ACTIVE-CROP SENSOR CALIBRATION USING THE VIRTUAL-REFERENCE CONCEPT

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Introduction

Calibration of laboratory and field instruments usually involves collecting data from some type of accepted standard materials or compounds. This approach works well for most physical and chemical measurements; however, such procedures become problematic when dealing with biological systems like plants that go through a number of physiological states during the growing season. In addition, genetic composition differences between cultivars can affect the architecture of plant canopies and relative color of the leaves. While laboratory procedures can be used to quantify parameters like leaf nitrogen (N) concentration, interpreting such data for the purpose of making management decisions is difficult because of cultivar and growth stage differences. Other factors such as cropping history, previous manure applications, and cultural practices can also affect crop vigor and color. For these reasons, Peterson et al. (1993) utilized the findings of Schepers et al., (1992) and proposed normalizing Minolta SPAD meter readings to a reference situation that was know to have received modestly excessive amounts of N fertilizer. The reference crop needs to be managed the same as the rest of the field or other treatments except for having received enough N so that the crop is not N deficient. This field situation is sometimes referred to as being “N-rich”. During the normalization process, the SPAD meter readings from the plants in question are divided by the reading from the reference plants. The resulting quotient was originally termed the “Sufficiency Index (SI)”. The SI concept was the basis for the patent for making in-season N fertilizer recommendations that is exclusively licensed to LI-COR, Inc. (Biggs et al., 2002). Scientists at Oklahoma State University prefer to discuss in-season crop vigor measurements in terms of the potential for a yield response so they invert the SI value and call it a “Response Index”. It should be noted that the reason the N-rich reference concept works to normalize SPAD data is because a little extra N availability is not harmful to corn plants. At some point along the scale of N adequacy, another nutrient becomes limiting and subsequent N uptake amounts to “luxury consumption”. At this point, leaf chlorophyll status is maximized as recorded by SPAD meters.

Adapting the SI concept to commercial production practices might seem to be straight forward until one realizes that the concept was developed for research plots that were intentionally positioned on the landscape to minimize spatial variability. Extending the normalization concept to whole-field situations raises questions related to determining the appropriate reference value. If one assumes that additional N in selected areas of the field will remove the spatial variability in yield, then the task at hand would be to characterize an area with adequate N and use that SPAD value as the reference for the entire field. In practice, producers following this strategy typically install one or more N-rich strips in their fields to use as the reference. For convenience purposes and to simplify record keeping, producers would prefer to use the same area of the field as the N-rich reference year-after-year. However, using the same area of the field as the N-rich reference for a second year violates the premise that the reference should represent the nutrient status of the rest of the field in all respects except for having received additional N fertilizer. Therefore, it is imperative that the N-rich reference strips be moved to a new area each year.

Raun and colleagues (2005) observed spatial variability in plant vigor within N-rich strips in most wheat fields so they developed sprayer equipment to establish a grouping of nine N-rate plots (each 1 m^2) in a 3 x 3 configuration (referred to as postage-stamp plots) . This application device allowed them to readily place many mini-N rate plots within a field. However, they found the border effect between N-rate plots made it difficult to clearly identify the reference plot within the group of nine plots. They subsequently transformed the 3 x 3 grouping into a field strip with progressively higher or lower N rates (referred to as ramped calibration strips). Each subplot was typically ~16-m long so multiple ramps of nine N rates could be established within a field strip. They soon realized that soil properties frequently changed substantially within the distance of one complete ramp (perhaps 150-m total length). Scharf et al. (2006) modified the ramp concept by establishing a series of adjacent N-rate strips that were harvested with a combine fitted with yield monitoring equipment. The yield map was broken into 16-m long segments which allowed them to construct a series of N-response function along the length of the field strip. It should be noted that the yield values were subject to the uncertainties associated with yield maps and the series of N rates were only randomized between strips. Roberts et al. (2009) enlarged the postage-stamp concept so that subplots were the width of the planter by 16-m long to keep the N-rate subplots in close proximity (used either 2 x 2 or 3 x 3 groupings). This design addressed the need for randomization within a grouping and made it possible to evaluate the effect of soil properties on the shape of individual N-response functions. Hand harvesting of such studies provides excellent data, but the approach is quite laborious. Below and colleagues (personal communication, 2009) established multiple N-rate groupings in fields according to management zones throughout the Midwest and found the yield plateau and shape of the N-response function varied within a field and especially between fields.

