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Aerial photographs to predict yield loss due to N deficiency in corn

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Abstract
Nitrogen fertilizer is a crucial input for corn production, and in the U.S. more nitrogen is applied to corn than to all other crops combined. In wet weather, nitrogen can be lost from soil by leaching and by denitrification. Which process predominates depends largely on soil drainage. Nitrogen deficiency in nearly any plant is expressed by a lighter green color of leaves than in nitrogen-sufficient plants. Nitrogen deficiency in corn can be easily seen from the air. Fields with yield maps, aerial photos, and appreciable N deficiency were used to develop a calibration between color and yield loss. Separately, fields with aerial photos and N rate trials were used to develop a calibration between color and optimal N rate. A new company, NVision Ag, has been formed to use these relationships to help farmers decide whether they need to apply rescue N to corn in wet years, and to provide them with variable-rate N fertilizer control files to put more N where more N was lost.

Keywords *corn, maize, nitrogen, fertilizer, variable-rate, remote sensing, aerial photo*

Introduction

Nitrogen fertilizer is one of the most disruptive technologies in history. Plant growth in nearly all terrestrial and marine environments is nitrogen-limited. The use of nitrogen fertilizer has increased food production so much that Smil (2001) estimates that 40% of the current human population would not be alive without it.

When crops do not have enough nitrogen, it severely limits their yield. Farmers growing corn spend more on nitrogen fertilizer than any other input in an effort to make sure that nitrogen deficiency does not limit their yield. In the U.S. more nitrogen fertilizer is applied to corn than to all other crops combined.

Nitrogen can be lost from soil by either leaching or denitrification during wet weather. Because of this, farmers in humid regions rarely count on any nitrogen carryover from the previous year.

However, in the U.S. Corn Belt, most farmers apply all of their intended N fertilizer before planting their corn crop. Rapid N uptake by the crop is likely to begin 8 to 10 weeks after planting; if wet weather intervenes, both soil N and fertilizer N can be lost before rapid uptake begins.

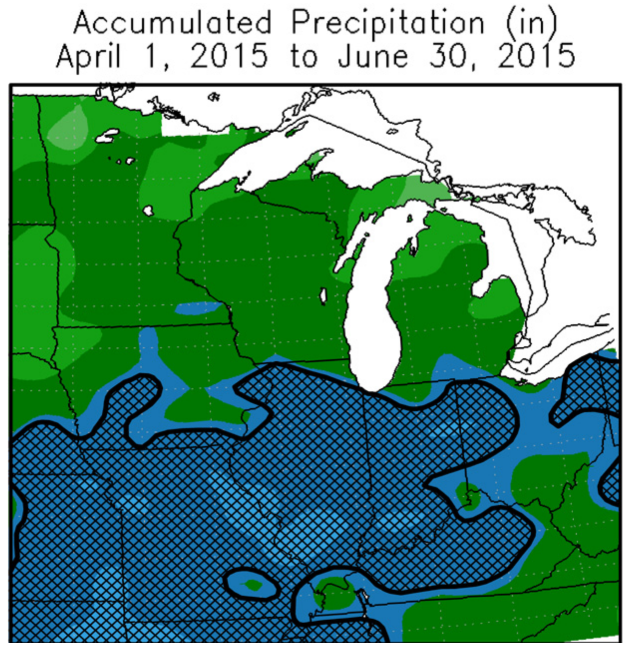
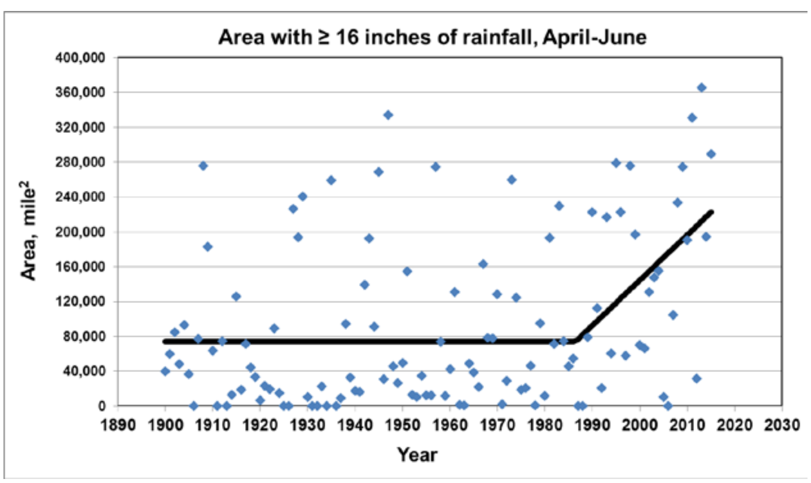


