Quantification of Ground Cover in Cover Cropping Systems: Image Analysis Using Open Source Tools

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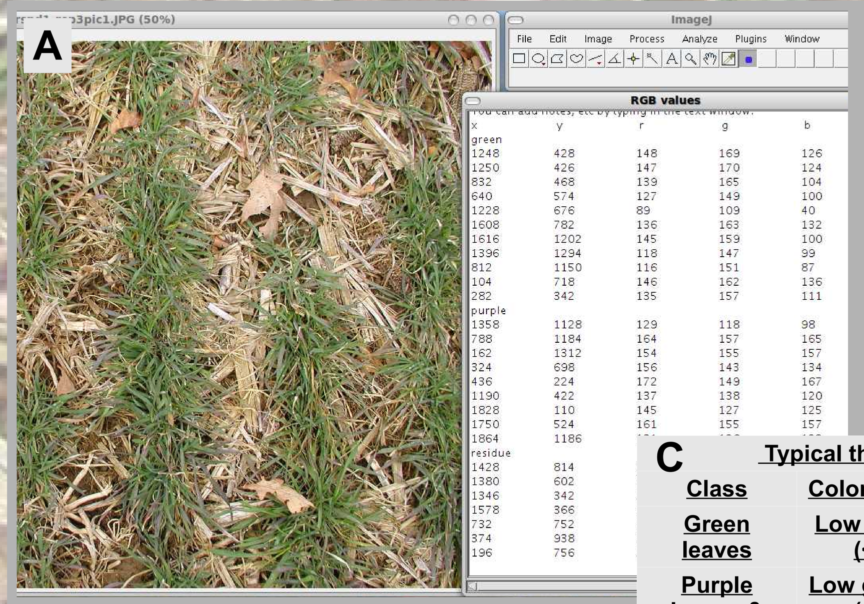
I. Objective

Find a tool to determine relative ground cover of living plants, plant residues, and bare soil by batch processing digital images.

II. Introduction

- Ground cover by crops or crop residues is an important modifier of the soil surface environment and affects germination and establishment of weeds.
- The accessibility of digital photography and computing power makes analysis of images an attractive tool for determining ground cover in field experiments.
- Commercial (proprietary) software tools exist for image analysis, but we did not find any that permitted color ratios to be used as thresholds.
- Free and Open Source Software (FOSS) includes several useful programs that together can provide a flexible set of tools for analyzing images. These tools may require customization to maximize their usefulness to particular applications.



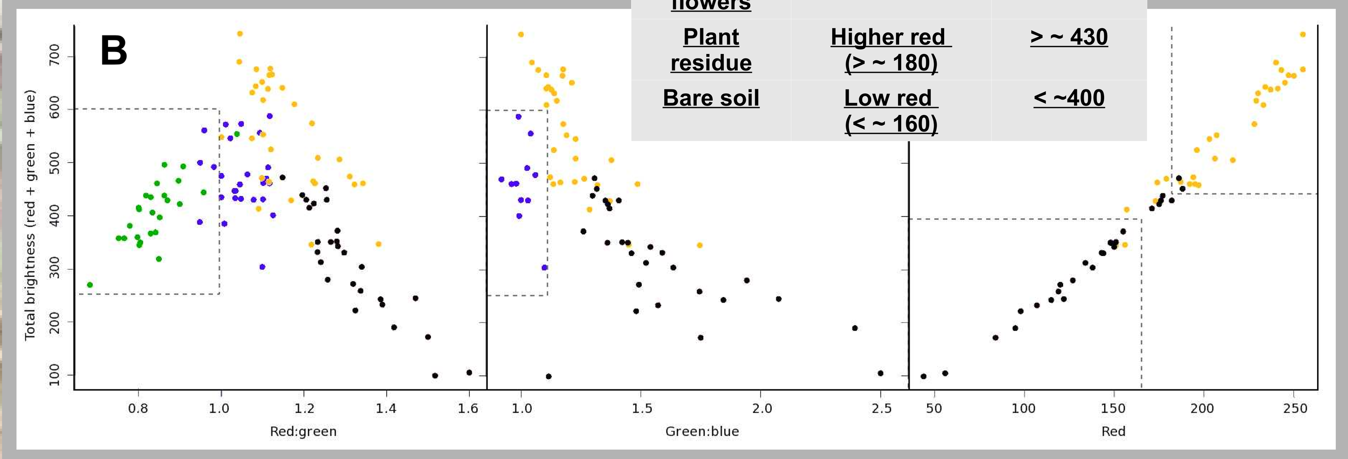


Figure 1. Graphical analysis of color classes. Pixel sampling from a typical image of early season rye using ImageJ (A). Graphical analysis of the pixel sample reveals typical thresholds (B). Typical threshold values (C).

