IN-FIELD TESTING OF NEW LOW-COST MULTISPECTRAL SENSOR FOR ASSESSING MAIZE YIELD POTENTIAL

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ABSTRACT

Active proximal sensing has been increasingly used to provide information about canopy properties in a large range of crops. In this study a low cost, active multispectral optical device named Plant-O-Meter (POM) was tested in real conditions at two experimental fields comparing it with the GreenSeeker handheld device. Treatments included five nitrogen (N) fertilisation rates applied during sowing. Maize was scanned between V5 to V8 growth stages. The results showed that measuring with the POM sensor within this growth stage window can provide good estimation of end-of-season yield, comparable to the GreenSeeker. This indicates that Plant-O-Meter exhibits strong potential for accurate plant canopy measurements and for real time variable rate fertilisation applications in maize.

Keywords*:* proximal sensors, multispectral, crop sensing, yield estimation

1. INTRODUCTION

Optical sensors have become very popular for nitrogen status diagnostic. Simple handling make them suitable for a wide range of applications on different crops, and instant data can be collected following a non-destructive sampling method (Magney et al., 2016; Kostić et al, 2016). The results of numerous studies on optical sensors offer a vast number of models which could be used in the prediction of maize maturity, yield potential, plant health estimation, etc. (Zecha et al., 2018). Spectral analysis of reflected waves from plant canopy is valuable in the recognition of spectral "fingerprints", which help identify some biotic or abiotic processes that are otherwise undetectable by humans or machines. Active multispectral sensors show great potential for rapid spatial assessment of nitrogen (N) status of growing plants in early season providing adequate precondition for optimization of nitrogen management (Bean et al., 2018). In addition, such sensors are not being compromised by differences in illumination conditions, such as cloudiness, thus are ideal for on-the-go variable rate N applications (Solari et al., 2008). Therefore, active proximal sensing has been increasingly used in agriculture for assessing crop status and growth, and has proved to be promising approach for end-of-season yield estimation in a range of crops (Tagarakis and Ketterings, 2017). Active sensors emit and measure the reflectance of specific spectra of light, typically in the visible and the near-infrared, from the plant canopy providing a range of vegetation indices such as the Normalized Difference Vegetation Index (NDVI; Rouse et al., 1973). The NDVI is the most widely used index for deriving yield estimates (Hatfield et al., 2008), but other indices have also been used. It has also been related to nitrogen status, chlorophyll content, biomass, and leaf area, at micro and macro scale (Solari et al., 2008; Wang et al., 2016).

Yield estimation from mid-season spectral canopy measurements is of particular importance since it is the first step in the development of an algorithm for real-time variable rate N applications (Moges et al., 2007). The timing of sensing, in terms of growth stage, greatly impacts the accuracy of yield predictions from sensor data (Raun et al., 2005). Previous studies in maize defined V7 – V8 (7 – 8 fully developed leaves) as the growth stages that provide the highest accuracy of end-of-season yield estimation and V6 as the stage with the highest variability in NDVI measurements (Tagarakis and Ketterings, 2017; Raun et al., 2005), important elements for maximizing the benefit of variable rate fertilisation.

Raun et al. (2002) introduced the In Season Estimated Yield (INSEY) (Eq 1,2) as an approach that normalizes NDVI measurements across time and various environmental conditions (Teal et al., 2006), accounting for the growing conditions from planting to sensing and providing an estimate of the N uptake per day (Lukina et al., 2001) and the biomass produced per day (Raun et al., 2005).

$$INSEY_{DAP} = NDVI / DAP \quad (1)$$

Where: $INSEY_{DAP}$ is the In Season Estimated Yield, NDVI is the Normalized Vegetation Index, DAP is the number of Days After Planting for days with GDD > 0, and GDD is defined as the growing degree days.

$$INSEY_{GDD} = NDVI / GDD \quad (2)$$

Where: $INSEY_{GDD}$ is the In Season Estimated Yield, NDVI is the Normalized Vegetation Index, and GDD is defined as the cumulative growing degree days from planting to sensing.

