EARLY DETECTION OF CORN N-DEFICIENCY BY ACTIVE FLUORESCENCE SENSING IN MAIZE

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ABSTRACT

The detection of nitrogen deficiency at the beginning of the period of maximum nitrogen uptake by corn would allow precise adjustment of nitrogen fertilizer supply to the plant prior to the point when nitrogen deficiency yield damage cannot be recovered. Active reflectance sensors do not allow reliable nitrogen deficiency detection prior to V8 growth stage of corn. Induced fluorescence appears as an alternative signal for crop canopy sensing that could possibly detect corn nitrogen deficiency at earlier growth stages. Our objective was to verify if induced fluorescence can detect corn nitrogen deficiency prior to V8 growth stage. In this greenhouse experiment, an induced fluorescence sensor was used to detect nitrogen deficiency based on the nitrogen balance index. Four nitrogen treatments were tested (i.e. 0, 75, 150 and 225 kg N/ha equivalent). Induced fluorescence showed strong potential to detect nitrogen deficiency from V5 growth stage of corn based on nitrogen balance index measured with either red or blue light induction.

KEYWORDS: Fluorescence, remote sensing, nitrogen status, early growth stages

INTRODUCTION

The maximum nitrogen (N) uptake period of corn is from V6 to V8 growth stages to about V16 to V18 growth stages (Scharf et al. 2006). For practical reasons, farmers tend to start applying N fertilizer even before the beginning of the maximum N uptake period. When trying to apply site-specific N, the most common approach for in-season crop N-status detection is the use of canopy reflectance sensors. Studies have demonstrated that NDVI provides a poor correlation with yield prior to V8 growth stage of corn (Elwadie et al. 2005; Teal et al. 2006; Martin et al. 2007). An emerging approach for in-field detection of N deficiency in corn is the use of fluorosensors. Chappelle et al. (1984) observed significant difference in red and far-red fluorescence emission between corn plants with complete nutrient supply and corn plants with N-deficiency. A fluorescence based index called the nitrogen balance index was developed to detect N-deficiency by the ratio of far-red fluorescence induced by UV light flash on the red fluorescence induced by either red or green light (Cartelat et al. 2005).

The hypothesis of this study was that the fluorescence based nitrogen balance index has the potential to detect N-deficiency in corn earlier than at V8 growth stage. The specific objectives were (1) to determine if induced fluorescence sensing can detect differences in corn plants treated with four different N rates and (2) to determine which fluorescence parameter is more reliable for early detection of N-deficiency in corn plants.

MATERIALS AND METHODS

This experiment was conducted in a greenhouse at Colorado State University from October 2010 to December 2010. The soil used for this experiment was collected at Colorado State University's Agricultural Research Development and Education Center, located in Fort Collins, Colorado (40° 40' 38.24" N, 104° 58' 44.76" W). Corn (*Zea maize* L.) plants (variety DKC45-79) were grown with four nitrogen treatments: control (0 kg N/ha equivalent), low (75 kg N/ha equivalent), intermediate (150 kg N/ha equivalent) and high (225 kg N/ha equivalent). For each nitrogen rate, 20 pots were prepared, giving a total of 80 pots. Reagent grade fertilizer was added to each pot prior to planting. Nitrogen was added under the form of ammonium nitrate (NH_4NO_3) at the rate of 0 mg/pot for "control" pots, 583 mg/pot for "low" N pots, 1167 mg/pot for "intermediate" N pots and 1750 mg/pot for "high" N pots. For each of the eighty pots, 2899 mg of potassium phosphate (KH_2PO_4) and 53 mg of zinc sulfate ($ZnSO_4$) were added. Five seeds were laid in place in a cross pattern. Water was sufficiently supplied by drip irrigation.

The sensor used for this study was the Mutiplex®3 (FORCE-A, Orsay, France) hand-held multi-parameter optical fluorescence sensor. The sensing area is about 10 cm in diameter. The Multiplex®3 was set to make an average over 500 induction/detection cycles for each reading. The four induction channels are UV, blue, green and red and the three detection channels are yellow (YF), red (RF) and far-red (FRF). The flash induces the emission of fluorescence and filters allow the selection of the wavebands of interest. The Multiplex®3 automatically

computes two nitrogen balance indexes (NBI), the green NBI (NBI_G) and the red NBI (NBI_R; Table 1).
Readings were acquired twice a week from V4 to V8 growth stage of corn. At tasseling, plants were cut, dried and weighted.