The above observations indicate that the in-season vegetation index value (integration of chlorophyll status and the amount of biomass) of the “reference” plants probably needs to be determined by management zone rather than for an entire field. The goal of this research effort was to test and evaluate a method developed by Holland (2007) that was convenient, reliable, and dynamic to systematically determine the vegetation index value of reference plants without using an N-rich strip.

Materials and Methods

The first phase of this project was conducted on a field with a single soil type (Hord silt loam; fine-silty, mixed mesic Pachic Haplustolls) with 0-1% slope. The field was under linear-drive sprinkler irrigation with 8-row wide strips (0.91-cm spacing) planted to Pioneer brand P33D83 on 20 May, 2009 at a population of 74,000 plants/ha. These 400-m long strips had been planted to continuous corn since 1991 with five N rates (0, 50, 100, 150, and 200 kg N/ha) applied at planting. Other strips were in a corn/soybean rotation or in continuous with a base N rate of 150 kg/ha. Individual plots were each 16-m long and separated with a 1-m wide bare-soil alley. Each strip accommodated four replications of the randomized treatments. Two strips were involved in the study, thus providing eight replications.

At the V9 and V12 growth stages, two ACS-470 (Holland Scientific, Inc., Lincoln, NE) active sensors were mounted on a John Deere high-clearance sprayer. Sensors were positioned at least 60-cm above the tallest plants in rows three and six of the 8-row plots. These sensors were outfitted to record canopy reflectance in the red (670 nm), red edge (730 nm), and near infrared (NIR, >760 nm) wavebands at 5 Hz to correspond with GPS data collected at the same rate. Rate of travel through the field was ~4.5 km hr^{-1} (~1.25 m s^{-1}) which amounts to a set of recorded sensor readings about every 25 cm (average of ~2 plants).

Results and Discussion

Sensor data collected while driving through the N-rate plots were used to represent the extremes in plant variability that producers might experience in commercial fields. A histogram of the red-edge chlorophyll index values ($\mathbf{CI}_{\mathit{Red\ Edge}} = \left[\rho_{NIR}/\rho_{Red\ Edge} - \mathbf{1}\right]$) was constructed to examine the shape of the distribution function (Figure 1). The average $CI_{Red\ Edge}$ for the plots receiving 0, 50, 100, 150, and 200 kg N/ha was 0.98. 1.33, 1.58, 1.62, and 1.70, respectively (sufficiency index values were 0.58, 0.78, 0.92, 0.95 and 1.00, respectively, when using the average $CI_{Red\ Edge}$ for the 200 kg N/ha plot within each replication as the reference). There were probably many plants that received <200 kg N/ha that had an abundant supply of N. Considering the entire sequence of plots (48 plots in two 400-m long strips) as a field strip, the 95 percentile value ($CI_{Red\ Edge}$ = 1.91) from the histogram was initially selected as the reference from which to make sufficiency index calculations and simulate fertilizer N applications. As a point of interest, the GreenSeeker approach uses readings for the highest three consecutive seconds in an N-rich strip to represent the reference value (personal communication, Bill Raun, 2008). This approach amounts to selecting the highest 30-point running-average value because the sensor records data at 10 Hz. Applying the GreenSeeker approach to the 800-m strip used in the above study with various N rates would have used a $CI_{Red\ Edge}$ reference value of 1.80 (85 percentile value). Traveling at 6 mph (~9 ft/s or ~3 m/s), the peak value gets extracted from ~27 ft (~3) out of the 2400-ft long strip (800-m long).

It stands to reason that establishing an N-rich strip(s) in a field near planting time is over-kill in terms of meeting the N needs of the crop between the V6 and V15 growth stages. For example, at the V9 growth stage of corn, plants have accumulated ~20% of the total N that will be in the crop at harvest, which only amounts to ~35 kg/ha for a 14 Mg/ha yield. Therefore, a planting time application of 60 to 80 kg N/ha should be adequate to avoid N stress until the V7-V10 growth stages.

After the 95 percentile reference value had been determined, the same strips were monitored again as though fertilizer N was being applied. The average application rate per plot varied from near zero to the maximum of 150 kg N/ha (Figure 2). The same strip was monitored a third time after programming the software to build and continuously update the histogram. The 95 percentile value was again used as the reference to calculate the sufficiency index values. However, in this case the reference value was allowed to float based on the N status of the previously monitored crop. Without the benefit of knowing the range of vegetation index values that were obtained by driving through the field before starting the fertilizer application, the N application rates for the first few plots were inaccurate when using the auto-calibrate mode (Figure 2). Once the sensors had briefly viewed a range of plants, the N application rate became quite accurate. In practice, the auto calibrate mode should work well in fields where it is possible to start in an area that shows minimal N deficiency symptoms.

