Fine Tuning Remote Sensing Technologies for Nitrogen Application in Semi-Arid Cereal Crops

By Tom Jensen

Sensor-based technologies have been researched and developed to the point that commercial technologies are now commonly used on the farm. Recent research focused on small grain systems of the semi-arid region of U.S. northwest indicates that refinements and technological advancements are leading towards more precise options to assess crop N status in these systems and guide fertilizer applications.

The interest in precision agriculture technologies continues to grow in the semi-arid, small grain producing areas of North America. The most common practice is auto steering of farm equipment used for fertilizing, planting, and pest control applications. This has come about because of technical advances in GPS, GIS, and remote steering technologies. Another growing area of adoption is variable rate application of fertilizers, including pre-plant, at planting, and in-crop operations. A technology of special interest is remote sensing of growing crops for N content status in order to make in-crop variable rate N applications. These are on-the-go, sensing technologies that consist of active sensors mounted on liquid N fertilizer applicators. This can be used to measure aboveground crop biomass and greenness (directly related to chlorophyll content). Two such related, but with somewhat different technologies are GreenSeeker® (Trimble Navigation Limited, Sunnyvale, CA, USA) that measures Normalized Difference Vegetation Index (NDVI); and Crop Circle™ (Holland Scientific, Inc., Lincoln, NE, USA) that measures NDVI and Normalized Difference Red Edge (NDRE), and can be used to calculate some other indexes.

Cooperative research by scientists with USDA-ARS and University of Idaho in eastern Oregon, Washington and Idaho, and northern Montana has assessed the above mentioned in-crop remote sensing technologies for how well they can be used to measure crop N status for small grain cereal crops grown in these dryland and water-limited conditions regions (Eitel et al., 2008). One observed limitation of active sensors currently used on-farm—and calculated indexes used for measuring crop N status and determining supplemental N applications—is that these technologies work well when available moisture is adequate and does not limit crop growth. Their research shows that by calculating other crop indexes that reduce the influence of crop biomass, and emphasize the N status of the crop, it is possible to obtain an improved correlation between the sensed and calculated index value of crop (wheat) N status. Their initial work was done at Zadok Crop Stages 57 to 60 (i.e., late heading to early flowering). At this crop stage if additional foliar N is applied it is possible to raise the protein content of spring wheat that is deficient in N.

A calculated crop-sensed index that was found to improve the correlation to crop N status under water limited growing conditions, compared to using NDVI or NDRE, was the ratio of Modified Chlorophyll Absorption Ratio Index (MCARI) and Second Modified Triangular Vegetation Index (MTVI2) or (MCARI/MTVI2) (Eitel et al., 2007; Eitel et al., 2008). This was shown by comparing the correlated r^2 values of the indices with the conventional flag leaf N status assessing methods using a Minolta Soil Plant Analysis Development (SPAD) 502 chlorophyll meter, or N content as measured using an automated dry combustion analyzer (**Table 1**). The improved r^2 values were attributed to the removal of the effect of crop top growth or leaf area index, and emphasis on leaf N status. The MCARI/MTVI2 index was also found to be robust to variation in soil color and brightness, due to different soil types, that produce different crop spectral reflectances within a N-rich reference strip.

Abbreviations and notes: N = nitrogen; GPS = global positioning system; GIS = geographic information systems.

