VISUAL CORRELATION OF AERIAL IMAGERY WITH TOPOGRAPHY AND CROP YIELD

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Abstract

A study is currently being conducted on several farms to evaluate the usefulness of aerial imagery of soil and of a growing crop to delineate within-field management zones for the purposes of site-specific management. Presented is information for one site in Kent county Ontario for which correlations between aerial images taken of the soil and of the growing crop with the spatial patterns of measured topography, soil texture, and corn yield were examined. Visual interpretation indicated a very good relationship between the reflectance in both of the images with topography and yield patterns in the field. It was concluded that, although the images may be useful in defining the yield patterns in the field, the usefulness in defining the yield response to crop inputs has yet to be evaluated.

Introduction

Traditionally, soil fertility research has been conducted using experimental designs, which attempted to minimize spatial variability. These methods are an effective means of investigating individual processes due to the limited variability of other factors such as landscape position, soil texture, soil moisture holding capacity, fertilization practice, etc. The results from these experiments have been used to develop soil management recommendations with the basic assumption that, on average, farm fields would respond similarly to the test plots. The recommendations built on this assumption undoubtedly result in over-application of nutrients in some areas of a field and under-application in others, resulting in both economic (loss of yield due to under application or fertilization without a response) and environmental concerns (excess nutrients may be lost to surface or ground water). Researchers have recognized that there is considerable variability in soil nutrient bioavailability and plant nutrient requirements from field to field and even within a field, but lacked the means to deal with this variability.

The availability of technologies such as global positioning systems (GPS), geographic information systems (GIS), on-the-go sensors, variable rate technology, remote sensing, and geostatistics have provided the opportunity for gathering, analyzing, and mapping the variability of soil and crop parameters. With the ability to produce accurate maps and vary the rate of farm inputs such as fertilizer on-the-go, the use of site specific management to effectively deal with soil heterogeneity is technologically feasible. With this in mind, this technology is currently being used to vary the rate of application of farm inputs in hopes of minimizing the economic and environmental concerns.

To conduct site-specific management, an expert map that delineates management zones in the field is required. There are several approaches currently being evaluated or in use. Some of these approaches use one of the following to delineate management zones within a field; soil classification, topography, direct response data, nutrient replacement, grid soil sampling, and/or use of remotely sensed imagery.

In Ontario, the most widely used commercial method to-date to characterize soil nutrient variability has been based on grid sampling, with grid sizes often based on the acceptability of the cost rather than the usefulness of the information being gathered. The field-specific characteristics of the soil test levels (i.e. the range of soil test levels and the nature of the spatial variability) ultimately determine the sampling intensity required. The increased income from reduced inputs and/or increased yields must off-set not only the costs of characterizing the soil variability, but also the technology required to implement variable application of fertilizer. Research such as that conducted by Lauzon (2002), indicates that in Ontario one would be required to soil sample using a 30 m or smaller grid (10 times as many samples as are currently being taken) in order to adequately evaluate the spatial variability of soil test P, Soil test K and soil pH. It was concluded that at this sampling intensity there would be little hope of recovering the cost of sampling in reduced fertilizer costs or increased revenues.

Remote sensing facilitates the collection of large amounts of timely information relating to both soil and crop parameters and reduces the need for intensive ground based sampling. Therefore, remote sensing may be valuable tool for site-specific crop management, and is increasingly becoming of interest in this area (Moran et al., 1997). In particular, interest has been generated relating to the use of aerial imagery in the process of defining management units (Blackmer and White, 1998; McCann et al., 1996).

Evaluation of aerial imagery for use in defining within-field management zones

Soil properties influence the amount of energy that is reflected from a soil surface (Baumgardner et al., 1985; Ben-Dor, 2002). Therefore, variation in soil reflectance patterns apparent in bare soil aerial images may be interpreted and used to identify areas within a field that can be considered management units. However, the use of aerial imagery for the purpose of defining management units has focused primarily on the use of mid-season images of growing crops. Evaluation of the variability observable in bare soil aerial images and images of growing crops suggests that the use of bare soil aerial images has considerable potential (Milfred and Kiefer, 1976).