C Typical threshold values

Class	Color Threshold	Brightness
Green leaves	Low red:green (< ~ 1.0)	~ 200 to ~ 600
Purple leaves & flowers	Low green:blue (< ~ 1.0)	~ 200 to ~ 600
Plant residue	Higher red (> ~ 180)	> ~ 430
Bare soil	Low red (< ~ 160)	< ~400

III. Methods: Development

- We identified four pixel classes in our images: green (leaves), purple (leaves and flowers), residue, and soil (Figure 2 A, 3A).
- To facilitate sampling pixels from images, we wrote a macro for ImageJ that records x and y position and red, green and blue color density for each pixel selected
- Samples of pixels from each class revealed differences in coloration that could be used to classify pixels (Figure 1).
- We wrote a program using CIMG (a free C++ library) that opens an image as a matrix of red, green, and blue color values, and classifies pixels based on threshold values provided. The program returns pixel counts for the leaves (green and purple), residue, and soil as well as ambiguous (unclassified) pixels and pixels within 2% of a threshold. The program also generates a false-color image to allow evaluation of accuracy of classification (Figure 2F, 3B).
- All code for these tools posted at roots.psu.edu under "Research Methods > General Methods" (http://roots.psu.edu/en/node/882)

Figure 2. Pixel classification. A typical image of an early season rye cover crop (A), and binary masks showing the pixels classified as leaves (B), residue (C), soil (D), as well as pixels classified as borderline – within 2% of a threshold (E). The false-color image (F) can used for verification.