The next level of sophistication would involve a system that either generates a separate histogram for each management zone or involves an algorithm that essentially changes the reference value as the implement passes from one management zone to another. A recently published algorithm for making in-season N recommendations allows the user to assign a factor for each management zone (Holland and Schepers, 2010). Perhaps someday agronomic software will be sophisticated enough to perform the auto-calibration procedure for each delineated management zone. In the mean time, the above algorithm makes it possible to modify the N recommendation for each management zone. This algorithm also incorporates a back-off function that reduces the N application rate in situations where the vegetation index values are sufficiently low to indicate that the crop will not be able to achieve high yields with large N applications (i.e., low biomass caused by stunted plants or low plant population). Figure 3 shows the algorithm programmed for three different back-off rates (nominal, intermediate and aggressive back-off rates).

References

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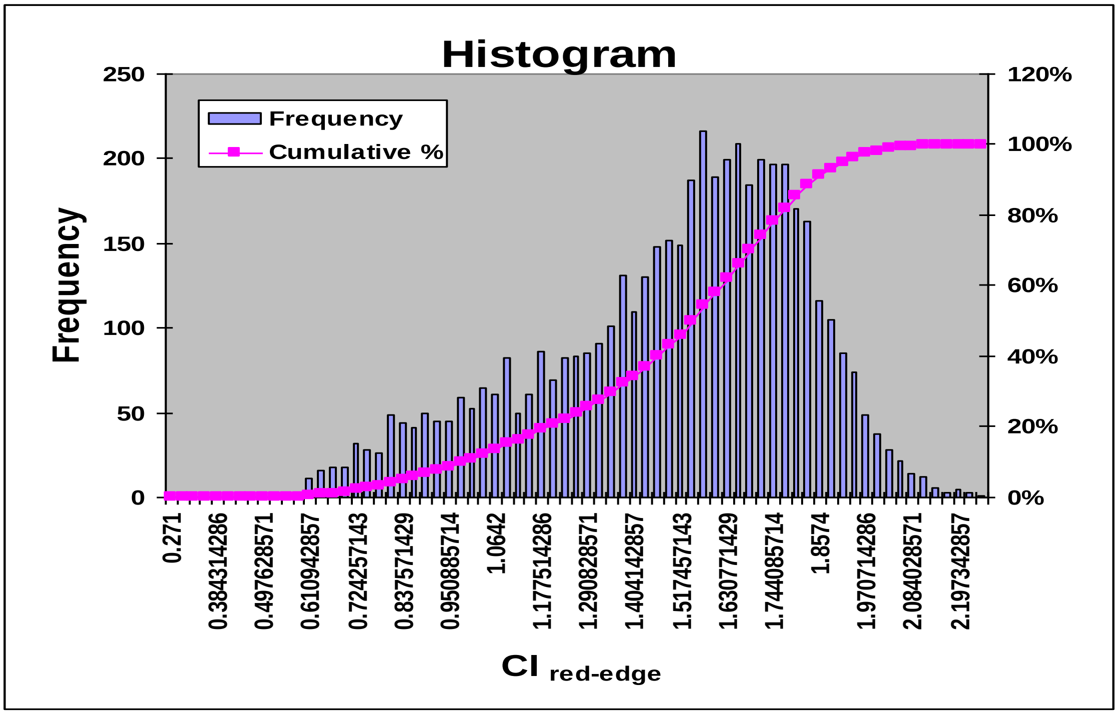

Figure 1. Histogram showing the frequency distribution and percentile values for red-edge chlorophyll index using Crop Circle ACS-470 sensors from 800-m strip of irrigated corn containing 48 plots (8 replications) fertilized at five N rates (21 July, 2009, V12 growth stage).