This paper examines some of the initial findings which relate the spatial patterns seen in aerial images to that of crop yield, soil properties and elevation.

Materials and Methods

As part of a larger study, 26 farm fields ranging in size from 3 to 40 ha have been studied since 1995 in an effort to identify management units for site-specific nitrogen management. All fields had a cropping rotation of corn-soybean or corn-soybean-small grain with tillage systems ranging from no-till to conventionally tilled.

The Cameron Farm was part of this long term project was selected as example for this study. The site is located in Southern Ontario in Kent County. Yield monitor data for the Cameron site has been collected since 1996. In 1995, the site was soil sampled (0-15 cm) on a 30 m grid and the samples were analyzed for levels of soil test P (sodium bicarbonate extractable), soil test K (ammonium acetate extractable), soil pH (1:1 soil: water) and texture (hydrometer method). Elevation mapping was performed using a high-resolution differential global positioning system mounted on an ATV, and digital terrain modeling was performed using Surfer (Golden Software, 2002). Cropping sequences and general site/soil characteristics are given in Table 1.

In 2001 aerial imagery was collected at approximately a 25cm pixel size. A visible [red-green-blue] and near-infrared image was captured simultaneously and with post-processing was spatially registered. Images were taken in the spring just after planting on 20 May and approximately at corn silking, 31 July. Black and white aerial images taken in a 1978 aerial imagery survey conducted by the Ontario government were also attained for the Cameron site.

The spatial patterns of seen on each of the images collected were visually compared to each other and to that of the spatial patterns of crop yield, topography, and soil texture.

Results and Discussion

The soil classification, field size and the cropping sequence over the years of the experiment are given in Table 1. Also included in Table 1 are the range and average sodium bicarbonate extractable P, ammonium acetate extractable K, and soil pH that were found at the two sites from soil samples taken on a 30 m grid. A representation of the topography of the site is given in Figure 1. The site has a complex topography with a large low-lying area on the Southeast side of the field.

The krigged results of soil textural analysis of the top 15 cm are given in Figure 2. The site has a high sand content which ranged from 26% to 96%. The texture was visually related with topography; with the low-lying areas having a finer texture than the high topographic points in the field.

Yield results for the Cameron site are given in Figures 3 to 5. In each case the yield scale on the maps was set based on the mean and standard deviation of the yield results from that year. The scale comprised of ±0.2, ±0.6, ±1.0, ±2.0, ±4.0, ±6.0 standard deviations from the field mean yield. By setting the scale this way one is able to visually compare the relative spatial patterns of yield from year to year and from crop to crop even though numerically the scale of the yield may change.

At the Cameron site one can see the similarity in the yielding patterns of corn and soybean between years (Figure 3 to 5). In 1998, half of the field was planted to corn (southwest side of the field) and half was planted to soybean (Northeast side of the field). From this year, one can see a continuation of the yield pattern from the corn to the soybean area of the field. In most years the low-lying areas of the field tended to have better yields than the higher topographic positions. This yield pattern is likely due to water availability at this generally sandy site. The low lying areas of the field generally had a finer texture which is likely to have a greater moisture holding capacity and presumably less likely to result in moisture stressed plants (or shorter periods of moisture stress) than the higher topographic areas and the areas with greater sand content in the field.

The aerial images taken in 2001are given in Figure 6a for 20 May and Figure 6b for 31 July. The images are false colored images. By false colored it is meant that the near-infrared wavelengths are presented in the red band, the green wavelengths are presented in the blue band and the red wavelengths are presented in the green band.

The reflectance in the bare soil image would be most affected by changes in soil moisture content and soil organic matter content. With increasing water content or organic matter content resulting in a greater absorbance. When the image was taken on 20 May, the soil was dry at the surface. Therefore, much of the contrast seen is likely due to changes in organic matter content as seen in Figure 6a. However, this site used conservation tillage, so it is likely that surface residue may influence the reflectance patterns seen.

Healthy plants tend to reflect more light in the near-infrared range and absorb more in the red and green wavelengths than do stressed or less developed plants. In the case of the image taken on 31July (given in Figure 6b) the areas of greater reflectance in the near-infrared and greater absorbance in the red and green wavelengths (presumably healthier plants) are indicated by a dark red visible color. The presumably poorer plant health areas of the field appear closer to white due to the increased reflectance in the green and red wavelengths.

