IN-SEASON OBSERVATION OF WHEAT GROWTH STATUS FOR YIELD PREDICTION: DO DIFFERENT OPTICAL SENSORS GIVE US THE SAME ANSWER?

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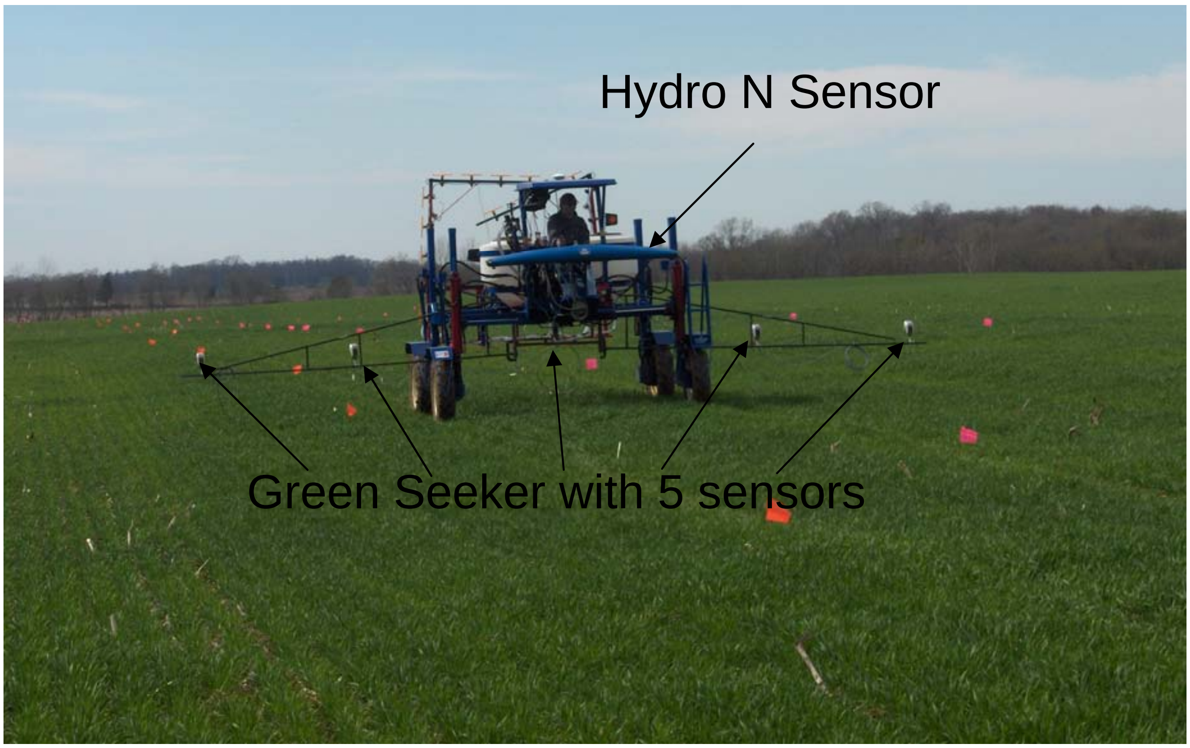


Figure 1. Remote sensing platform with the Hydro N Sensor and the Green Seeker.

Introduction:

Farmers are well aware of the fact that crop yield varies within their fields although fields are managed with constant planting density, and fertilizer and pesticide application rates. The reasons for yield variation within an individual field are many and it is impossible to fully understand why at some locations within a field the crop grows better than at others, why some locations yield more than others in every year, and why some locations yield more than the average in some years and less in other years. However, the spatial variability pattern of yield does not appear suddenly before harvest, but develops over the growing season. Hence, in most years, we can already see relatively early in the season, where the crop biomass is better and where it is less developed, and we expect yields to turn out accordingly. In order to measure the crop status in the growing season, the green intensity of the canopy can be determined using optical instruments.

These instruments are mounted to a tractor or vehicle such as the one shown in Figure 1. The vehicle is linked to a global positioning system (GPS) which assigns a location to the measurement while it is moving through the field. Some instruments are already available for on-farm use. But basic investigations are missing that would tell about specific details of the instruments, how reliable they are, how consistent the measured result is, and whether different sensors would provide the same answer.