Figure 1. Cross-hatching indicates areas with more than 16 inches of rain April through June of 2015. Nitrogen loss is likely in many fields in these areas. Precipitation map from the Midwest Regional Climate Center.

Wet spring weather has been on the rise in the central U.S. Figure 1 shows areas of the central U.S. with more than 16 inches of rain April through June in 2015, based on a map from the Midwest Regional Climate Center.

Similar maps were obtained for the period 1900-2015, georeferenced, and the area with more than 16 inches April-June rain measured. There was no trend in the size of the wet area from 1900 to about 1980, then its size started going up (Figure 2) and has more than doubled.



Farmers are dealing with wet springs much more than a generation ago.

In years with wet spring weather, farmers often wonder whether they have lost N that they applied and, if so, how much. Many have observed N deficiency symptoms in their crop in wet years. As a consequence, farmers have shifted to more in-season N

Figure 2. Trend analysis of area in the cent
April to June from 1900 to 2015. A plateau-
The probability that there is no trend ov

applications in the Corn Belt in recent years (Arbuckle, 2016). I am aware of 60 to 80 new high-clearance N applicators in Missouri, Illinois, and Iowa over the past 10 years, largely in response to N loss in wet springs.

Figure 3. Aerial photos quickly reveal where corn is N-sufficient (dark green) and where it is N-deficient (light green or yellow-green) due to N loss.

Nitrogen deficiency in nearly any plant species is expressed by a lighter green color of leaves than in nitrogen-sufficient plants. This is due to lower chlorophyll levels. Both chlorophyll and the enzymes required to make it are N-rich molecules.

The lighter green color of nitrogen-deficient corn leaves is easily visible from the air (Figure 3) (and from the ground). Aerial observation offers the advantages of being able to survey/diagnose large areas in a short time, and to delineate spatial patterns of nitrogen deficiency. This allows additional N to be applied only where it is needed.

Methods

Yield loss prediction

Calibration of aerial photographs to corn yield loss started by identifying fields with appreciable N deficiency for which we were able to obtain both yield maps and aerial photos.

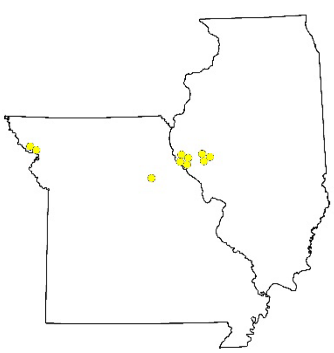


Figure 4. Locations of fields used in calibrating yield loss prediction from aerial photos.

We started by looking in areas of excessive rainfall as identified in Figure 1. Locations of 10 fields used in this calibration are all in Illinois and Missouri, and are shown in Figure 4.

Field-average yield loss due to N deficiency (as defined below) ranged from 15 to 62 bushels/acre in these fields. Other fields were analyzed as well but were discarded from the analysis because field-average yield loss due to N deficiency was below 15 bushels/acre. This value was arbitrarily chosen as the value above which noise would not interfere too much with signal to give reliable results.

Nine of the aerial photos were obtained from the National Agriculture Imagery Program (NAIP) of USDA; the 10th was taken by me from a small aircraft. Photos were all acquired in the last half of June, and corn was at least waist-high but not yet tasseled at the time of photo acquisition.

