Determining the controls on nitrogen uptake from space

Troy Magney (tmagney@uidaho.edu) UI, Matt Yourek UI, Nicole Ward UI, Sam Finch UI, Jan Eitel UI, Lee Vierling UI, Erin Brooks UI, Dave Huggins USDA-ARS, and Dave Brown WSU

The word "determine" in the title should come with a caveat. While more advanced technologies are being marketed to growers as must-have tools for precision farm management (e.g., drones), caution is advisable before hasty adoption. Precision agriculture and remote sensing technologies are not fully capable of "determining," say, exactly how much fertilizer should be applied where; rather, they can provide us with a map of how crop patterns vary across a field in both time and space. Further, highly resolved satellite images, such as the ones described in this research, do not provide us with a process-based understanding of what is driving these patterns. To begin to understand the controls on crop nitrogen uptake, for example, we can use geostatistical approaches, ranging from simple to complex, to compare crop patterns with ancillary information on what is actually happening in the soil. Using a combination of data and models that provide maps of soil, water, and weather conditions together with satellite maps of crop variability will enable us to analyze why some parts of a field might be consuming more nitrogen than others.

IMPACT

Satellite imagery provides a means to estimate the patterns of crop nitrogen uptake from space. With this information, growers can begin to use these patterns to determine zones as a way to maximize the efficiency of fertilizer application. When coupled with soil and water information, these zones will help growers determine the specific factors that are driving these patterns.

The widespread adoption of precision agriculture has been guided by the idea of devising a decision support system to optimize returns on inputs while reducing the economic and environmental consequences of overapplication. Many growers and crop consultants currently use historical yield maps to determine nitrogen management zones. In the Palouse, where patterns of soil water content in this notoriously heterogeneous landscape have a large influence on crop productivity, a greater understanding of the spatiotemporal variability of factors that affect crop nitrogen use efficiency (NUE) and water use is needed. As a first cut to investigate this, we used images taken every 10 (or so) days by the RapidEye-BlackBridge™ satellite system with a 17-foot spatial resolution (pixel size) and compared them to a widely used model, called Soil Moisture Routing (SMR), which provides a map of daily soil volumetric water content (SVWC) across the field. This article will focus on a spring wheat crop at a farm in Colfax, WA, during the 2013 growing season.

Before using a model or satellite image to infer a process, we first need to validate how well this tool actually measures what we are interested in. Figures 1 and 2 demonstrate some of the validation steps we used to understand not only how accurately the model performs, but also how much uncertainty is inherent in the model. Figure 1 shows the temporal trend of soil water over two seasons for one particular point where SVWC has been measured. It can be observed that both the magnitude and the timing of the observed (actual) and predicted (model) SVWC values at this site are remarkably similar.

To validate the satellite image (Figure 2), we first needed to decide what variable we were interested in mapping. Because reflected solar energy from vegetation is primarily a product of leaf area (biomass) and chlorophyll content, satellite measurements of plants are primarily related to these two biophysical properties. However, in an effort to understand where management zones should be located, a grower might be interested in how much nitrogen is actually removed from the ground and into the standing crop. Fortunately, the amount of nitrogen in wheat (used here) is highly correlated to total aboveground chlorophyll (chlorophyll concentration multiplied by leaf area). The simple regression output in Figure 2 shows that by using a particular combination

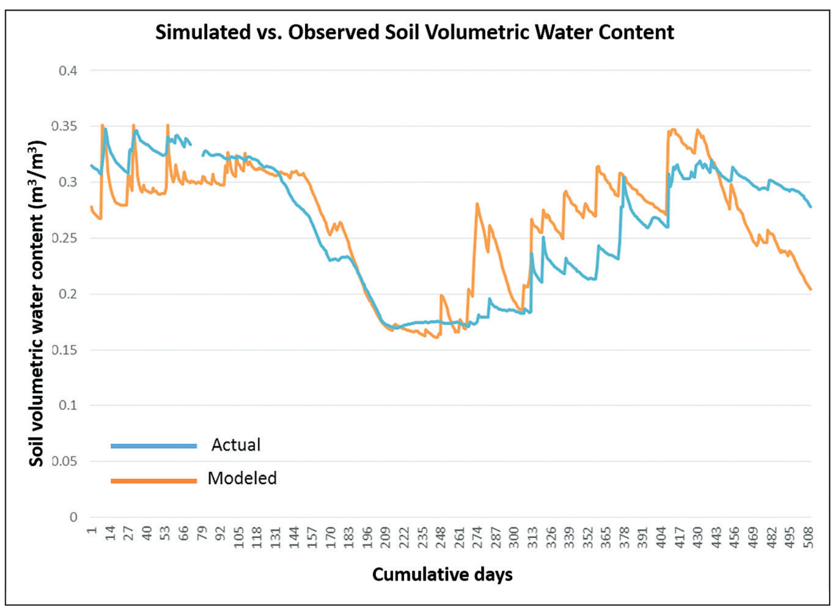

Figure 1. *Comparison of modeled (using the Soil Moisture Routing model) temporal variability of soil water at one site on the Colfax, WA, farm to actual soil water measured from a Decagon soil moisture probe.*

