) was used to determine significant differences in first day fractional emergence and grain yield among the eight corn hybrids used in this experiment.

Results and Discussion

Corn spike first-emergence varied by location from 4 days after planting (DAP) to 10 DAP (data not shown). The Matrice 210 RTK equipped with the Zenmuse X5S flown at a height of 30 m resulted in an image width and height of 5280 pixels (px) and 3956 px, respectively. Ground sampling distance (GSD) represents the distance between centers of adjacent pixels within a photo. The minimum GSD acquired was 0.66 cm/pixel. Photos from the drone were occasionally confounded, mostly because of wind and gimbal image stabilization, resulting in Pix-4D stitching errors or distortions in the resulting orthomosaic .tif file. Stitching errors were sometimes caused by Pix 4D's inability to stitch photos from a low altitude with minimal ground control points (GCP), which are standard issues found in all UAV data collection. This occasionally resulted in the inability to measure seedling counts in some of the hybrid plots within each of the field trials. Overall, Pix4D was sufficient in producing point clouds and orthomosaics on standard, push-button settings.

Corn emergence measured using orthomosaic imaging on the first day of emergence was positively correlated to the hand counts ($p < 0.05$, R = 0.45) (Figure 1). Unfortunately, this relationship was weak ($R^2 = 0.2$). The very limited leaf exposure of emerging corn spikes made it difficult to identify emerging spikes in either the RGB or red-edge images. This resulted in an undercounting of emerged seedlings and relatively weak relationships between hand counted and image-measured data.

By day 2, the emerged spikes had 24 h to emerge and grow which created a difference in plant size, so the sensors were able to capture plants that should have been counted on day 1 but were too small within the individual images or became large enough to get a sufficient pixel value average overall within the orthomosaic image classification procedure. When comparing plant counts from imaging with observed spikes, a positive correlation between the orthomosaic estimates of corn emergence versus hand counting of seedling emergence was observed ($p < 0.05$, R = 0.75) (Figure 2). Using UAV images to count corn seedlings on the second day of emergence resulted in a much stronger relationship between counts using orthomosaic images and those made by hand. While there was evidence of both undercounting and overcounting the overall trend was close to the 1:1 line representing perfect accuracy.

Surprisingly, at three and four days after initial emergence of seedlings, orthomosaic estimates of corn emergence versus hand counting of seedling emergence did not improve the relationship found on day two of emergence. In fact, when only the newly emerged plants were measured on days 3 and 4, the correlations between counts taken using orthomosaic images and hand counts were not significant ($p > 0.05$, R = 0.01 and 0.07, respectively.) This was due to the fact that there were very few plants emerging on days three and four and these plants were difficult to identify with orhomosaic imagery due to interference from previously emerged seedlings. These results suggest that UAV forthomosaic imagery is time sensitive and that imagery taken on the first two days of corn emergence is essential in order to make accurate comparisons and assumptions about uniformity in corn emergence.

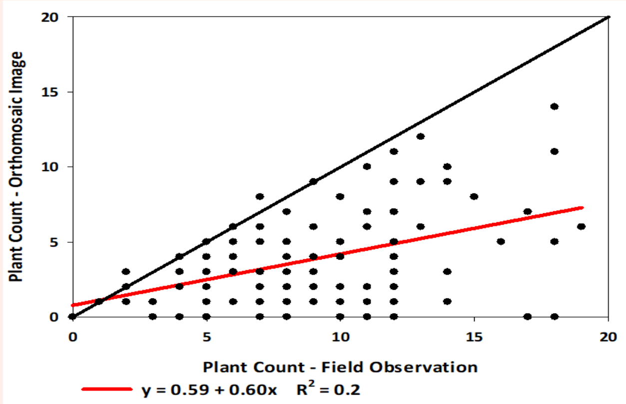

Figure 1: Comparison of seedling counts measured on the first day of observed emergence between field (hand) counts and counts estimated using orthmosaic imagery.