The <u>objective</u> of this study was to investigate in a farmer's field whether optical sensor measurements reflect crop status and nitrogen supply early in the season and whether these observations are related to final yield. Moreover, we wanted to know whether two different sensors, i.e., the Hydro N Sensor and the Green Seeker, that are available for farmers' use would provide the same answer when they were applied in the same field at the same time.

Material and Methods:

The experiment was performed in a wheat field of the farmer Trevor Gilkey in Princeton, Caldwell County, Kentucky, in the spring of 2007. The experiment was conducted in an area of 90 ft by 2050 ft. The Hydro N sensor is a passive apparatus and measures canopy light reflectance caused by sunlight, which means that it only works under daylight conditions. The Green Seeker is an active sensor which measures the reflectance of an active laser beam, sent to the canopy. This sensor can be used during day and night because it is active. The Hydro N sensor integrates over a larger area, whereas the Green Seeker provides point measurements. Both sensors measure the light reflectance of red and near-infrared light. From these measurements, the normalized difference vegetation index (NDVI) is calculated.

In Figure 1, the vehicle is shown carrying both sensors. The Hydro N sensor is the 6-feet-wide blue device on the front, while the Green Seeker has five sensor heads distributed over the boom which had been mounted between the front and back wheels. The Hydro N sensor measures reflection from an area on the left and right hand side of the vehicle. This area is approximately covered by the two outer sensors of the Green Seeker on both sides of the boom.

Nitrogen fertilizer (liquid urea-ammonium-nitrate) was applied on March 6 and March 21. N rates from 0 to 75 lb. acre^{-1} were applied on both dates in order to study the behavior and the sensitivity of both instruments, and the relation between results measured with both sensors. The total N rates (0, 30, 60, 90, 120, and 150 lb N acre^{-1}) were applied in a continuous manner as four-and-a-half waves across the field (Figure 2). This design deviates from the classical randomized plot experiment, because in this study, we intend to address the continuity of observations across the landscape. We expect that the resulting wheat yield and optical indices are always affected by many additional trends and soil properties that cannot all be measured in their complexity and impact on plant growth and yield. But if we apply nitrogen with continuously varying rates, the response can be derived and compared relative to the local neighborhood.

Results:

From the left to the right hand side of Figure 2, the first two waves of nitrogen application (green step line) along the transect affected the wheat yield (Figure 2, red symbols). No yield response was observed at the third wave from approximately 280 to 400 m. In the last 200 m, yields again reflected the nitrogen applications. We can also notice, that yields turned out to be higher between 0 and 300 m than between 300 and 645 m. Especially the zero- and low-nitrogen areas yielded less in the right hand part of the field than in the left part. This observation is related to the different cropping histories and soil differences. The previous crop was tobacco in the left hand zone of the field and corn in the right hand zone. Moreover, in the right hand part, the soil was more clayey than in the left part.

Also shown in Figure 2 is the Leaf Area Index (LAI, blue symbols), measured on March 21, which is the area of leafs measured over a specific area of ground. This index reflects the amount of biomass to a certain extent early in the growing season. The LAI follows the wave-like pattern of nitrogen application.

The NDVI results across the transect for three different dates are shown in Figure 3 for both sensors. During all three sampling dates, the results differed between both sensors. For the first sampling on March 12, NDVI proceeded parallel for both sensors, while the magnitude of NDVI was consistently larger for the Hydro N Sensor than for the Green Seeker. The data range, i.e., the difference between largest and smallest NDVI values is larger for the Green Seeker compared to the Hydro N Sensor. This result indicates a greater sensitivity of the Green Seeker. The measurements on March 21 exhibited a lower pronunciation of spatial differences for the Hydro N Sensor as compared to the Green Seeker. At the last measurement on April 25, 2004 which is about seven weeks before harvest, and three weeks after a severe low temperature period, only the Green Seeker was able to distinguish spatial differences of NDVI across the experimental field.

On March 12 and March 21, leaf area index (LAI) was measured at the center of each nitrogen plot. The difference in leaf area index between the measurement dates reflects biomass increases from March 12 to 21. In other words: In areas where the leaf area index increased strongly from the first to the second time, plants must have grown more than in areas with low difference in LAI. This difference is shown in Figure 4 as DELTA LAI (red symbols). In the first part of the transect (0-300 m) with the better soil, the differences in LAI resulting from both times were more variable than in the second half (300 to 645 m).

Can we predict the relative wheat yield and how it behaves across the field?