Teal et al. (2006) developed models to predict maize grain yield based on NDVI, $INSEY_{GDD}$, and $INSEY_{DAP}$ showing similarly good results (R^2 ranged from 0.73–0.77). In recent study conducted by Rogers (2016) good correlation was achieved between combined optical sensor readings, collected during two growing seasons at V6 to V8 growth stage, and final yield (R^2>0.68). Similarly good results were reported by Tagarakis and Ketterings (2017) who defined V7 as the growth stage that provides the most accurate estimation of end-of-season yield for grain maize in New York (R^2 = 0.78).

Most active proximal sensors vary in central wavelengths or bandwidths for calculating NDVI (Kim et al., 2010; Yao et al., 2013). Therefore, this study has been conducted to evaluate the performance of the recently developed active multispectral proximal sensor Plant-O-Meter in real field conditions, and compare it with the GreenSeeker handheld which is a widely accepted sensor. The main objectives of this study were to: (1) define the relationship between the NDVI measurements derived from the two sensors, (2) determine the specific growth stage at which the sensors provide more reliable end-of-season yield estimation under the specific climatic conditions in Vojvodina region, and (3) define the ability of Plant-O-Meter to estimate end-of-season yield from mid-season canopy measurements as compared with the GreenSeeker handheld sensor device.

2. MATERIALS AND METHODS

<u>Field trials and experimental design</u>

The present study was carried out at two experimental fields in Bajmok and Ravno Selo, located respectively in northern and central Vojvodina region in Serbia. Three maize hybrids (Zea mays L.) of different maturity classes and length of vegetation period were sown, namely P9537 (FAO 340), P9911 (FAO 450) and P0412 (FAO 530). The fields were sown at 70 cm inter-row spacing and 20 cm spacing between plants in the row. The study included five different N treatments (0, 50, 100, 150 and 200 kg N ha^{-1}) applied pre-plant by incorporating granular urea (46% N). The experiment was conducted following randomized complete block design (RCBD) with three replications. Each plot contained four rows of maize; the central part, 6m long, of the two middle rows was measured while the side rows served as guard rows.

Sensor measurements and sensor description

Two active proximal sensors were used to measure NDVI at V5, V6 and V8 growth stages of maize; the GreenSeeker handheld (Trimble Inc., CA, USA) and a recently developed active multispectral optical sensor named Plant-O-Meter (POM) (BioSense Institute, Serbia).

GreenSeeker is an active hand-held sensor, which emits light and measures the reflectance at 660 nm (R) and 770 nm (NIR) calculating the NDVI (Tremblay et al., 2009). In-field reflectance measurements were taken by holding the GreenSeeker sensor approximately 60 cm above the crop canopy, with the sensing footprint perpendicular to the row direction, manually recording four average measurements from the measuring area in each plot.

Plant-O-Meter senses at four bands (Blue, Green, Red and Infrared) and provides the reflectance separately for each band providing the ability to calculate more than 20 different indices. It connects to any Android device and uses its processing and storing capacity for data logging and processing. In addition, it uses the device's GNSS antenna to georeference the measurements. In-field reflectance measurements were taken by holding the Plant-O-Meter approximately 60 cm above the crop canopy, with the sensing footprint perpendicular to the row direction and scanning the whole length of the two middle rows in continuous mode at frequency of 1Hz. The central part, (6 m) of each measured row (2 middle rows per plot), was selected after processing the data using GIS software (QGIS Development Team, 2018). The NDVI measurements with both instruments were made close to noon, between 11:00 a.m. and 1:00 p.m.

Harvest

At the stage of full maturity, the plants from the central part, 6 m long, of the two middle rows in each plot were hand-harvested by manually picking all developed ears and collecting in pre-labelled bags. The gross weight of each plot was measured and the content of each bag was shelled to calculate the net grain weight. A GAC® 2500-INTL Grain Analysis Computer (Dickey-John, IL, U.S.A.) was used to measure grain moisture content (MC) and the final yield was normalized at 14% MC.