An attempt to visually categorize and identify spatial patterns of reflectance from the 31 July aerial image is given in Figure 6b. The polygon map generated from the categorization process was then overlaid on the 20 May image, textural maps (Figure 2) and the yield map for 2001 (Figure 5). One can see a great deal of similarity in the yield patterns which tended to be at least visually stable over the years and what is indicated in the images of the soil and of the growing crop. Visually the darker areas on the aerial images relate to the higher yielding, lower lying (with respect to adjacent areas in the field), finer textured areas in the field.

At the Cameron site, the pattern of yield is clearly defined by the visual reflectance from this site. All of the areas that were generally found to be higher yielding are identified well on the two aerial images from 2001 by a slightly darker color. One can clearly see the visually darker area in the south east side of the field and the intermixed darker areas in the North west side of the field which corresponds to the low lying areas of the field which were generally a higher yielding. This same pattern is also evident on the airborne imagery taken in the spring of 1978.

Conclusion

It has been shown that for the Cameron site, the aerial images are related, at least visually, to the spatial patterns of yield. What is currently required is an unbiased method of determining these zones. Further testing of methodologies over a wide range of soils, field complexities and climates is needed to ascertain the usefulness of the aerial imagery. Although, there is a relationship between yield and the aerial imagery, whether or not this can be related to yield response is yet to be seen and is under investigation.

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Table 1: Cropping history and background site information for the Cameron site

Location		Cameron Site
Field Size		19 ha
Soil Classification		Brookston Silt Loam, Berrien Sand and Granby Sand (Wilson, 1994)
Cropping History		1996 Soybean 1997 Corn 1998 Corn-Soybean 1999 Corn 2000 Soybean 2001 Corn
Soil Test P	Minimum	3
	Maximum	72
	Average	22
Soil Test K	Minimum	40
	Maximum	283
	Average	136
Soil pH	Minimum	4
	Maximum	7.7
	Average	6.1