The spatial distribution of differences in LAI measured on March 12 and 21, and differences in NDVI between on March 12 and April 25 were used in a spatial model to describe the yield pattern across the field. The results are shown in Figure 5, where the grey-shaded area is the estimation result. The model estimation agrees well to measured data except for a few extreme high and low yield values.

<u>Acknowledgements:</u>

We gratefully acknowledge the Kentucky Small Grain Growers' Association and the UK College of Agriculture for their support. We thank the farmer Trevor Gilkey for helpful cooperation, and R. Jason Walton and James Dollarhide for excellent technical assistance, and John James for his permanent help. We also thank Dr. Charles Dougherty for providing the Green Seeker sensors.

What we learn from our first experiments:

1. Both instruments, the Hydro N sensor and the Green Seeker are robust and eligible for use under farm conditions.
2. Both sensors differ with respect to NDVI, which is a widely used index that reflects the green intensity of the canopy. The NDVI is also related to the nitrogen supply and the biomass status.
3. The Hydro N Sensor resulted in larger NDVI values than the Green Seeker, however, until the end of March, the relative results were similar, which means: The spatial variation of NDVI was detected by both sensors, while the Green Seeker was more sensitive than the Hydro N Sensor.
4. Towards the late growing season (late April), the Green Seeker better identified different nitrogen supply whereas the Hydro N Sensor was not able anymore to detect any spatial differences in NDVI.
5. The data processing for the Green Seeker is still complex and needs to be simplified for rapid use of data.

What is next?

In future investigations, the experimental fertilizer application design will be maintained. Parallel to the transect with varying nitrogen application rates, base-line observations will be taken in the field managed by the farmer with a homogeneous nitrogen application. Moreover, soil samples will be taken in order to quantify some effects that caused the spatial differences between the zone from 0 to 300 m and 300 to 645 m.

Figure 2. Experimental design of nitrogen application rate (NAR) and resulting wheat grain yield. Raw yield data were aggregated over 15 ft distance and the resulting averages are presented here.

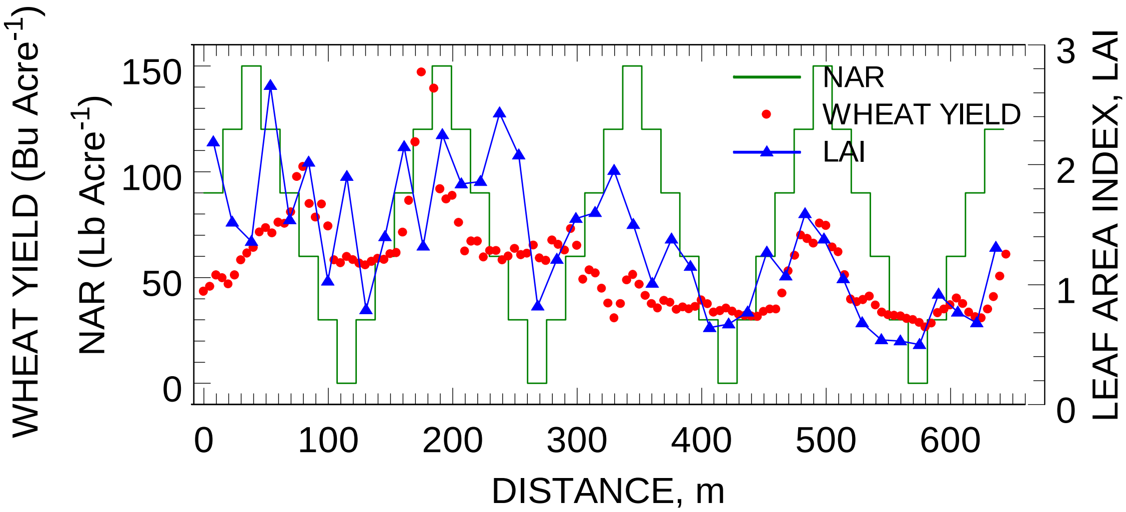


Figure 3. Normalized difference vegetation index (NDVI) calculated based on Hydro N Sensor (HN) and Green Seeker (GS) measurements along the transect where different amounts of nitrogen were applied. Measurements were taken at three different times in spring 2007. NDVI data were aggregated over 15-ft intervals.