Individual farmers in regions with excessive rainfall and NAIP imagery were approached to obtain yield maps.

All fields had been fully fertilized before planting, and no additional N was added after planting. A range of cultural practices and hybrids were represented.

We started by dividing each field into a 20-meter grid. Within each grid cell, we calculated average red, green, and blue.

We made the assumption that at least 20% of the corn in each field remained N-sufficient. In my judgement, looking at the aerial photos, this was true for each of these fields. We used the 10th percentile value for each color band (red, green, blue) among the grid cells in each field to represent corn that had sufficient N and was otherwise representative of corn in the field. These were designated the 'reference red,' 'reference green,' and 'reference blue' values for that field.

For each grid cell, relative red, relative green, relative blue, red difference, green difference, and blue difference were calculated. Relative red was calculated as (red for that cell)/(reference red). Red difference was calculated as (red for that cell) – (reference red). Relative green and blue, and green and blue differences, were calculated analogously.

Reference yield was calculated as the average yield for the darkest 20% green of grid cells in each field. Yield loss was calculated as (reference yield) – (yield for that cell).

Regression analysis was used to describe the relationship between yield loss and the six color variables (relative red, green, blue; red, green, blue difference) for each field and for all fields pooled.

Nitrogen rate prediction

Calibration of aerial photographs to economically optimal nitrogen rate (EONR) for corn was carried out in a separate set of 26 field experiments. Nitrogen fertilizer rates applied preplant were 0 or 100 lb N/acre in most experiments, plus at least one treatment that received a high N rate preplant. Nitrogen fertilizer rates applied at sidedress ranged from 0 to a rate to give a total of at least 250 lb N/acre. Aerial photos were mostly obtained by me from a small aircraft. In one field, the aerial photo was obtained by Geovantage. Photos were all acquired in the last half of June, and corn was at least waist-high but not yet tasseled at the time of photo acquisition.

A quadratic-plateau function was used to model corn yield response to N rate, and EONR was calculated from this function and representative prices for corn and nitrogen fertilizer. In experiments with different pre-plant N rates (0 and 100), EONR values were calculated independently for each pre-plant N rate.

Reference red, green, and blue values were obtained from individual high-nitrogen plots in the aerial photos. Relative red, green, and blue were calculated for plots with either 0 or 100 lb N/acre applied pre-plant as described above for predicting yield loss.

Regression analysis was used to describe the relationships between EONR and relative red, green, and blue.

Results

Relative red, green, and blue were significant predictors of yield loss in each of the ten fields, with r^2 values ranging from 0.16 to 0.80. Average r^2 values across the ten fields were 0.54, 0.59, and 0.37 for relative red, green, and blue, respectively. The relationship between relative green and yield loss for one field is shown in Figure 5. This field was selected

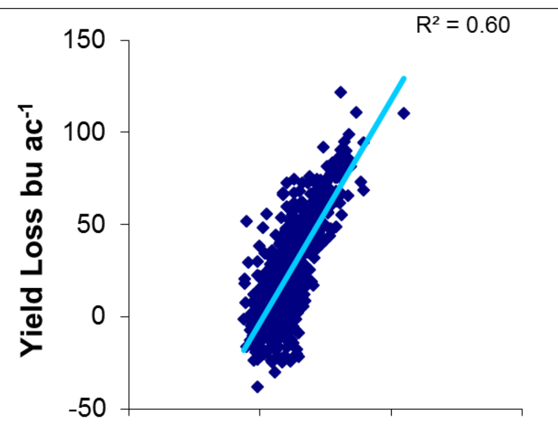


Figure 5. Relationship between relative green and yield loss in one of the ten fields. This field has the r^2 value that is closest to average r^2 over all ten fields.

to show because it is the field whose r^2 is closest to the average.

Although average r^2 values were good enough to produce predictions that would be useful in making management decisions, relationships varied somewhat from field to field. With data pooled across all ten fields, r^2 was lower than when averaged across the ten fields. This was found to be due, in part, to intrinsic and measurable qualities of the photographs for each field.