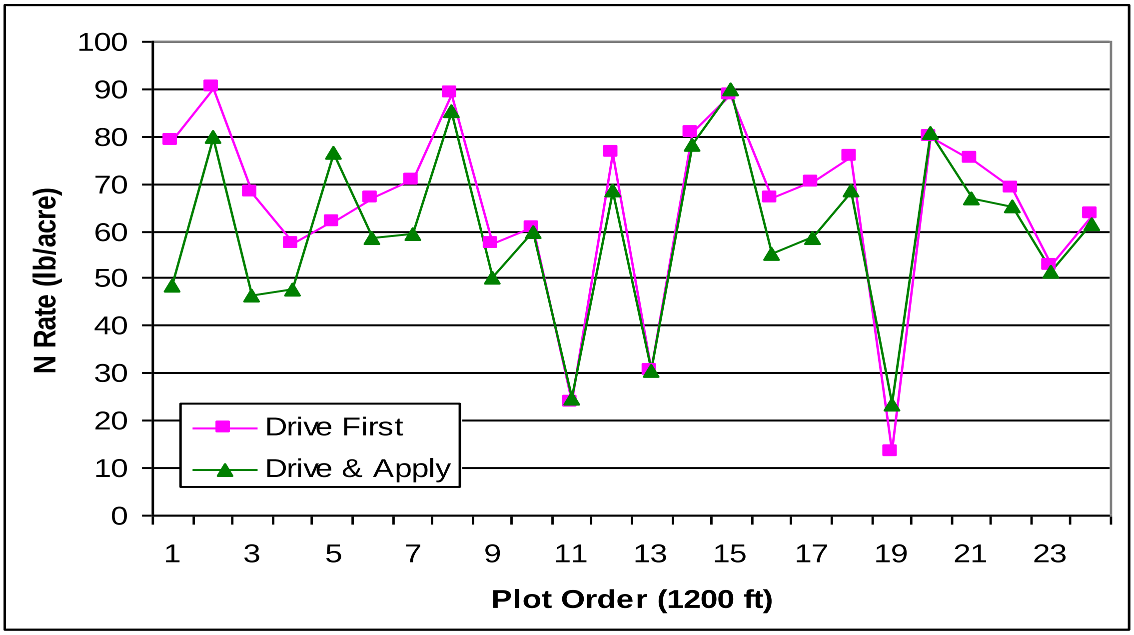

Figure 2. Average N application rates to plots having received five N rates at planting based on: 1) driving through the plots before application to establish adequately fertilized reference value from composite histogram and 2) N rates based on real-time generation of histogram while driving through the field.

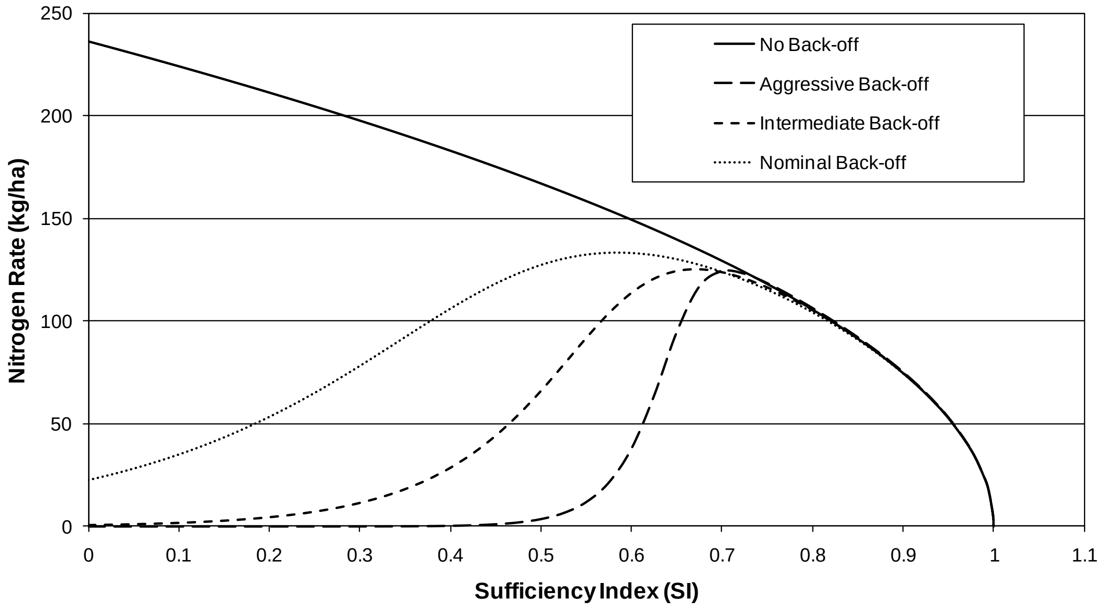

Figure 3. Nitrogen application algorithm programmed for three different back-off rates. Varying degrees of N conversation can be achieved by incorporating a back-off feature in an N application algorithm.