Computers and Electronics in Agriculture 124 (2016) 254–262

Contents lists available at ScienceDirect

Computers and Electronics in Agriculture

journal homepage: www.elsevier.com/locate/compag

Original papers

# Use of corn height measured with an acoustic sensor improves yield estimation with ground based active optical sensors

L.K. Sharma [a], H. Bu [b], D.W. Franzen [b,*], A. Denton [c]

[a] University of Maine, 57 Houlton Road, Presque Isle, ME 04769, United States
[b] North Dakota State University, Department 7180, PO Box 6050, Fargo, ND 58108, United States
[c] North Dakota State University, Computer Science Department, PO Box 6050, Fargo, ND 58108, United States

A R T I C L E  I N F O

*Article history:*
Received 9 March 2015
Received in revised form 12 April 2016
Accepted 20 April 2016

*Keywords:*
Corn height
Corn yield
Acoustic height sensor
Active-optical sensor
NDVI

A B S T R A C T

Corn height measured manually has shown promising results in improving the relationship between active-optical (AO) sensor readings and crop yield. Manual measurement of corn height is not practical in US commercial corn production, so an alternative automatic method must be found in order to capture the benefit of including canopy height into in-season yield estimates and from there into in-season nitrogen (N) fertilizer applications. One existing alternative to measure canopy height is an acoustic height sensor. A commercial acoustic height sensor was utilized in these experiments at two corn growth stages (V6 and V12) along with AO sensors. Eight corn N rate sites in North Dakota, USA, were used to compare the acoustic height sensor as a practical alternative to manual height measurements as an additional parameter to increase the relationship between AO sensor readings and corn yield. Six N treatments, 0, 45, 90, 134, 179, and 224 kg $ha^{-1}$, were applied before planting in a randomized complete block experimental design with four replications. Height measurement using the acoustic sensor provided an improved yield relationship compared to manual height at all locations. The level of improvement of the relationship between AO readings multiplied by acoustic sensor readings and yield was greater at V6 growth stage compared to the V12 growth stage. At V12, corn height measured manually and with the acoustic sensor multiplied by AO readings provided similar improvement to the relationship with yield compared to relating AO readings alone with yield at most locations. The acoustic height sensor may be useful in increasing the usefulness of AO sensor corn yield prediction algorithms for use in on-the-go in-season N application to corn particularly if the sensor height is normalized within site before combining multiple locations.



## 1. Introduction

Use of precision agricultural techniques by farmers and ag-industry farm input providers has increased steadily over the past twenty-five years Precision agricultural methods for soil sampling have the ability to improve delineation of nutrient management patterns as a basis for site-specific nutrient application (Sadler et al., 2000). Crop yield is affected by pest infestation, rainfall, soil properties, climate variations, crop stress and landscape topography (Raun et al., 2005), which vary spatially and temporally and complicate site-specific nutrient management due to small-scale variability. On-the-go active-optical (AO) sensor technology has been used to detect small-scale variability of crop N status within a field, sometimes at as small a scale as 1 $m^2$, enabling more efficient N fertilizer application to corn, wheat, cotton and sorghum (Gitelson and Merzlyak, 1997; Raun et al., 2001 and 2002; Kitchen, 2006; Holland and Schepers, 2010; Franzen et al., 2014).

Algorithms developed for the use with AO sensors in relating crop yield with sensor readings contain considerable error despite their value in improving small-scale site-specific N management. The measurement of crop growth in another manner at the time of AO sensor reading may provide an improved yield prediction algorithm. Measuring corn height corn might help detect yield differences due to water stress, evapotranspiration rate, and other crop stresses (Sammis et al., 1988) at a scale similar to that of AO sensors. Under optimum N availability conditions, corn plants grow to their full potential and reach a maximum height; however, if there is a stress due to suboptimal water supply or fertilizer deficiency, plant height will be reduced along with yield (Venuprasad et al., 2008; Li et al., 2013). Crop height as a single

* Corresponding author.
*E-mail addresses:* honggang.bu@ndsu.edu (H. Bu), david.franzen@ndsu.edu (D. W. Franzen), anne.denton@ndsu.edu (A. Denton).

http://dx.doi.org/10.1016/j.compag.2016.04.016
0168-1699/© 2016 Published by Elsevier B.V.

factor could be used to measure the vegetative growth and potential yield of corn. Corn plant height is a highly sensitive growth parameter and is influenced by soil water content (Hussain et al., 1999), texture (Kladivko et al., 1986), fertilizer rate (Kapusta et al., 1996), and cultivation methods (Kladivko et al., 1986; Sharma and Franzen, 2014). Machado et al. (2002) found that corn height could explain 60% of yield variability.

Red NDVI (normalized differential vegetative index, [red − near infrared]/[red + near infrared]) reflectance is based on two-dimensional measurement of the plant canopy, and is most successfully utilized during early growth stages when leaves do not shade the inter-plant spaces completely. At later growth stages red NDVI readings fall into a narrow range from 0.85 to 0.95 and discrimination between weaker plants and healthier plants becomes impossible as leaves cover the soil surface regardless of plant health. This problem is called 'saturation' (Wilhelm et al., 2000; Haboudane et al., 2004; Sharma and Franzen, 2014). A weak relationship between red NDVI sensor readings and yield was found by Sharma and Franzen (2014) at the V12 stage of corn due to red NDVI saturation. Franzen et al. (2003), found improvement in estimation of sugar beet top leaf N concentration and dry matter content in Minnesota using the GreenSeeker® AO red NDVI readings at sugar beet harvest when optical sensor readings were multiplied by a manually obtained plant canopy height, which helped to overcome red NDVI saturation.