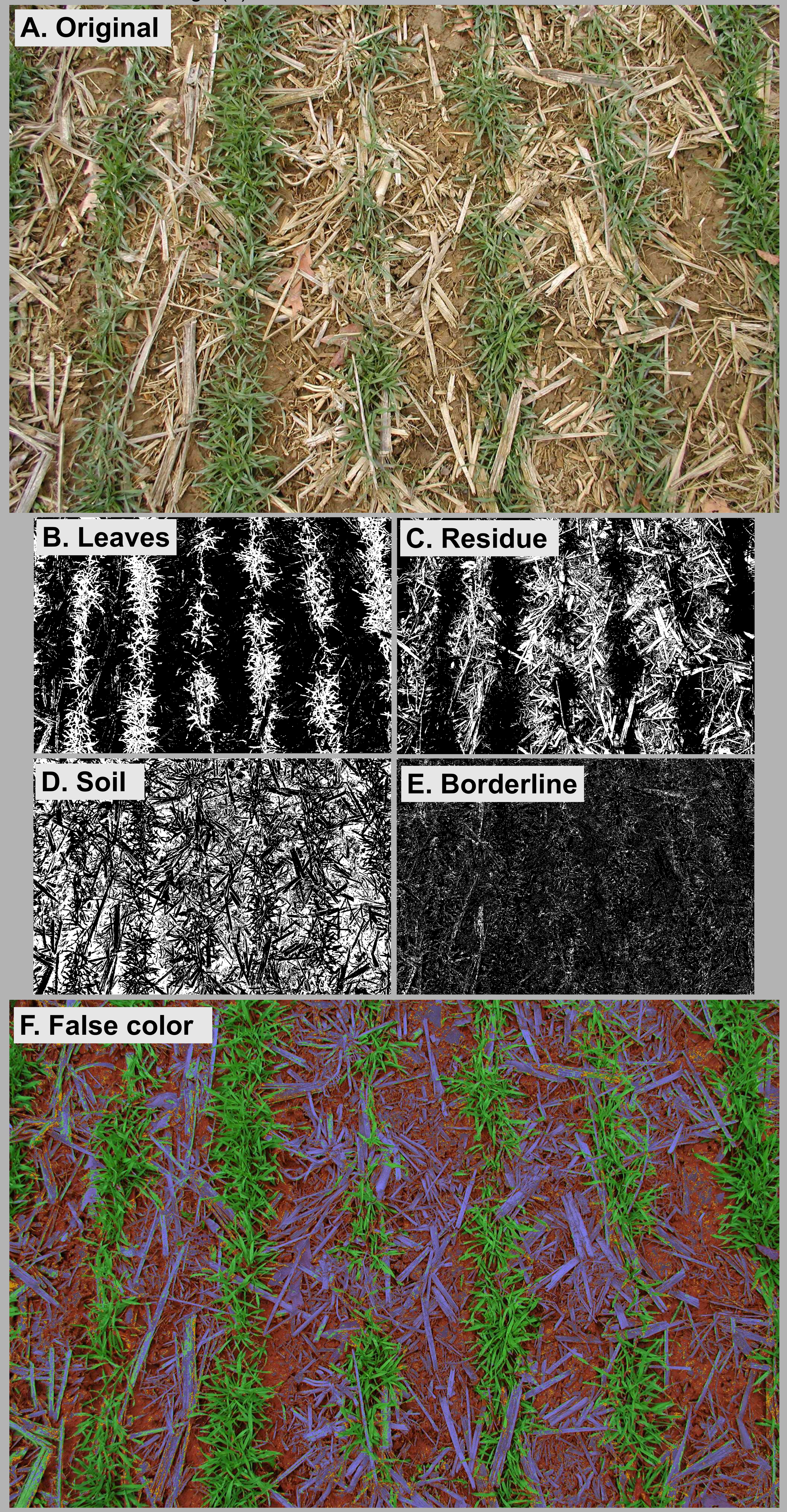
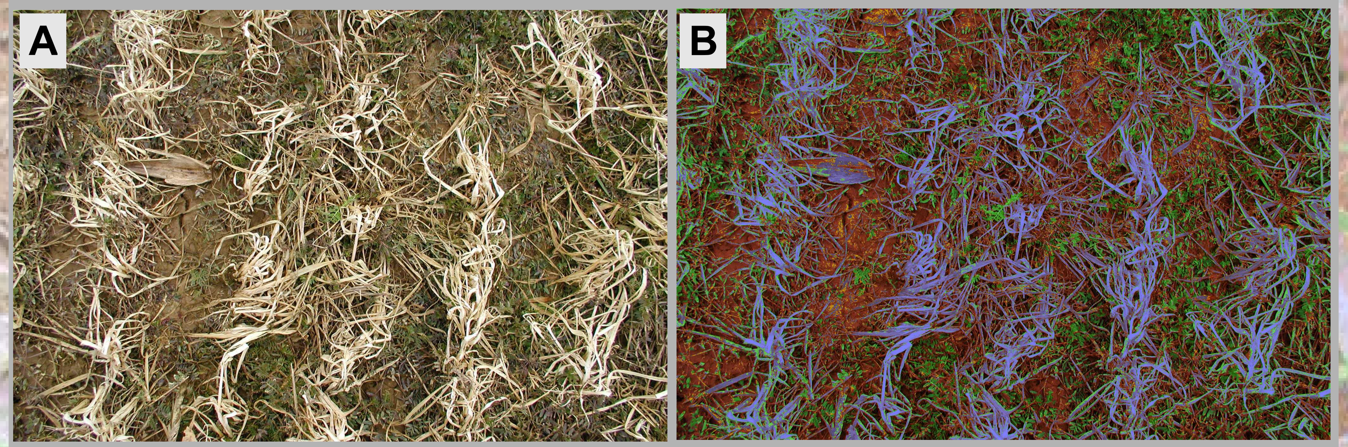


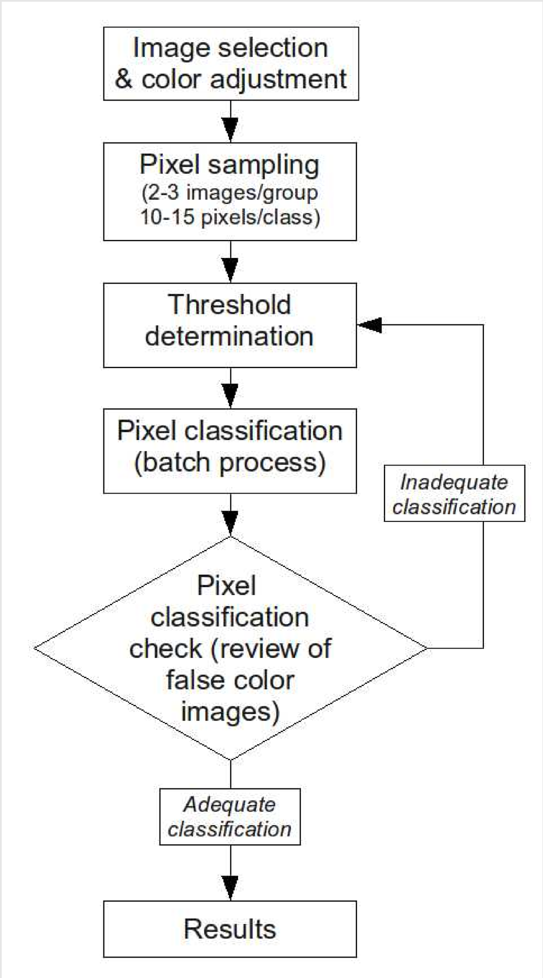
Figure 3. Original (A) and false color (B) images of an early season hairy vetch cover crop, with residue of a spring oats nurse crop.



