# SATELLITE IMAGERY FOR SMALL PLOT RESEARCH AND PRECISION FARMING - NITROGEN RELATIONSHIPS IN IRRIGATED CORN

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## ABSTRACT

High quality satellite imagery that recently became available may be useful for predicting the N status of crops, need for additional N fertilization, and crop yield potential. Our objective was to determine if the high-resolution digital images from the QuickBird™ satellite launched in late 2001 had potential in predicting irrigated corn biomass and grain yields and available N at planting as indicated by leaf color on 27 July 2002 from conventional till and no-till research size plot areas. Overall, the strongest relationships with corn yields were obtained using the green (520-600 nm) and red (630-690 nm) wavelength band digital number (DN) values and NIR/red ratio values for both tillage and continuous corn N treatments. Weaker relationships were obtained with the blue and panchromatic DN values and corn yield. Except for near infrared (NIR), resulting DN values correlated fairly well with the level of available N at planting. No relationships ($r^2 < 0.12$) were found between NIR wavelength band (760-900 nm) and corn yields or available N. Results indicated that the QuickBird™ satellite imagery has potential for use in small plot research, developing N management zones for site-specific farming, and predicting irrigated corn grain and biomass yields.

## INTRODUCTION

Managing N fertility in crop production systems to attain a high N use-efficiency and minimize $NO_3$-N leaching potential has important agronomic and environmental significance. Site specific management of nutrients on a field scale basis has promise for optimizing grain yields and economic returns while minimizing the amount of nutrient, especially N, available for leaching and groundwater contamination (Khosla, et al., 2002). Management zones have been identified as a way of managing N more efficiently. Soil maps, grid sampling, electromagnetic soil conductivity, and Order 1 soil surveys have been used for defining management zones (Franzen et al., 2002; Anderson-Cook et al., 2002).

Satellite imagery has been used in agricultural research applications since 1972 when the Earth Resources Technology Satellite (ERTS-1) was launched (Bauer and Cipra, 1973). Spatial

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and spectral resolution of multi-spectral scanners has improved steadily since 1972, with the 'sharpest satellite image' currently available for civilian use being that from the QuickBird™ satellite[a] (DigitalGlobe, 2001), launched successfully in late 2001.

Aerial photography, satellite digital images, and ground based spectral radiometers (Bausch and Diker, 2001) have been used to identify the need to add N during the growing season to optimize yield potential. Scharf and Lory (2002) used aerial photographs and a ground-based spectral radiometer to calibrate the relationship between corn color and N need. They reported that corn leaf color was a significant predictor of N need, and that leaf color relative to well-fertilized corn in the same field was a far better predictor of N need than absolute color. Other research has shown that a good relationship exists between several of the color bands, especially green, of multispectral aerial images and crop yield and the need for sidedress N application (Shanahan et al., 2001; Osborne et al., 2002). Research shows definite potential to use aerial imagery as a means of managing N and predicting corn grain yields.

Landsat thematic mapper images are readily available at low cost, but the relatively large pixel size (15 x 15 m panchromatic and 30 x 30 m multi-spectral) has limited its use in identifying small zones within fields that may need different management. Satellite imagery has not been used extensively in small plot research in the past, due to the relatively large pixel size (10 to 30 m). Smaller pixel size from high resolution satellite data would allow greater use in small plot research and in identifying management zones within a field. Irrigated farmers often have small field sizes and could benefit from satellite imagery that had high quality and small pixel size.

In November 2001, the QuickBird™ (DigitalGlobe 2001) satellite was launched which provides satellite images with smaller pixel size (2.4 x 2.4 m) than available from most other satellites. Imagery from this satellite taken on 27 July 2002 of the Colorado State University, Agricultural Research, Education, and Development Center (ARDEC) was made available to the Soil and Crop Science Department for evaluation. This paper presents the relationships developed between the panchromatic and multispectral digital numbers and the corn grain and biomass yields, and available N level at planting from a corn N fertility study being conducted by the USDA-Agricultural Research Service at the ARDEC site near Ft. Collins, CO.