Data analysis

In order to analyze the sensors' data, the measurements were transformed to $INSEY_{DAP}$ dividing the NDVI by the days after planting as recommended by previous studies (Tagarakis and Ketterings, 2017). Using INSEY adjusted the sensor measurements to the specific growing conditions of each field from planting until sensing. Regression analysis was used to define the relationship between the GreenSekeer and Plant-O-Meter NDVI measurements. In addition, linear regression models were used for the relationships between the INSEY and end-of-season yield for each growth stage.

3. Results and Discussion

Regression analysis between INSEY and end-of-season yield showed that for both sensors, good yield estimation can be achieved when scanning at V6 – V8 growth stages. This finding is in agreement with the results by Tagarakis and Keterings (2017) who defined V6 as the earliest growth stage for accurate yield estimations. The most accurate estimation of yield for both sensors was achieved at V8 growth stage consistent with the findings of previous studies (Teal et al., 2006). The coefficient of determination (R^2) was 0.8 and 0.75 for Plant-O-Meter and GreenSeeker respectively (Figure 1). In general, Plant-O-Meter seemed to provide better estimation of end-of-season yield for all three maize growth stages. However, this needs to be further investigated in various environmental and climatic conditions and at more detailed temporal resolution.

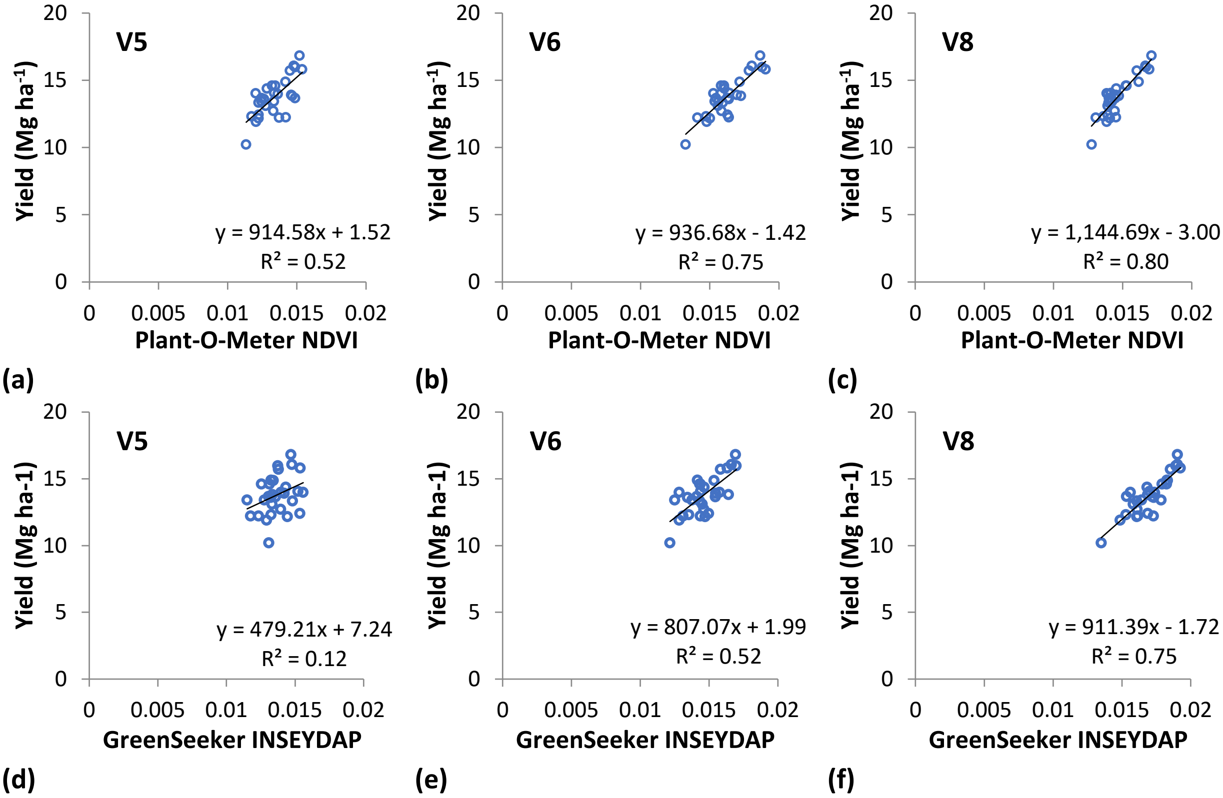

Figure 1. Relationship between end-of-season yield and In Season Estimated Yield (INSEYDAP) measured using the Plant-O-Meter at V5 (a), V6 (b) and V8 (c) maize growth stages and using the GreenSeeker at V5 (d), V6 (e) and V8 (f) maize growth stages.

Regression analysis was used for the comparison between the Plant-O-Meter and GreenSeeker sensors. Despite the fact that both Plant-O-Meter and GreenSeeker sensors measure canopy reflectance at different wavelengths, the results confirmed a strong relationship between the NDVI measurements from the two sensors (R^2 = 0.89), on overall basis (Figure 2). This result suggests that the Plant-O-Meter sensor shows good potential to be used for on-the-go variable rate applications as it performs similarly to the GreenSeeker in real field conditions.