For each selected parameter and for each growth stage, an ANOVA was used to detect significant difference among fluorescence reading (*a*=0.05). In the case of significant difference, a Tukey's HSD test was used to compare treatments. The same analysis was done for corn plants dry weight. All statistical analysis was done using the statistical software R with the functions "aov" and "TukeyHSD" (R Development Core Team 2010).

Table 1. Parameters used for this study along with their description and formula.

Parameter	Description	Formula*
NBI_R	Nitrogen balance index (red)	$\frac{1}{500}\sum_{i=1}^{500} FRF_{UV_i}/RF_{\boldsymbol{R}_i}$
NBI_G	Nitrogen balance index (green)	$\frac{1}{500}\sum_{i=1}^{500} FRF_{UV_i}/RF_{\boldsymbol{G}_i}$

*Induction waveband is in subscript. UV=Ultra-violet; G=Green; R=Red; B=Blue.

RESULTS AND DISCUSSION

Dry biomass was significantly different from one N treatment to the other except for treatments 150 and 225 kg/ha (Fig. 1). This is typical of a normal crop response to nitrogen, showing an increase in biomass with increasing N rate until it reaches a plateau at N saturation (Shapiro and Wortmann 2006). Plants were thus considered suitable to conduct the experiment.

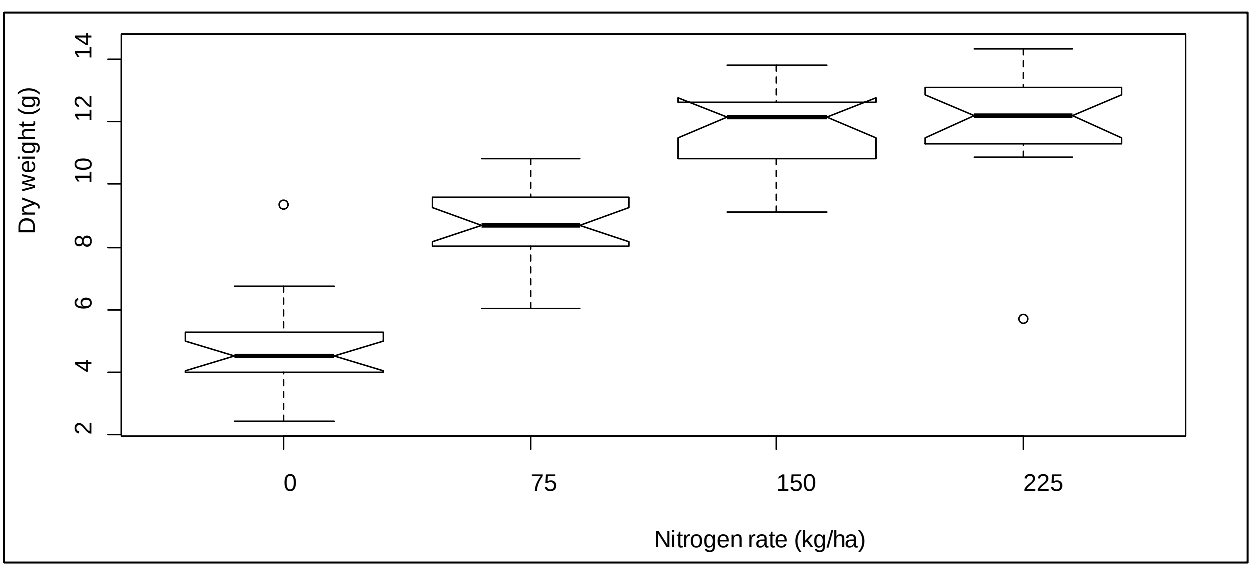

Fig. 1. Boxplots of the difference in dry weight of corn plants at tasseling for the four N rate treatments. Boxplots with notches that do not overlap are significantly different (α=0.05).

For both NBI_R and NBI_G, perfect distinction (all significantly different with α=0.05) among the N treatments was observed at V7 and V8 growth stage of corn (Fig. 2). Both NBI_R and NBI_G enabled the distinction between the lowest N rate (0 kg/ha) and the highest N rate (225 kg/ha) at all growth stage of corn of this experiment. Induced fluorescence, as measured by Mutiplex®3, enabled the detection of N deficiency prior to V8 growth stage of corn (Fig. 2). Previous studies have observed the potential of induced fluorescence to detect N deficiency but no mention was made about detection at early growth stages (Chappelle et al., 1984; Cartelat et al., 2005; Zhang & Tremblay, 2010).