## METHODS AND MATERIALS

Nitrogen fertility and tillage treatments were established on an irrigated Fort Collins clay loam soil at the Agricultural Research, Development, and Education Center (ARDEC) near Fort Collins, CO as described by Halvorson et al. (2002). Two tillage treatments, no-till (NT) and conventional-till (CT) treatments were established in 1999. The CT treatment consisted of preparing a seedbed using disking and plow tillage followed by roller harrowing and leveling operations. In 2002, five N fertilizer rates (0, 34, 67, 134, and 201 kg N/ha) were present in the CT system and six N rates (0, 34, 67, 101, 134, and 201 kg N/ha) in the NT system. Residual soil $NO_3$-N was determined to a depth of 90 cm in early April 2002 prior to N fertilizer application. A randomized complete block design was used with 3 replications for the NT and 4

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[a]Trade names and company names are included for the benefit of the reader and do not imply any endorsement or preferential treatment of the product by the authors or the USDA, Agricultural Research Service.

replications for the CT system. All plots were 10 x 14 m in size, except for the 67, 134, and 201 kg N/ha plots in the CT system were 10 x 42 m in size.

Corn (Pioneer 37H26LL) was planted on April 24, 2002. Growing season precipitation totaled 139 mm. Approximately 505 mm of irrigation water was applied to the corn during the growing season in 16 irrigations with a linear move irrigation system. Total biomass yields were estimated on September 16, 2002 by collecting 15 corn plants at random from each plot and using plant population counts from each plot to calculate an estimated biomass yield. Biomass yields are expressed on an oven dry basis. Grain yields were estimated at physiological maturity (November 5, 2002) by collecting the ears from two corn rows 7.62 m long. Grain yields are expressed at 15.5% moisture content.

Satellite imagery was collected on July 27, 2002 via QuickBird™ satellite with the image of the plot area at ARDEC provided by Digital Globe, Longmont, CO. The corn was in the VT/R1 growth stage in the CT plots and early VT stage in the NT plots. The satellite image was precision geo-referenced with ArcGIS[a] (ESRI, Redlands, CA). Using a procedure suggested by Cipra (2003), we created buffer zones 2.4 m inside each of the N plots and selected pixels occurring inside the buffer zones for analysis. The plot layout was digitized in ArcGIS and saved as a shapefile. The shapefile was buffered to one pixel (Cipra, 2003) and used to clip/extract spectral DN values from the imagery. Spectral data values (digital numbers - DN) for the four multi-spectral and the panchromatic bands were extracted using ERDAS Imagine[a] image processing software. Vegetation indices (VI) were calculated. DN and VI values were regressed in various combinations with measured crop and soil parameters. Normalized difference vegetation index (NDVI) and green normalized difference vegetation index (GNDVI), as well as NIR/red and NIR/green, were calculated for each plot. Regression analyses were performed using SigmaPlot[a] graphing software to compare spectral variables (or indices) with agronomic variables.

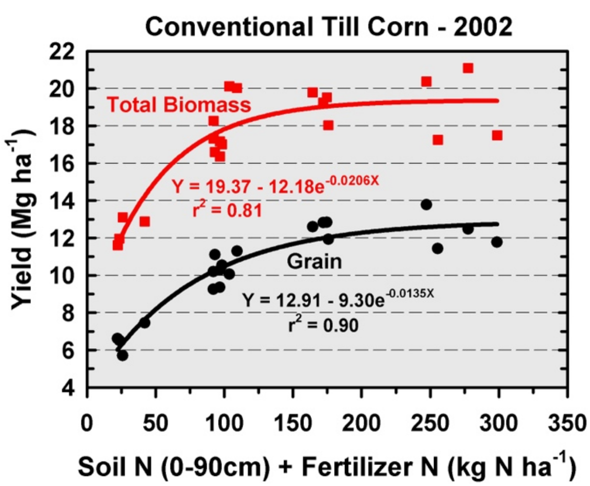


Figure 1. Corn grain and total biomass yield as a function of available N in the CT plots.