What those qualities are will not be revealed here, but we developed procedures to normalize across the photos and predict yield loss from relative green. These procedures do not use any information not contained in the photographs and can be completely automated. Yield loss predictions over all polygons of all ten fields (9629 in total) are shown in Figure 6, relative to actual yield losses observed in those polygons.

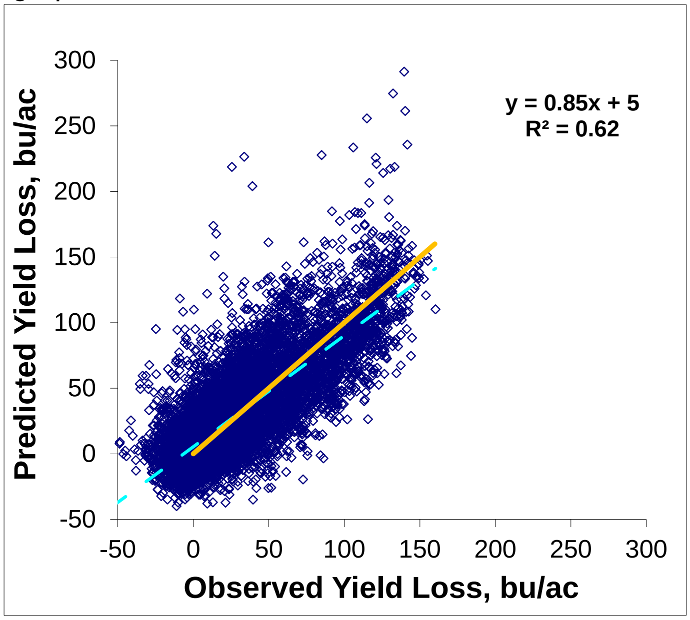


Figure 6. Predicted yield loss vs. observed yield loss over 10 calibration fields. The dashed line is the regression relationship between the two variables. The solid line is the 1:1 line.

I believe that the quality of the yield loss predictions shown in Figure 6 is good enough to allow corn producers to improve their decisions about whether to apply more (rescue) N fertilizer when earlier N applications may have been lost due to wet weather. The equation used to produce the yield loss predictions in Figure 6 is currently in use in the automated, aerial photo-based yield loss predictions provided by NVision Ag (see next section).

Commercial application

Three patents based on this research have been issued to the University of Missouri, and a Continuation in Part is still being prosecuted. I have started a new company, NVision Ag, which has licensed this intellectual property from the University of Missouri.

NVision Ag has two main products: yield loss maps and fertilizer rate control files (Figure 7). Commercial production was launched June 5, 2015, when excess rain was widespread across the southern Corn Belt (Figure 1).

The yield loss maps support the decision of whether to purchase and apply more N fertilizer when N loss is suspected. Total yield loss and dollar loss for the field are provided, which can be balanced against the cost of the fertilizer and the application. The yield loss map identifies the locations within the field where the most (and least) yield loss are expected to occur.

Nitrogen loss is nearly always patchy (Figure 3), due to variations in topsoil wetness and soil hydrology. The most N-stressed corn will require high rates of rescue N to reach its full potential, while the least-stressed is unlikely to give a yield response to additional N. Optimal management requires matching rate of rescue N to crop need. Color from aerial photos can predict economically optimal N rate spatially across a field, and these predictions can be used to produce fertilizer rate control files. NVision Ag can currently produce N rate control files for all common N-only fertilizers.

NVision Ag can also support farmers who have partially-fertilized a field and want to use color-guided variable-rate application for the balance of the field. This approach requires the establishment of a high-nitrogen reference area with known boundaries in the field. Equations for calculating EONR are different than in the rescue N situation. Calibration research across a range of platforms has consistently shown that partly-fertilized corn that looks as good as the high-N reference early in the season should have a low rate of fertilizer applied (Scharf and Lory, 2002; Scharf et al., 2006; Scharf and Lory, 2009). Limited research suggests that fully fertilized corn that looks great is unlikely to respond to additional N.