Figure 1. Spatial patterns of elevation for the Cameron farm

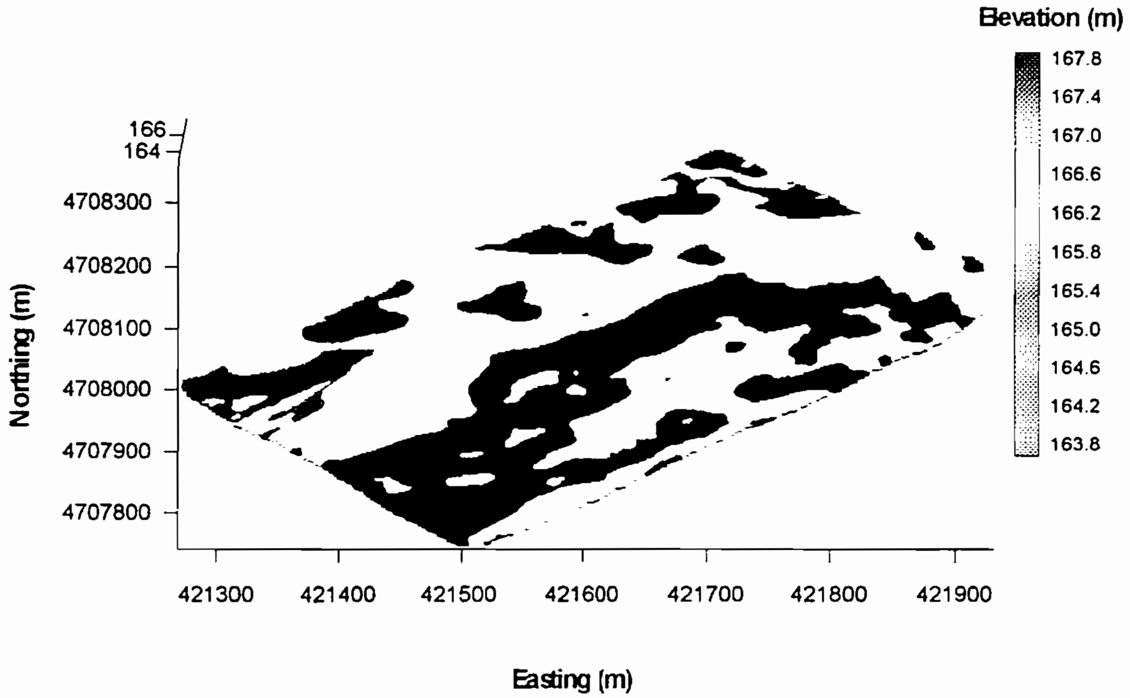