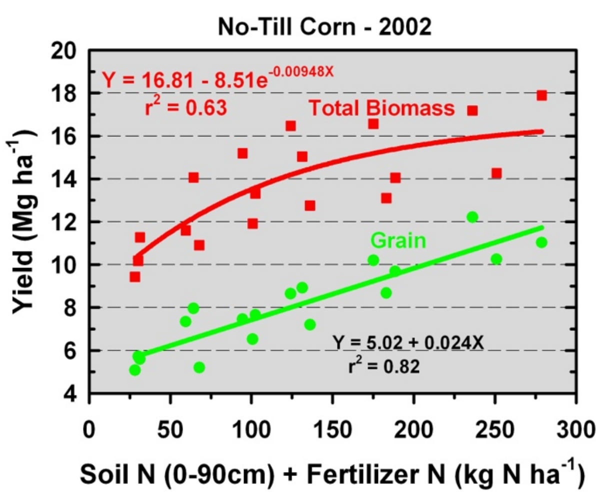


Figure 2. Corn grain and total biomass yield as a function of available N in the NT plots.

| Table 1. Constants for quadratic equations ($Y= a + bX +cX^2$) and regression coefficients for corn grain yield (Y) as a function of DN value (X) for CT and NT plots. | | | | |
|---|---|---|---|---|
| Color Factor | a | b constant | c constant | $r^2$ |
| CT Plots | | | | |
| Blue | -1409 | 14.44 | -0.0367 | 0.69 |
| Green | 296.6 | -1.786 | 0.0027 | 0.87 |
| Red | 133.0 | -1.296 | 0.0032 | 0.80 |
| NIR | 1264 | -2.778 | 0.0015 | 0.09 |
| Panchromatic | -1379 | 5.929 | -0.0063 | 0.69 |
| NIR/Red | 49.49 | -19.64 | 2.161 | 0.83 |
| NIR/Green | -34.52 | 17.45 | -1.045 | 0.69 |
| NDVI | -535.4 | 14.13 | -0.0909 | 0.62 |
| GNDVI | -2.509 | -0.4556 | 0.0135 | 0.69 |
| NT Plots | | | | |
| Blue | 1214 | -11.01 | 0.0251 | 0.76 |
| Green | 345.1 | -2.056 | 0.0031 | 0.89 |
| Red | 433.9 | -4.940 | 0.0142 | 0.83 |
| NIR | -700.7 | 1.469 | -0.0008 | 0.12 |
| Panchromatic | 846.7 | -3.095 | 0.0028 | 0.50 |
| NIR/Red | -3.425 | -1.066 | 0.4983 | 0.61 |
| NIR/Green | -47.14 | 27.72 | -3.1825 | 0.62 |
| NDVI | -506.4 | 13.63 | -0.0899 | 0.54 |
| GNDVI | -54.55 | 1.789 | -0.0110 | 0.62 |

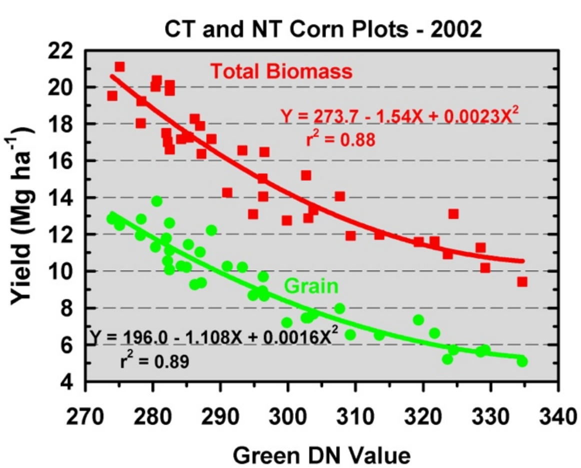


Figure 3. Relationship of biomass and grain yields to green DN value for all CT and NT plots.

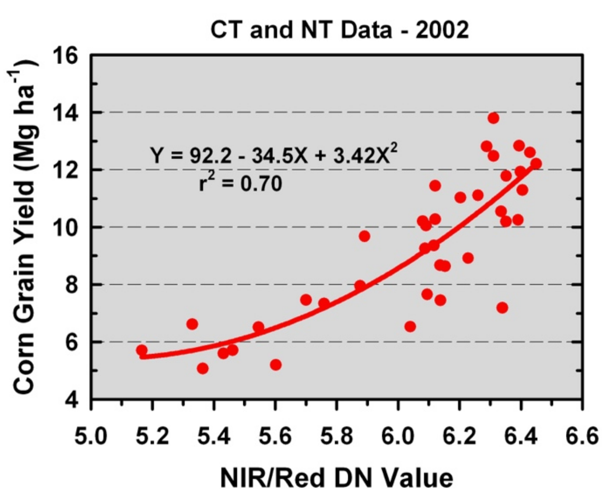


Figure 4. Relationship of grain yield to NIR/red value for all CT and NT plots.