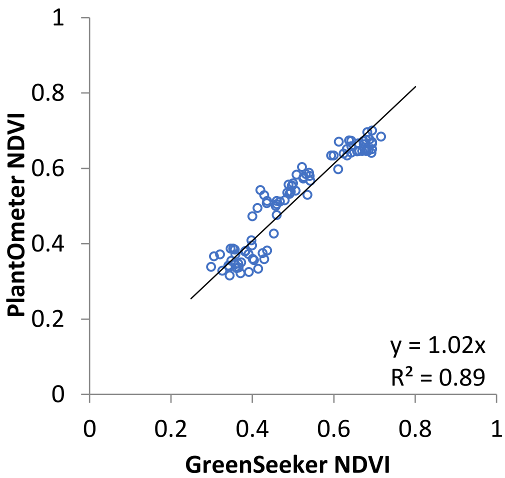

Figure 2. Relationship between NDVI measured using the Plant-O-Meter (y axis) and NDVI measured using the GreenSeeker (x axis)

This was the first trial for in-field testing of the Plant-O-Meter multispectral active proximal sensor. The results revealed its potential to estimate end-of-season yield form mid-season canopy measurements which is the first step in the development of an algorithm for variable rate nitrogen applications (Moges et al., 2007).

5. CONCLUSIONS

Based on the present findings reliable end-of-season yield estimation is attained measuring the mid-season NDVI between V7 and V8 stage. The overall results indicated that NDVI obtained using Green-Seeker was very similar to the NDVI measured by the Plant-O-Meter. In addition, both sensors provided good estimation of end-of-season yield at V8 growth stage of maize crop. The Plant-O-Meter provided slightly better estimation of end-of-season yield especially for the measurements performed earlier in the season (V5 and V6 stages). This result indicates that Plant-O-Meter exhibits good potential for accurate plant canopy measurements and for real time variable rate fertilisation applications in maize. Considering that the optimal stages for measuring NDVI depend on the environmental conditions, further studies in more diverse conditions are needed to test and evaluate Plant-O-Meter's performance. The final equation for end-of-season yield estimation using mid-season crop canopy measurements need to be finalized completing the first step for the development of an algorithm for real time VRN application. Furthermore, the low cost and the ease of use of the Plant-O-Meter sensor are expected to make it a reliable and affordable solution for small and medium size farmers in order to apply precision agriculture.

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