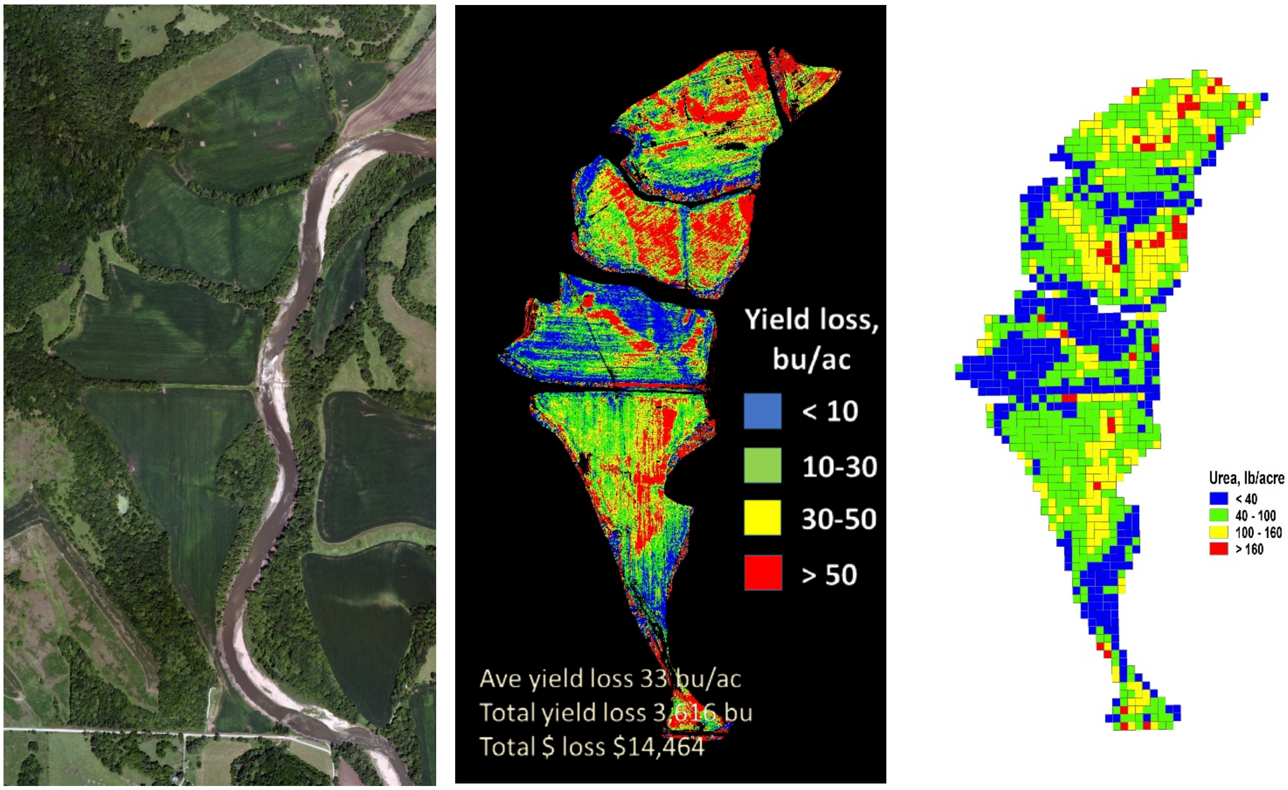


Figure 7. Aerial photo, yield loss map, and visual of rate control file for a 2015 field analyzed by NVision Ag.

Summary

Nitrogen loss due to wet weather can limit corn yields. Yield loss due to N deficiency can be predicted from crop color in aerial photos, helping farmers make sound business decisions about whether to purchase and apply additional N fertilizer.

NVision Ag (http://NVisionAg.com) is making these predictions available to farmers via a cloud-based platform.

Acknowledgements

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