COMPARISON OF REMOTE SENSING IMAGERY FOR NITROGEN MANAGEMENT

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ABSTRACT

Different types of remotely sensed imagery are available and many claims have been made about the usefulness of these data for nutrient management. We set up an experiment at the Beltsville Agricultural Research Center, with three planting dates of maize with five levels of applied nitrogen. Color infrared photographs with a pixel size of 0.2 m, taken from a radio-controlled model aircraft in August, showed strong relationships between vegetation indices and plant density, but no relationships with applied nitrogen. AISA Airborne Imaging Spectrometer data with pixel sizes of 2.5 m showed relationships with both density and applied nitrogen in August, because of the additional bands on the AISA sensor. Because most vegetation indices are highly correlated, there needs to be more than 3 or 4 broad bands in a sensor to separate nitrogen deficiency from differences in plant density.

Keywords: Airborne remote sensing, radio-controlled model aircraft, maize, nitrogen management

INTRODUCTION

Selection of a specific sensor on board a specific remote sensing platform is a compromise among spatial resolution, spectral resolution, and cost. Spatial resolution is determined by the pixel size; generally, imagery with small pixel sizes cover smaller areas on the ground and these images have large map scale. Spectral resolution is the number of bands on the sensor, and whether these bands cover a small or large wavelength interval (narrow and wide bands, respectively). For most image acquisitions, there is a tradeoff between pixel size and cost, the smaller the pixel size, the larger the cost (Fig. 1). One of the most important questions for nutrient management is the optimum compromise between image availability and cost (Moran et al., 1997).

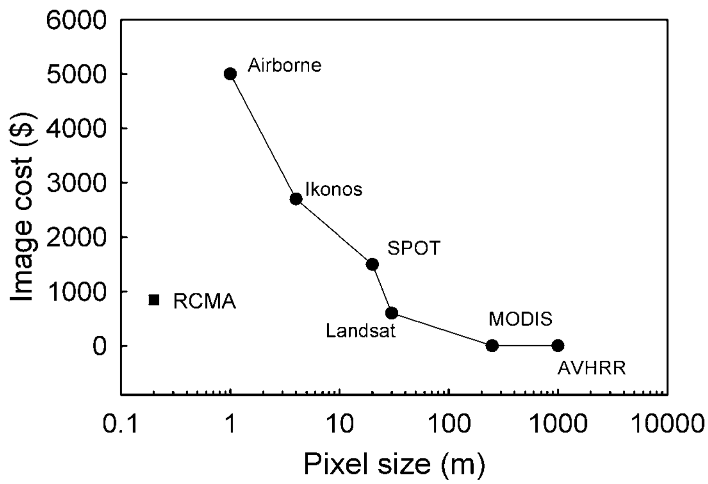

Fig. 1. Image cost for various imagery. RCMA stands for Radio-Controlled Model Aircraft; the cost is for RCMA is for the entire system: almost ready-to-fly model plane with hardware, and camera, film and developing.

Quilter and Anderson (2001) suggested radio-controlled model aircraft (RCMA) with a mounted camera can provide a low-cost method of obtaining aerial photographs. Flying these aircraft is a hobby enjoyed by people all over the world, and in response to the large demand, there have been many technological advances in engines, materials, and hardware. There are several private companies now offering image acquisition services using various RCMA: fixed-wing aircraft, helicopters, and blimps. Our findings suggest that the cost for RCMA imagery is significantly lower than expected for the small pixel sizes (Fig. 1). On the other hand, there are significant limitations to the area covered and the radiometric resolution of the camera/film used to acquire the imagery.

We compare RCMA imagery with an airborne multispectral sensor system (AISA) to determine if these data are adequate for nutrient management in precision agriculture. The pixel size is certainly desirable, particularly for the cost.

MATERIALS AND METHODS

All model aircraft are susceptible to wind and flight failures. Fixed-wing aircraft can tolerate moderate levels of wind, and can glide to a landing in case of flight failure. A “Almost Ready-to-Fly” fixed-wing trainer aircraft (Hanger 9 Xtra Easy, Horizon Hobby, Champaign, Illinois) was assembled from a kit with a MDS 0.41 cubic inch engine and a JR XF421EX five-change radio transmitter. An Olympus XB41F automatic camera was mounted on the aircraft fuselage with a constructed balsa-wood box. The camera shutter button was operated using a servo motor connected to the fifth channel of the radio transmitter, so pictures were taken under the control of the pilot. Taking one picture per second along a flight line at 100 m altitude results in a picture overlap of about 50%, allowing for easier geographic registration of the multiple images. The camera lens has a focal length of 28 mm (wide angle). The film used was Kodak (Rochester, New York) Ektachrome Professional Infrared EIR slide film, with a film speed of ISO 200. The front of the camera was covered with two sheets of yellow cellophane film, to serve as a yellow filter for the color infrared film and to protect the camera from oily engine exhaust. The default film speed of the camera was ISO 100, so the slides were overexposed, which was compensated by underdevelopment with the E6 process. Color infrared slides were scanned at 1600 lines per inch.