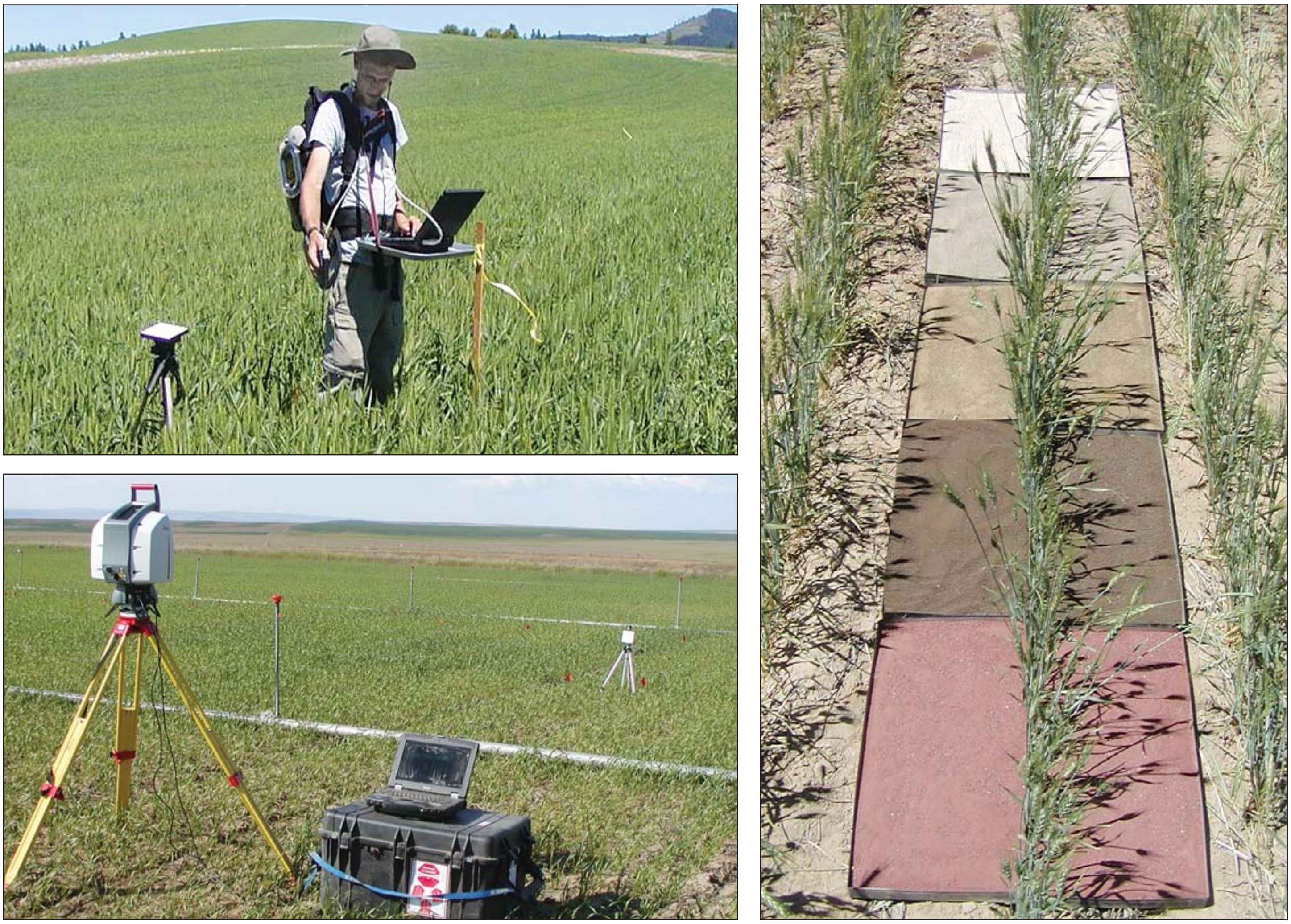
Active crop sensor attached to the front of a liquid N fertilizer applicator.

Table 1. Examples of coefficients of simple determination (r^2), and statistical probabilities, for the relationship between a selected spectral index, leaf area index (LAI) and relative chlorophyll meter values using a SPAD meter, or laboratory analyzed flag leaf N concentration, in various sets of experiments.

	Average r^2 value relationships to physically measured N status		
Spectral Index	SPAD relative chlorophyll content	Flag leaf N concentration	Reference of sets of experiments
NDVI	0.03 (0.025†)	0.00 (0.229)	Eitel et al. 2007
MCARI/MTVI2	0.60 (0.001)	0.48 (0.001)	
NDVI	0.06 (0.10)	0.05 (0.14)	Eitel et al. 2008
GNDVI (Green NDVI)	0.02 (0.34)	0.07 (0.06)	
MCARI/MTVI2	0.70 (<0.01)	0.54 (<0.01)	

†statistical probability or p value.

Even though it is possible to more accurately assess leaf N status at the early heading stage of wheat, using the calculated index described above, this is only useful for foliar application for protein enhancement. Ideally it would be beneficial



Dr. Jan Eitel taking remotely sensed measurements in a field of spring wheat. Scanning green laser equipment is shown measuring early stage crop N status (bottom left). Inserted trays of different colored soils were used to measure the effect of soil background reflectance on vegetation indices used for in-season N management (right).

if the N status of a crop could be accurately assessed at an early stage of crop development (e.g., late tillering to early stem elongation). If a N deficient crop could be identified and supplemental N applied then, it would be possible to not only increase grain protein, but to effectively increase crop yield. The challenge, especially when assessing small grain cereal crops such as wheat, is that the amount of plant biomass is small at the earlier growth stages and the spectral interference reflected from soil and previous crop residues is too great to adequately estimate crop N status.

Researchers are now assessing the possible use of a green scanning laser, that can be used to assess the greenness of crop leaves, while separating out the effect of soil, previous crop residues, and leaf edges (Eitel et al., 2011). The r^2 values measured using this green laser scanning system ranged between 0.53 and 0.58 for regression models relating foliar N concentration to raw laser return intensity values, when used at Zadoks stage 32 (i.e., late tillering to early stem elongation). Such significant correlation at early stages of small grain cereal growth has not been possible previously using NDVI or NDRE systems, or even the MCARI/MTVI2 ratio described above, which more accurately estimated leaf N content under low moisture restrictions. The research using the green scanning laser has been limited to stationary equipment in research plots, and there will need to be further equipment developments and research done to determine if a liquid N fertilizer applicator might be equipped with this technology.

This leading edge research shows that there can be improvements in using remote sensing in small grain cereal producing areas to assess crop N status when low levels of available moisture limit crop growth and interfere with the assessment of whether or not there is an existing N deficiency. These improvements are presently restricted to supplemental foliar N applications at early crop heading for grain protein increases. New technologies such as a scanning green laser system may be developed to assess crop N status at an earlier crop growth stage such as at early stem elongation. BC

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