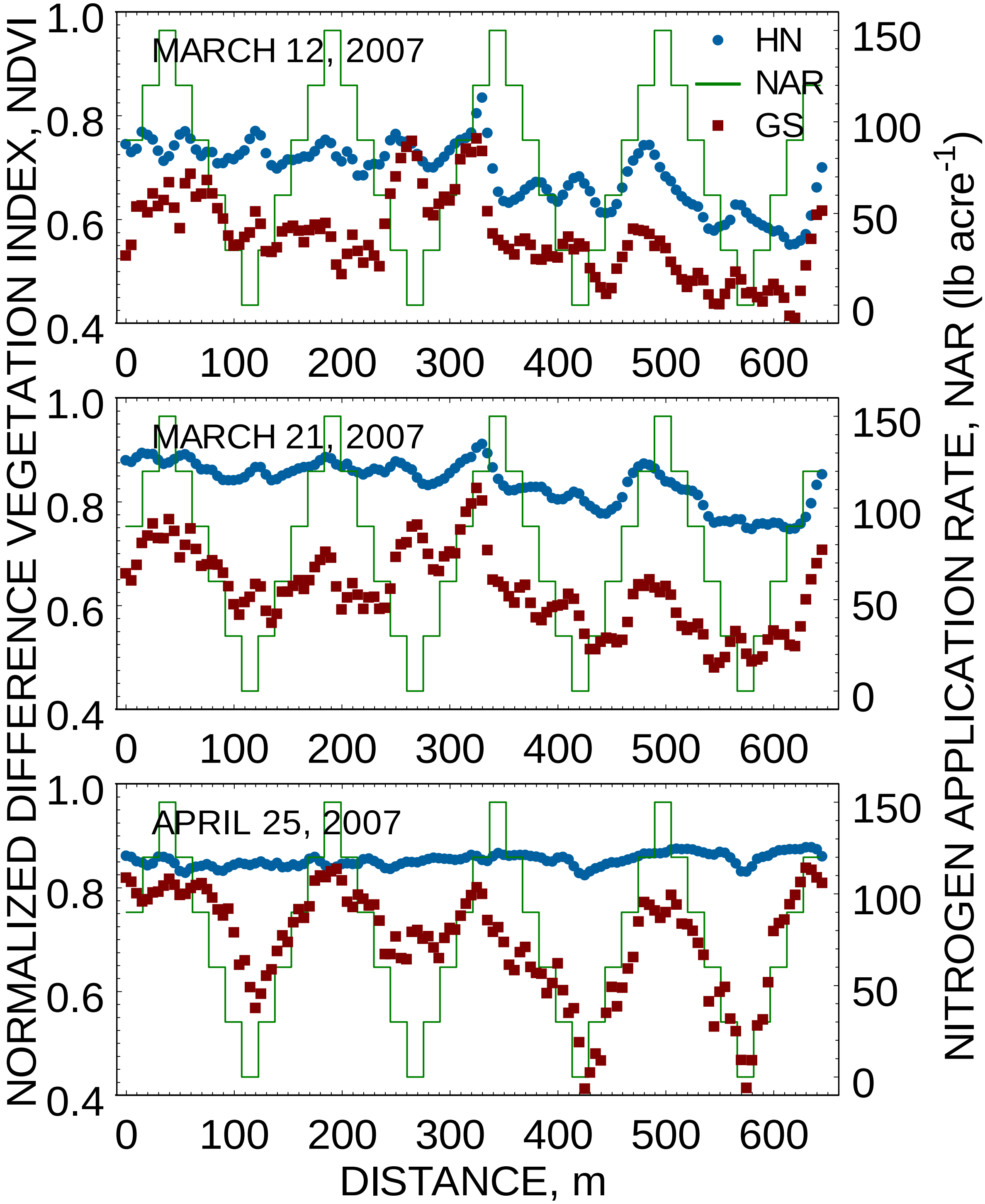


Figure 4. Change of NDVI (DELTA NDVI) and the leaf area index (DELTA LAI) measured at two different times, and their behavior as a function of underlying nitrogen fertilizer application.