IV. Methods: Image Processing

- Images grouped into batches by cropping system and date to maximize uniformity.
- When multiple images available, images selected for uniformity of exposure and color
- Occasional images possessed atypical color – in these cases, color balance was adjusted on a copy of the image, and both the original and copy were analyzed. (After review of false color images, the adjusted copy was retained only if classification was improved.)
- Pixels sampled using a custom macro in ImageJ.
- Thresholds determined graphically for each batch of images (using R).
- Images were batch processed using a shell script that called the C++ image analysis program and compiled the output.
- False color images reviewed to assure correct classification. Thresholds adjusted and batch processing repeated if needed.

Figure 4. image analysis batch process flowchart



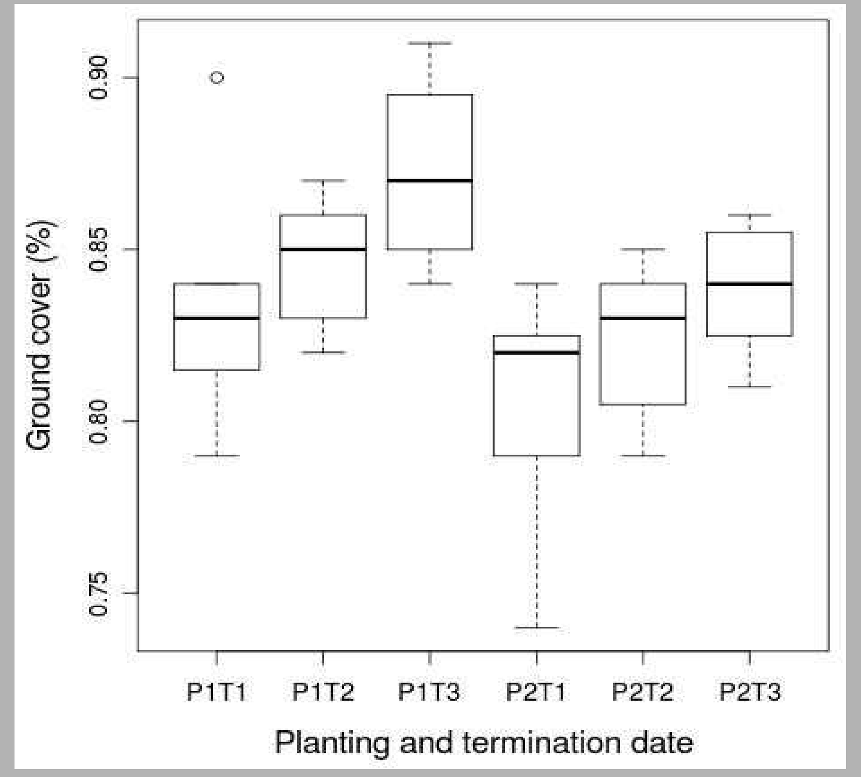
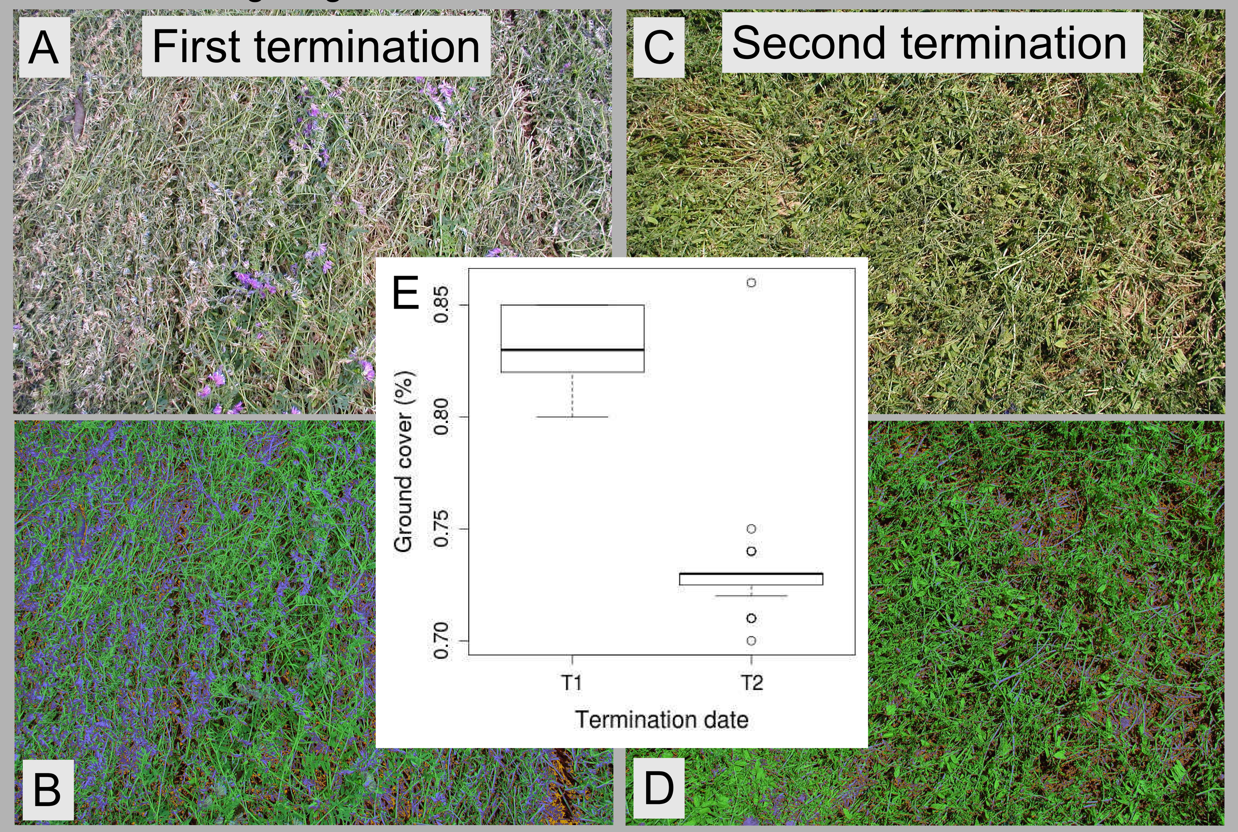