Figure 2. Textural maps for the Cameron site

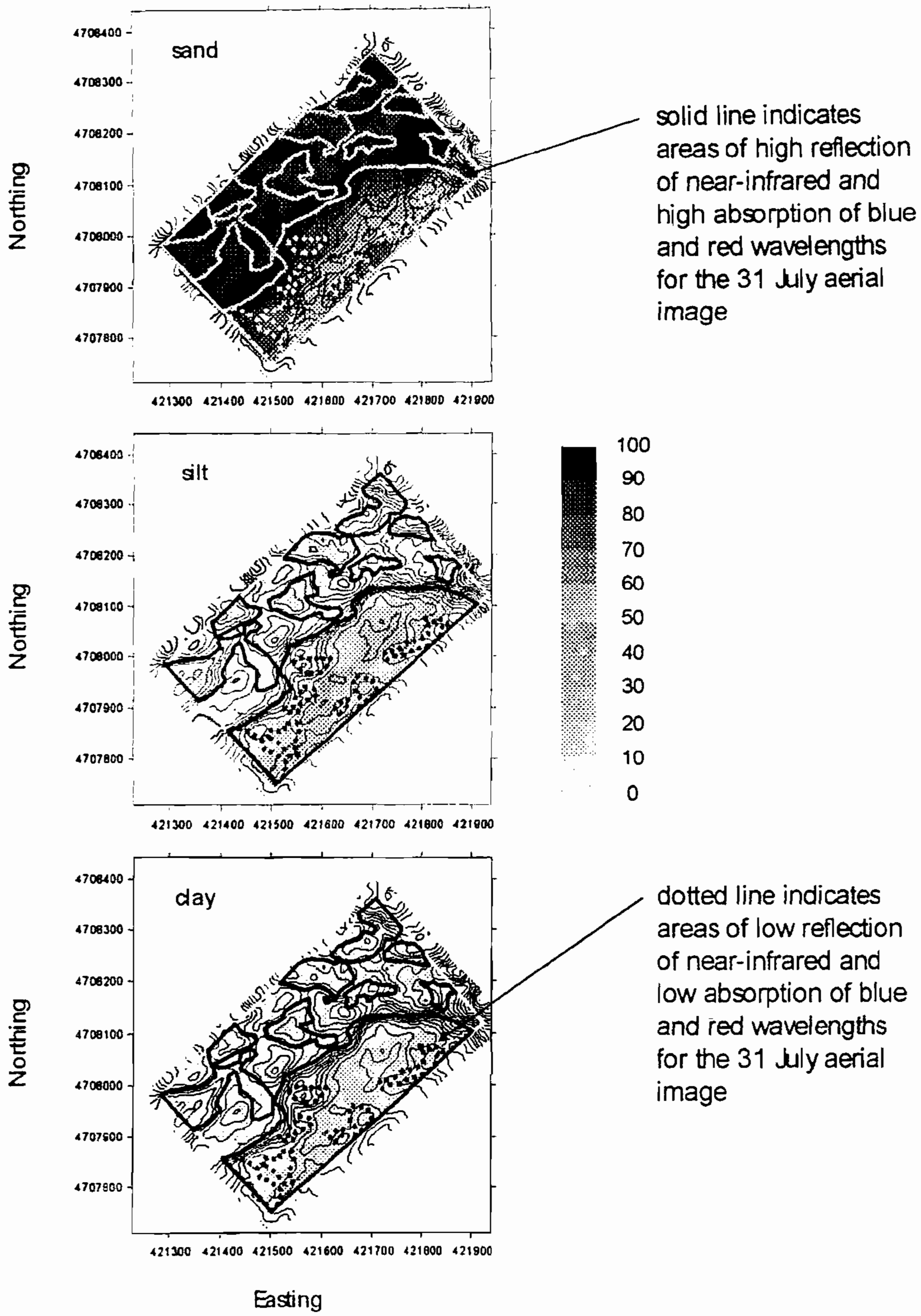