The expense of multiple aircraft overflights was reduced by having three planting dates of maize: an early planting on May 2, 2001, a middle planting on May 31, and a late planting on June 15, 2002 (Fig. 2). For each planting date, eleven plots of 30.5 m by 36.6 m were established (except for the third plot which was 36.6 m by 36.6 m). The field was split with plots 1-6 in one block and 7-11 in a second block, and plots within each block were randomly assigned a nitrogen treatment (Fig. 2). The nitrogen levels were 0%, 25%, 50%, 100%, and 150% of 165 kg N/ha applied as side-dress.

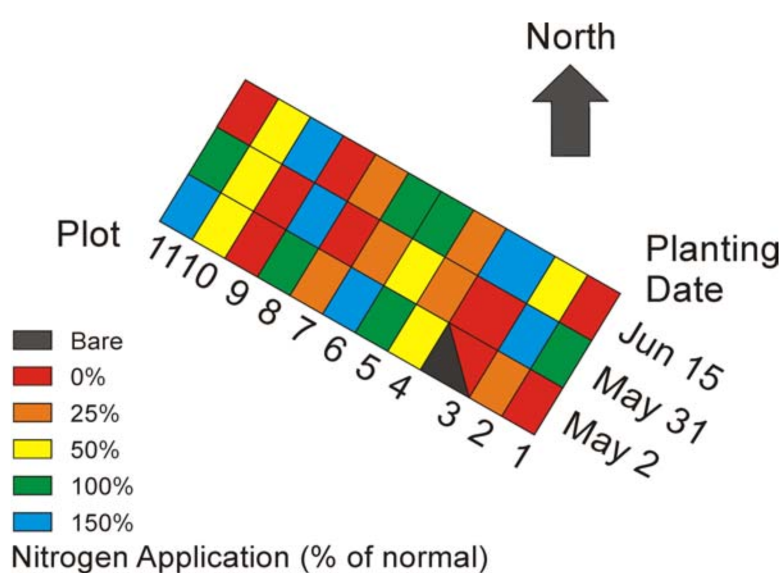

Fig. 2. Experimental design with different planting dates and levels of applied nitrogen in maize at the Beltsville Agricultural Research Center. The bare area in plot 3 (early planting date) had a very low initial density of seedlings, and was maintained as bare soil for image calibration.

AISA images (Specim, Spectral Imaging Ltd, Oulu, Finland: www.specim.fi) were acquired from a private company (3Di LLC, Easton, Maryland) on two dates: July 7 and August 22, 2001. These data were georeferenced with a differential global positioning system and inertial guidance unit to an accuracy of 5 meters. The number of bands are user selectable; the data acquired had 34 narrow bands from 400 to 900 nm wavelength. The radiance values for each band were corrected to reflectance using an uplooking pyranometer.

Two vegetation indices were calculated from the plot average reflectances. The first is the normalized difference vegetation index (NDVI):

$$NDVI = (R_{806} - R_{681})/(R_{806} + R_{681}) \quad [1]$$

whereR_{806} is the near infrared band and R_{681} is the red band for the AISA image. Also, the Modified Chlorophyll Absorptance Reflectance Index (MCARI) from Kim (1994) and Daughtry et al. (2000) was calculated:

$$MCARI = [(R_{698} - R_{681}) - 0.2(R_{698} - R_{549})](R_{698}/R_{681}) \quad [2]$$

which estimates the depth of the chlorophyll absorption feature in a reflectance spectrum.

RESULTS AND DISCUSSION

There were large differences in plant density among the plots caused by differences in soil texture. Areas of coarse soil texture followed former roads and walls when the field was used for pig breeding, a factor which was not known when the experiment was established.

Average plot NDVI from the RCMA and AISA imagery were highly correlated to plant density, but not correlated with applied nitrogen level (Fig. 3 and Fig. 4). MCARI could not be calculated using the RCMA image because the color infrared film has only three broad bands (green, red and near infrared). The MCARI index was correlated to applied nitrogen level for the August-22 AISA image, but not for the July-7 AISA image (Data not shown).

The differences in density were more apparent with visual inspection with the RCMA imagery (Fig. 3) than for the AISA imagery (Fig. 4). This is expected because the pixel size of the RCMA image was about 0.2 m whereas the pixel size for the AISA image was about 2.5 m.

One of the problems with RCMA imagery was the noticeable effect of canopy anisotropy, where the center of the image is brighter than the edges (Fig. 3). This was in part due to the wide angle used in the camera. Even though canopy anisotropy affects vegetation indices (Walthall et al., 2000; Walter-Shea et al., 1997), NDVI calculated from the August-22 AISA image were correlated to NDVI of the August-29 RCMA image (Fig. 5).