## RESULTS AND DISCUSSION

The key relationships between the satellite spectral measurements and crop and soil parameters for combined data from the NT and CT plots will be shown graphically for the green and NIR/red wavelength bands. Regression relationships for grain yield with blue, green, red, NIR, and panchromatic DN values, and NIR/red, NIR/green, NDVI, and GNDVI values will be shown separately in Table 1 for the NT and CT plots.

Total corn biomass increased with increasing level of available N within both tillage treatments (Fig. 1 and 2). Corn grain yields also increased with increasing level of available N (Fig. 1 and 2).

The relationships between each of the wavelength bands and corn yield are presented in Table 1 as regression equation constants and $r^2$ values for each tillage treatment. Combining data from both tillage treatments, the best relationships were with the green DN values for grain yield as well as biomass (Fig. 3) and for the NIR/red DN ratio and grain yield (Fig. 4). The excellent relationship between green DN and grain yield and total biomass is in agreement with the observations reported by Shanahan et al. (2001) and Osborne et al. (2002). The panchromatic DN values also showed fairly good relationships to grain and total biomass (data not shown) yields, especially for the CT plots.

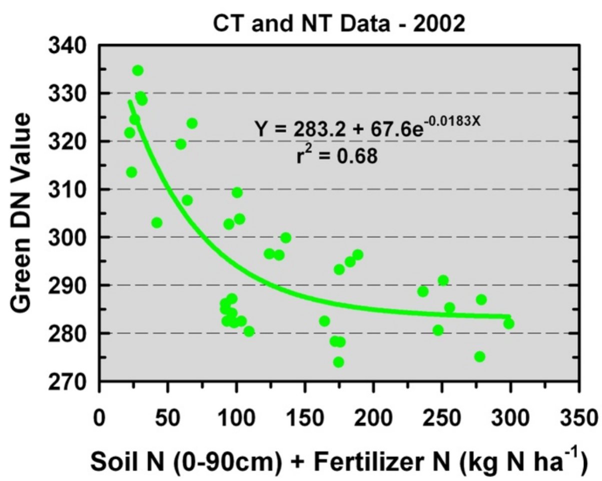


Figure 5. Influence of available N (soil N plus fertilizer N) at planting on green DN values in CT and NT plots.

An exponential decay function was used to develop relationships between the various wavelength DN values and the level of soil N plus fertilizer N available at planting. An example of the relationship between the green DN number and soil plus fertilizer N is shown in Fig. 5. The green DN numbers were well correlated with N fertility status of the corn crop and could be used to identify zones of low N fertility.

Spectral DN values in the visible bands (green and red) were highly correlated with corn biomass, grain yield, and soil available N, however, the NIR (near infrared) band showed no relationships to any agronomic variables (Table 1). The variable, soil N plus fertilizer N at planting, was more highly correlated with spectral DN values than fertilizer N applied at planting alone. Exponential equations provided the best fit to the plant available N data. The normalized vegetation indices, NDVI and GNDVI, were generally not as highly correlated with crop parameters as individual bands or the NIR/red ratio.

## SUMMARY AND CONCLUSIONS

The results from this study indicate a potential for using QuickBird$^{TM}$ satellite imagery to complement aerial imagery and ground based sensors in managing N in irrigated corn fields. The small pixel size also lends itself for potential use in small plot research, which could be used to more accurately calibrate DN values with well-managed crop plots for future extrapolation to larger field areas.

The green (520-600nm) and red (630-690 nm) bands tended to be the most highly correlated with crop parameters overall. The high resolution QuickBird$^{TM}$ satellite imagery we used had spectral and spatial parameters which made it useable in our small plot research in irrigated corn. Plots size as small as 10 x 14 m provided sufficient location accuracy and pixel count to allow monitoring of crop N status. Depending on availability, turnaround time, cost, and other factors, digital precision satellite imagery could have utility for commercial agriculture and for research.

The strong correlations of the multi-spectral and panchromatic DN values with grain yield and total biomass in this study show potential for researchers and crop consultants to use the QuickBird$^{TM}$ imagery to predict potential corn grain yields and/or develop N management zones for variable rate N application.

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