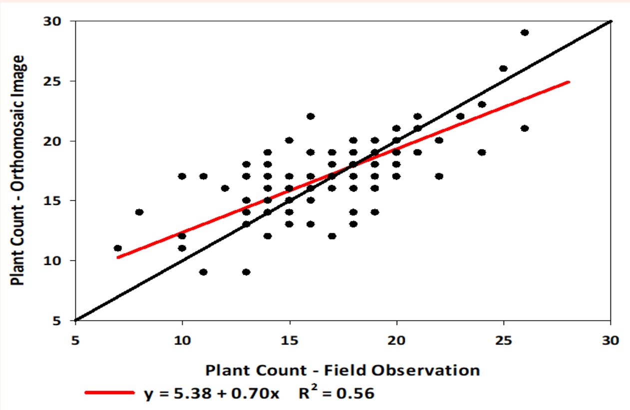

Figure 2: Comparison of seedling counts measured on the second day of observed emergence between field (hand) counts and counts estimated using orthmosaic imagery.

The importance of measuring uniformity of corn emergence is demonstrated by considering the relationship between uniformity of emergence and grain yield. Statistical analysis found significant differences in both first day fractional emergence and grain yield among the eight corn hybrids used in this study (Figure 3). DeKalb DKC 64-35, DKC 67-44, and Pioneer 1847 had significantly greater first day fractional emergence compared to the other hybrids tested. Two of these hybrids, DeKalb DKC64-35 and DKC67-44 had significantly greater grain yield compared to the remaining hybrids. While grain yield from Pioneer 1847 was not significantly greater than the remaining three hybrids, it was numerically greater.

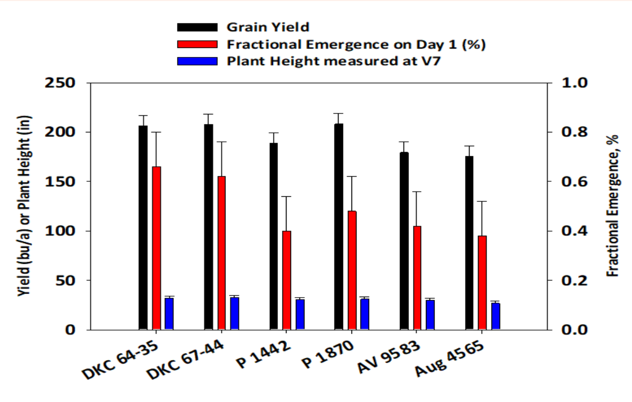

Figure 3: Differences in first day fractional emergence measured by hand counts, plant height at V7, and grain yield among eight hybrids tested in this study. Error bars for first day fractional emergence show a difference of 0.14 % and those for grain yield a difference of 10.6 bushel per acre at an LSD of p <= 0.05.

Conclusion

The time taken to walk and manually count each field was significantly greater than the time taken for UAV flight and subsequent data analysis. Averaged across the four site-years the time taken to walk and count each sample plot for each time and location was around one and a half hours.. The time taken for data collection via UAV averaged eight minutes. During peak planting time, it can be difficult to dedicate time to walking each field. The time savings for data collection via UAV l can significantly streamline data collection. Not only can UAV-based emergence data collection save time, once the flight is complete and the photos are backed up to an external hard drive (which is done automatically for most flights) then the photos can be compiled at a later date. That data can be analyzed and reviewed at any time, which can free up researchers from pen-and-paper emergence data collection that would otherwise have to be collected immediately following planting.

This study shows that to accurately measure small emerging seedlings it is critical to use stitching software with the ability to merge images with minimal ground control points and the importance of high-resolution images with very small ground sampling distances. It is also critical to capture images within the first two days after initial emergence to achieve accurate counts. Currently, UAV corn emergence data collection early vegetative stages is worthwhile but can be difficult due achieve due to factors including plant size, sensor limitations, weather conditions including cloud cover, UAV flight campaign height, data processing, and UAV battery limitations. None-the-less, our results provide data supporting use of UAV platforms for early emergence data collection to increase efficiency of research.

Given the relationships between uniformity in corn emergence and grain yield (Figure 3) it is important to learn more about the role of genetics in early, uniform emergence. The goal for this research was to develop a method for measuring the uniformity of corn emergence on hundreds of corn hybrids at all eleven North Carolina Official Variety Testing locations. Work is underway to automate image analysis and plant recognition using neural networks (Deep Learning) through MATLAB (MathWorks, Inc, Natick, MA) toolbox, which could automate counting via neural net as opposed to the limited and manual processes used in this study.

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