Figure 5. Ground cover increased with later cover crop termination and decreased with later planting. The planting date effect was not significant ($p = 0.16$) but termination date was highly significant ($p < 0.0001$). Ground cover was correlated with rye biomass ($p = 0.0002$), but was not strongly predictive of biomass ($R^2 = 0.25$).

V. Results

- For images acquired on a single day, the ground cover estimates conformed to our expectations that cover should be greater for later termination date and earlier planting date (Figure 5).
- Differences in image exposure can be problematic. Data suggest that *earlier* terminated hairy vetch cover crops had greater ground cover (Fig. 6E), but this is likely an artifact of differences in lighting – strong direct lighting in the images of the late terminated vetch created very dark shadows, which were interpreted as soil (Figure 6C, 6D)

Figure 6. Analysis of hairy vetch cover crop terminated by rolling at two dates. Original (A & C) and false color (B & D) images for the first and second termination dates. Strong differences in ground cover (E) artifacts of differences in lighting.



VI. Conclusions:

- Free and Open Source Software (FOSS) provides adequate tools for image analysis.
- Small differences in ground cover can be detected.
- Ground cover can quickly be analyzed from a large number of images. Efficiency is maximized when many images can be analyzed with the same thresholds.
- This image analysis approach is powerful – commercial alternatives we examined did not facilitate the calculation of color ratios.
- This approach to image analysis is very flexible, and could be customized to other analysis problems.

VII. Caveats:

- Power and flexibility come at a price – this approach requires that the users customize the tools to their own application.
- Image quality and uniformity is very important – greater uniformity in exposure and lighting with a batch of pictures will likely increase accuracy. Comparisons between images acquired under different conditions should be avoided.
- Soil color is important. Soil that is light colored or dry may not be easily separated from dead plant residue.

VIII. Acknowledgments:

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