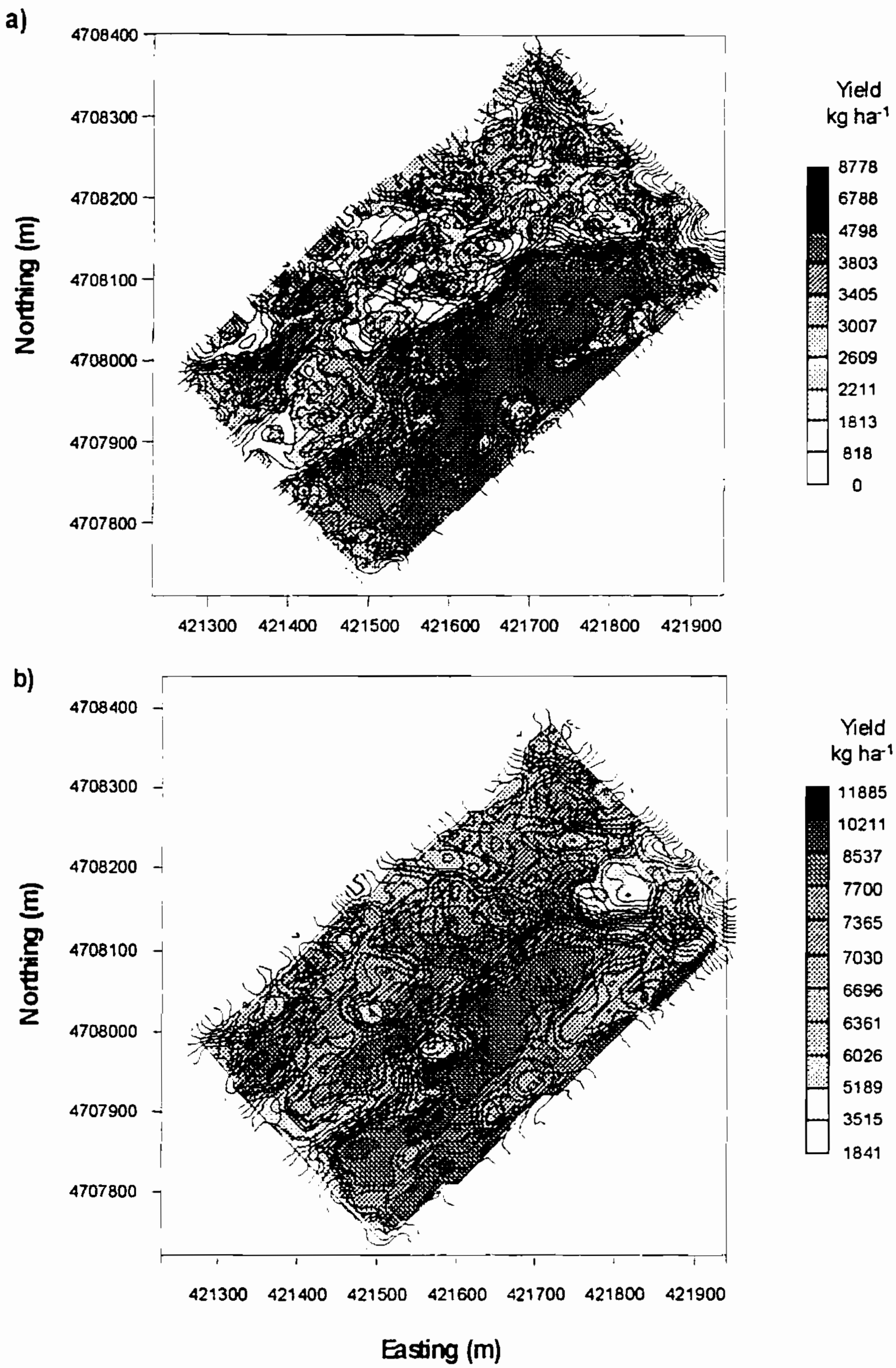
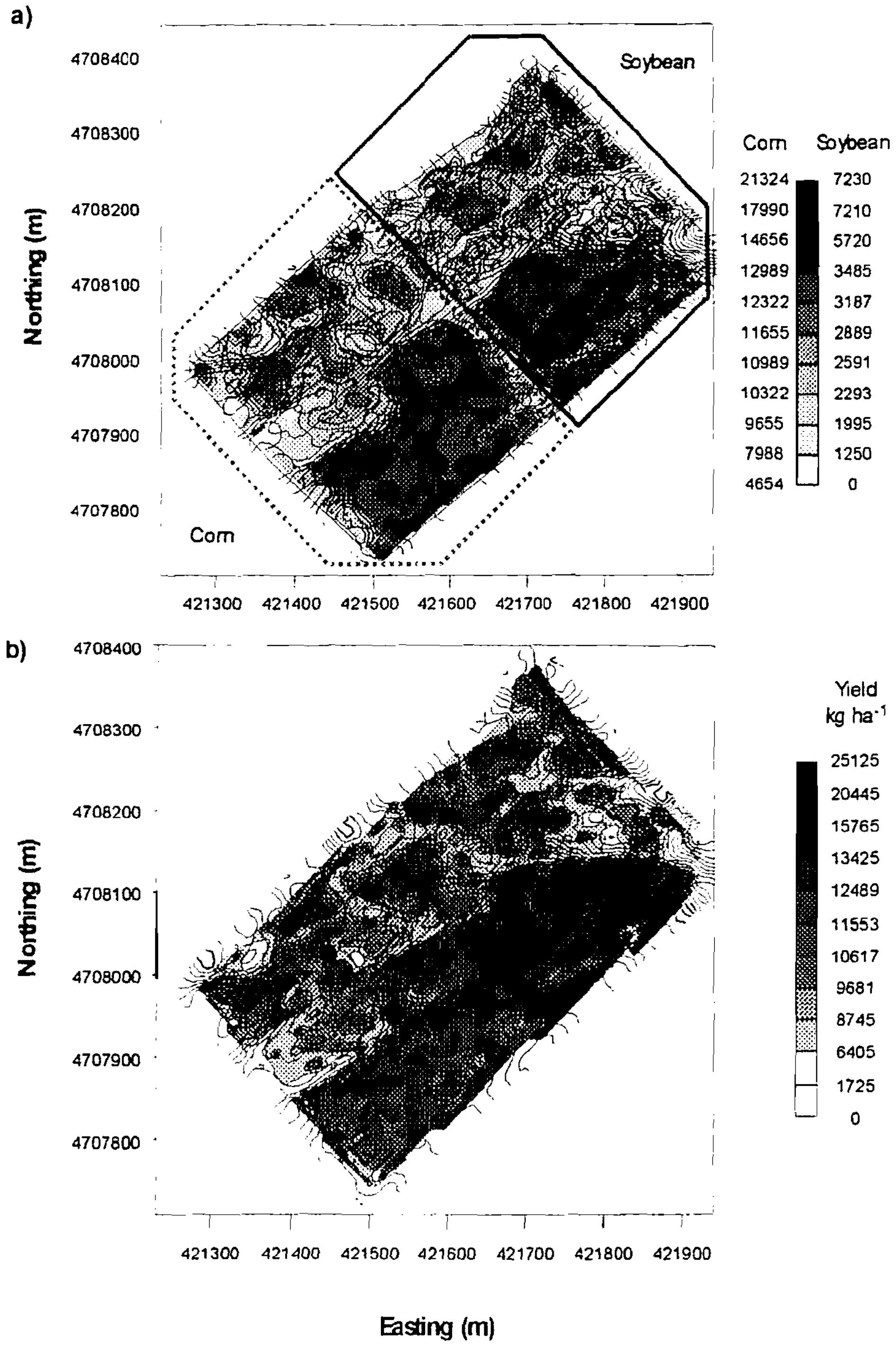