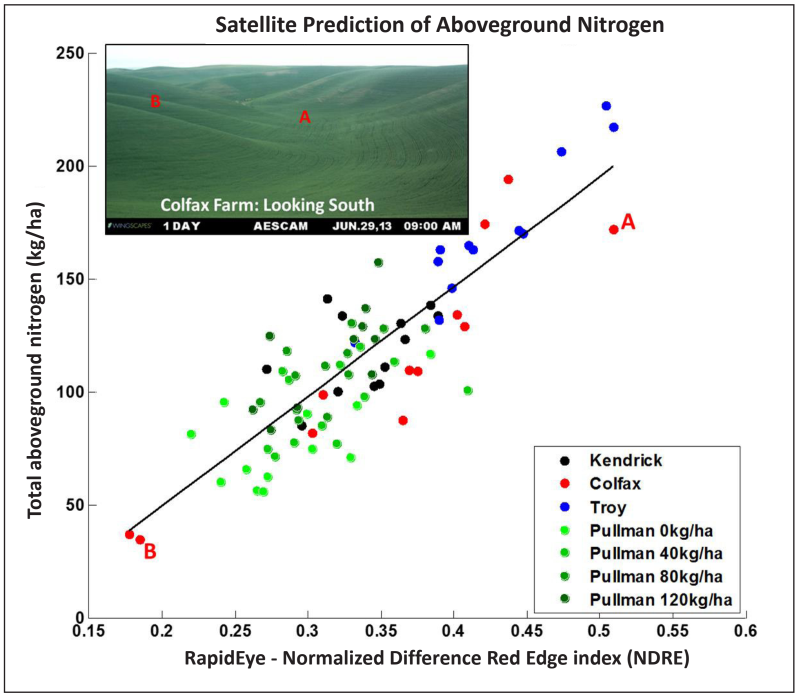

Figure 2. *Validation of the satellite-derived Normalized Difference Red-Edge Index (NDRE) in estimating total aboveground nitrogen. RapidEye satellite images were taken at peak biomass and compared with harvested total biomass multiplied by nitrogen concentration at four farms across the Palouse. Dots in different shades of green represent fertilizer treatments at study plots. (kilograms per hectare x 0.89 = pounds per acre)*

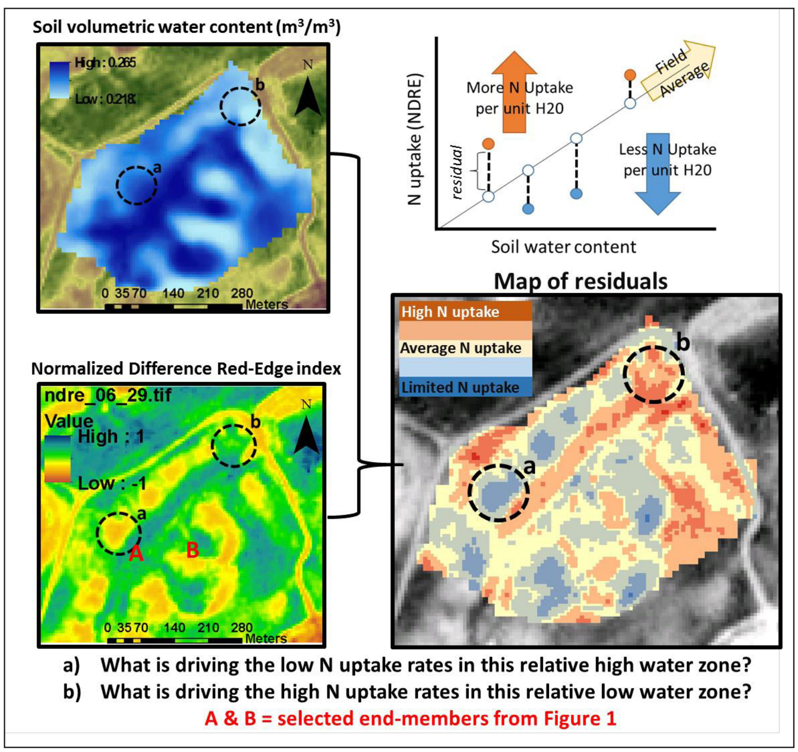

Figure 3. *Schematic illustrating the approach of combining data from the soil moisture routing model (top left) and the satellite image (bottom left, where a high value is used as an indicator of greater nitrogen uptake by the plant) to tease apart areas of the field that deviate from the average rate of nitrogen uptake per soil water content (bottom right). The top-right panel was designed to illustrate how the residuals map was created.*

of satellite "bands," the near-infrared and red-edge bands, we can get a pretty good estimate of nitrogen in the plant ($R^2 = 0.72$), especially compared to the digital photo in Figure 2, which was taken on the same day, with the same "bands" we see with our own eyes (see "Using time-lapse imagery for applied agricultural monitoring" later in this report page 102). The near-infrared and red-edge bands outperformed any other combination of bands in this validation step, and are combined mathematically to create the Normalized Difference Red-Edge Index (or NDRE).

With this confidence, and an understanding of the model and satellite uncertainties, we can compare spatially where patterns of crop nitrogen uptake are consistent or deviate from soil water content (Figure 3). An ordinary least squares regression between the pixel values on these two maps can provide us with a field-scale average of how much nitrogen uptake occurs per SVWC (depicted in the top right of Figure 3). Using the distance (residual) from the field average, we can begin to elucidate areas that are very resource efficient (area *b* in the bottom-right map of Figure 3) and areas where nitrogen uptake is low compared to SVWC (area *a*). By locating the anomalies in these maps, we can use ancillary information such as weather, inputs, and soil conditions (often derived from other models such as CropSyst) to gain a better idea of what is driving plant nitrogen uptake across space and time. Our interdisciplinary team is currently working to investigate these processes further using other data sources. Eventually, maps similar to these will enable growers to develop decision support systems that can help them achieve the holy grail of maximizing outputs (yield) while minimizing inputs (fertilizer, pesticides, etc.).