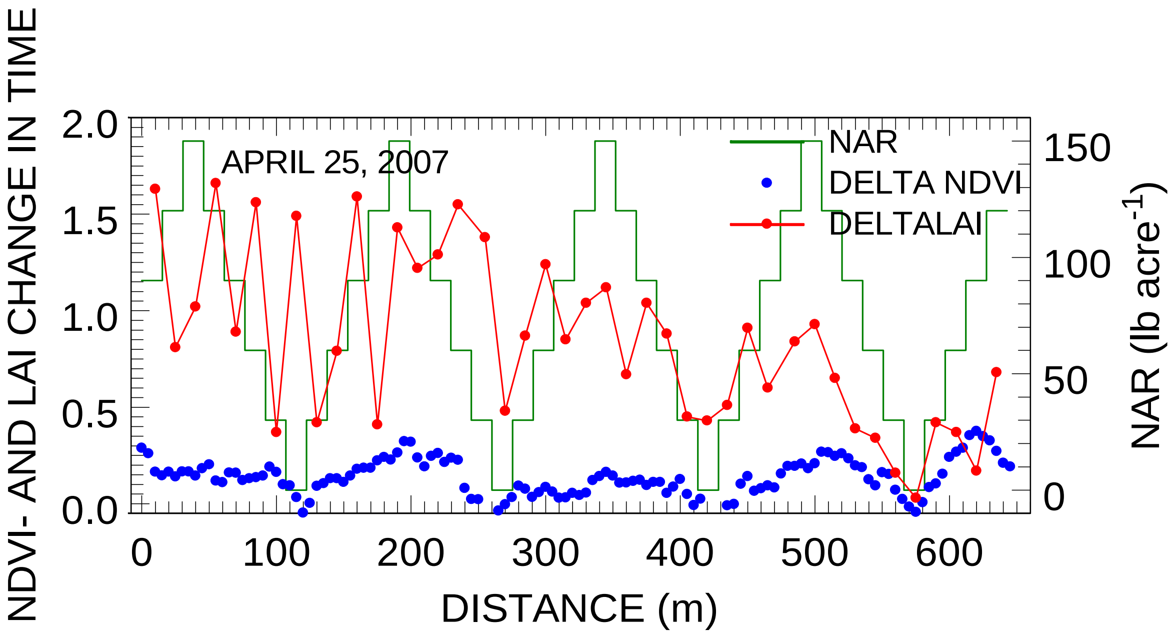
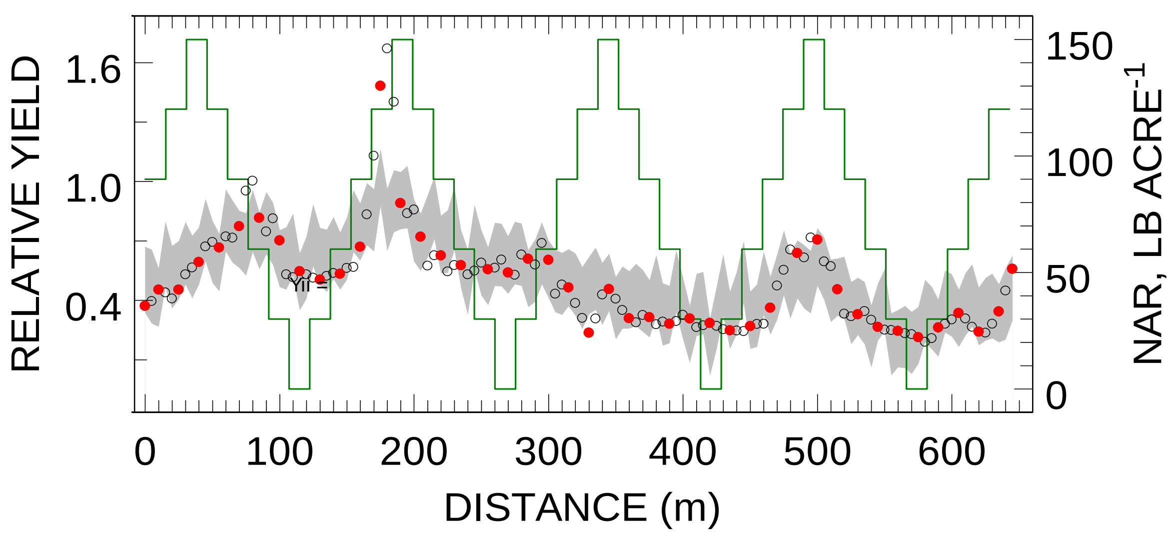


Figure 5. Autoregressive state-space model describing the yield variation of winter wheat based on change of leaf area index (DLAI) and change of NDVI (DNDVI) measured at two different times.



$$Yi_i = 0.60\ Yi_{i-1} + 0.48\ DLAI_{i-1} - 0.04\ DNDVI_{i-1} + \omega_i$$