Figure 3. Spatial patterns of yield for the Cameron farm in 1996 and 1997



a 1996 yield map (soybean)
b 1997 yield map (corn)

Figure 4. Spatial patterns of yield for the Cameron farm in 1998 and 1999



a 1998 yield map (soybean/corn)
b 1999 yield map (corn)

Figure 5. Spatial patterns of yield for the Cameron farm in 2001 with spatial patterns from the 31 July aerial imagery

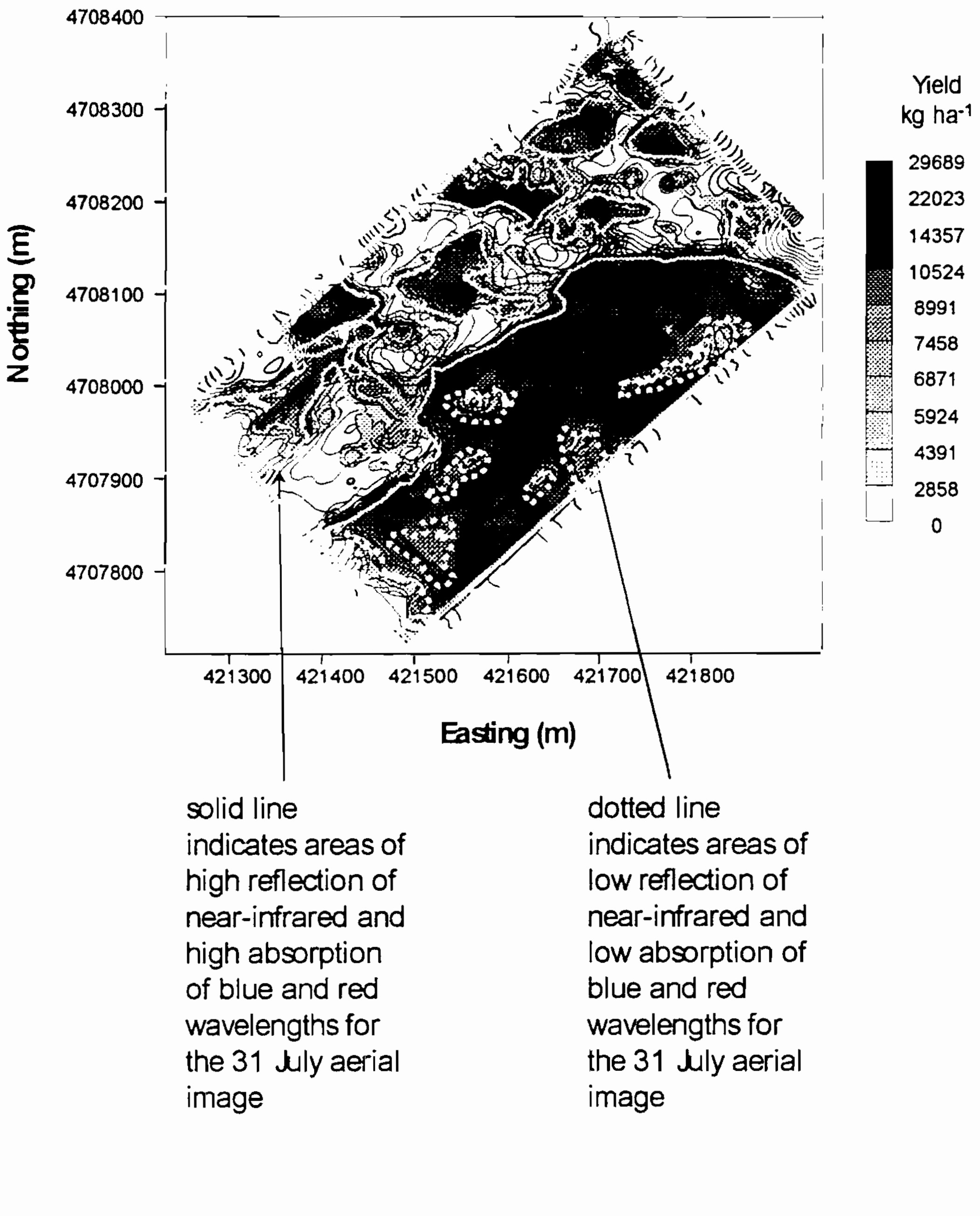
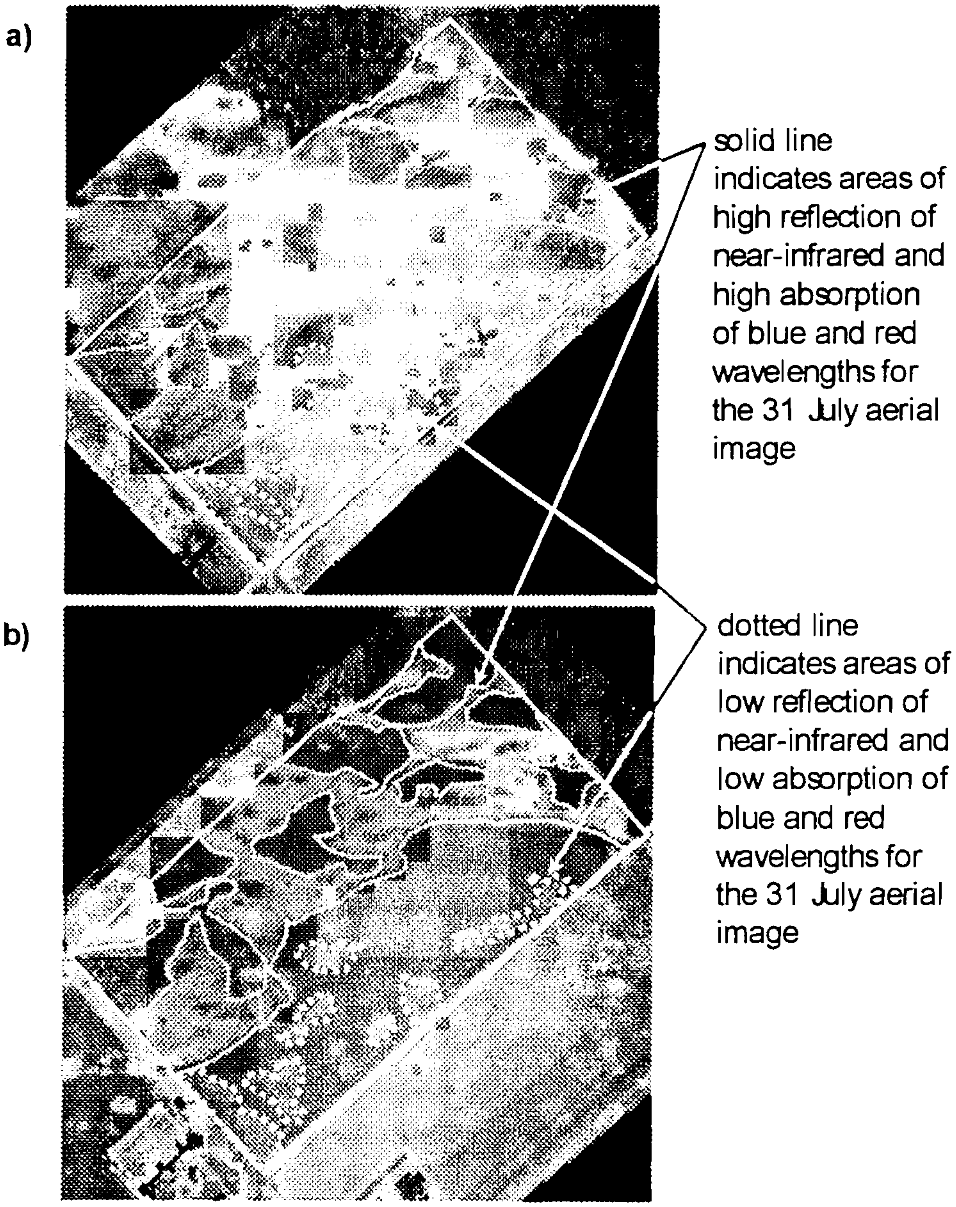


Figure 6. Aerial images of the Cameron farm with spatial patterns from the 31 July aerial imagery



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