Whereas the differences in plant density could be more easily seen in the RCMA image, vegetation indices with larger pixel size picked up the differences among plots. Since NDVI was not related to applied nitrogen, either for the AISA or RCMA imagery, RCMA imagery with color infrared photographic film can not be used for nutrient management, but may have other uses in precision agriculture. It was the higher spectral resolution of the AISA sensor that was able to detect various levels of applied nitrogen in maize.

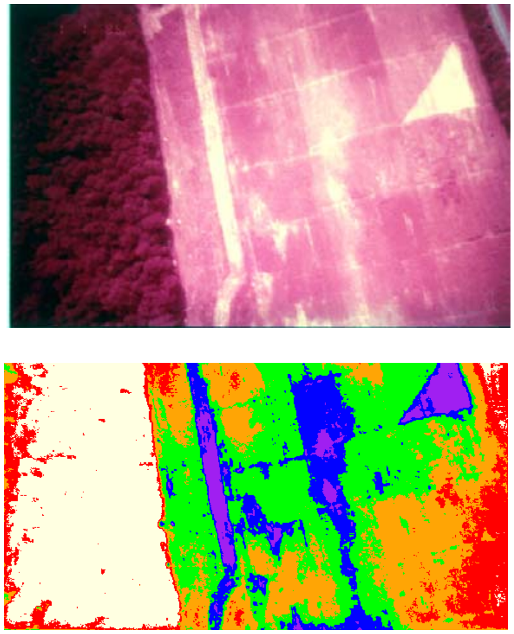

Fig. 3. A. Color infrared photograph acquired by the RCMA on August 29, 2001 and **B.** NDVI calculated from the near-infrared and red bands. Cool colors represent low NDVI and warm colors represent high NDVI.

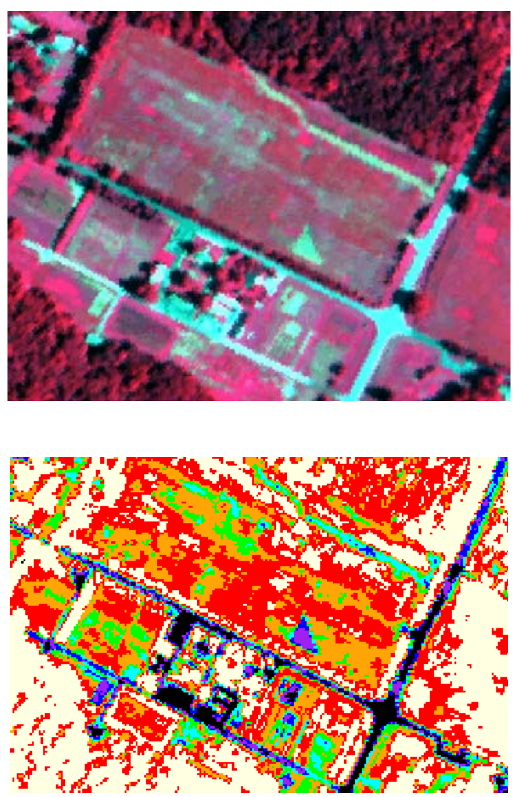

Fig. 4. A. Color infrared image acquired by the AISA on August 22, 2001and **B.** NDVI calculated from wavelengths of 802 and 681 nm. The color scale is the same as Fig. 3.

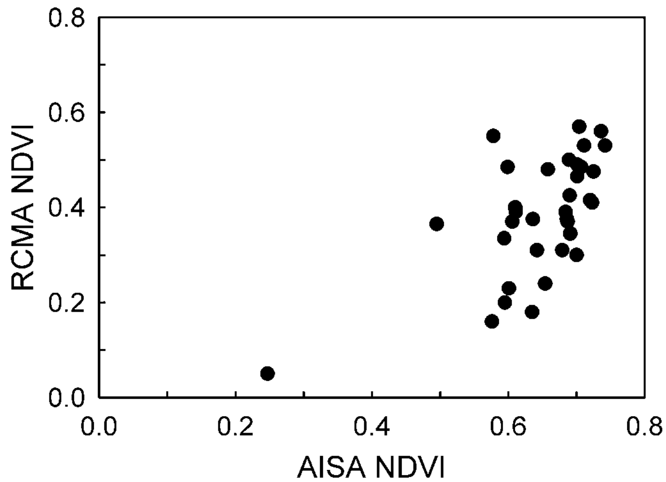

Fig. 5. Comparison of NDVI between the AISA and RCMA imagery using the averages for each plot. The lowest NDVI for both the AISA and the RCMA was the bare soil area in plot 3.

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