Manually measured corn height combined with AO sensors has improved the relationship between AO sensor readings and corn yield. Several studies have used corn height in addition to GreenSeeker® sensor readings to estimate yield (Sharma and Franzen, 2014; Freeman et al., 2007; Martin et al., 2012). In all of these studies, significant relationships were found between yield and AO sensor readings multiplied by corn height. Corn height alone has been used to estimate corn yield (Yin et al., 2011a,b; Machado et al., 2002; Katsvairo et al., 2003). Sharma and Franzen (2014) found that corn height can improve corn yield estimates and could be used along with AO sensor readings to improve the algorithms developed to direct in-season N rate application. Although including corn height may have the ability to improve AO sensor algorithms, manual measurement of plant height is highly labor intensive and impractical on a commercial scale.

Several nondestructive methods have been used to measure plant height, including image processing (Changgui and Wenyi, 2007), 3-D perspective view to measure tree height (Zhang and Huang, 2009), 3-D view with a 3 point correction (Han, 2011) and light detection and ranging (LIDAR) (Zhang and Grift, 2012). Using plant image for height measurement has been successfully tested by several researchers (Morden et al., 1997; Van Henten and Bontsema, 1995; Tarbell and Reid, 1991; Tarbell et al., 1991). Plant height could also be measured using high resolution ultrasound distance sensing of the crop canopy (Shrestha et al., 2002; Katsvairo et al., 2003) and stereo vision (Shrestha and Steward, 2001). Use of stereo vision is most applicable for small scale work in laboratories and greenhouses (Matsuura et al., 2001; Kanuma et al., 1998; Lines et al., 2001). In some studies, remote sensing techniques such as synthetic aperture radar (SAR) (Ulander et al., 1995; Dammert and Askne, 1998; Shimada et al., 2001) and airborne LIDAR (Nilsson, 1996; Magnussen et al., 1999; Persson et al., 2002; Kwak et al., 2007; Yamamoto et al., 2011) was used to measure the plant height. All of these techniques and instruments have been used effectively in the greenhouse or laboratory, but their practical application to use in the field is questionable.

In order to measure plant height at low cost in real-time and to incorporate plant height into AO sensor algorithms for use in in-season N management, the SenixView™ model TSPC-30S1-232 (Senix Corporation, Hinesburg, Vermont, USA) automated ultrasonic acoustic sensor was used at two different corn stages (V6 and V12). This study was conducted to compare the use of corn height measured with the acoustic sensor with corn height measured manually to determine if sensor height measurements combined with AO sensor readings are similarly related to corn yield as previous studies indicate using manually measured corn height combined with AO sensor.

## 2. Materials and methods

### 2.1. Research sites and soil analysis

Eight experimental sites were established on farm fields in 2013 in eastern and western North Dakota, USA. At each location, eight soil sample cores were taken before planting and N application using a 2.5-cm diameter hand probe. Soil cores were obtained to a depth of 0–15 cm for analysis of nitrate-nitrogen (N), phosphorous (P), potassium (K), zinc (Zn), organic matter, and pH. A 0–60 cm soil core depth was taken for residual soil nitrate-N analysis (Table 1). For preplant soil test analysis, soil samples were air-dried after they collected from the research site, ground to pass through a 2 mm screen, and thoroughly mixed. Nitrate-N was analyzed using cadmium reduction described by Gelderman and Beegle (1998). Plant available phosphorus was analyzed using

**Table 1**
Preplant soil analysis for the eight experimental sites.

| Location | Depth cm | Nitrate-N (kg ha$^{-1}$) | P (mg kg$^{-1}$) | K (mg kg$^{-1}$) | Zn (mg kg$^{-1}$) | Organic matter (g kg$^{-1}$) | pH |
|---|---|---|---|---|---|---|---|
| Arthur | 0–15 | 5 | 9 | 110 | 1.16 | 22 | 6.6 |
| | 0–60 | 12 | | | | | |
| Beach | 0–15 | 17 | 22 | 300 | 0.85 | 30 | 6.2 |
| | 0–60 | 7 | | | | | |
| Durbin | 0–15 | 5 | 34 | 460 | 0.62 | 59 | 7.5 |
| | 0–60 | 45 | | | | | |
| Jamestown | 0–15 | 10 | 8 | 220 | 1.14 | 33 | 5.7 |
| | 0–60 | 12 | | | | | |
| Mott | 0–15 | 18 | 4 | 230 | 0.95 | 52 | 7.6 |
| | 0–60 | 10 | | | | | |
| New Leipzig | 0–15 | 24 | 16 | 560 | 1.46 | 52 | 5.6 |
| | 0–60 | 18 | | | | | |
| Richardton | 0–15 | 11 | 33 | 170 | 0.65 | 32 | 5.1 |
| | 0–60 | 8 | | | | | |
| Rutland | 0–15 | 20 | 8 | 415 | 0.72 | 61 | 7.0 |
| | 0–60 | 54 | | | | | |