The NBI_R performed slightly better than the NBI_G as is showed significant difference between 0 and 150 kg/ha at V5 while NBI_G did not (Fig. 2). Chlorophyll light absorption mainly in blue and red light green light reflection may potentially explain this phenomenon (Seely 1977). Blue and red light are highly absorbed at the surface of the leaf and thus induce fluorescence emission from the surface of the leaf while green light penetrates deeper in the leaf mesophyll and the red fluorescence emitted deeper in the leaf mesophyll may be re-absorbed upper in the mesophyll (Vogelmann and Evans 2002; Buschmann 2007).

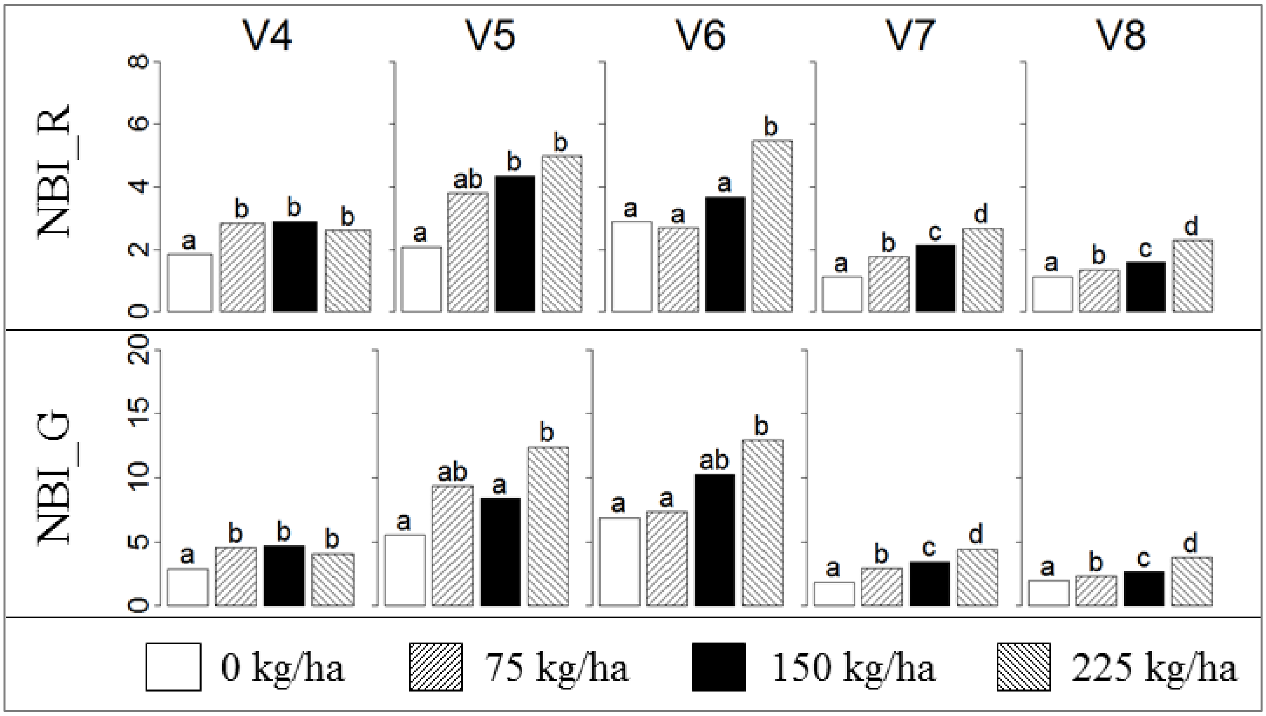

Fig. 2. Bar graphs of the average value of each parameter (mentioned on the left axis), for each growth stages from V4 to V8 (mentioned on the top of the figure) and for each nitrogen rate (legend at the bottom of the figure). Different letters indicate significant difference (α=0.05) within the same growth stage and the same fluorescence parameter.

CONCLUSION

Fluorescence and notably nitrogen balance index using red light induction offers a great potential for early detection of corn nitrogen deficiency. In field active fluorescence sensors thus appear as practical tools for farmers who desire to apply variable rates of N fertilizers across their field to increase their nitrogen use efficiency.

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