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Software to quantify and map vegetative cover in fallow fields for weed management decisions

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ABSTRACT

Mapping weed cover during the fallow period of dryland crop rotations would be valuable for weed management in subsequent crops and could be done with low cost color digital cameras, however most managers lack the specialized software and expertise needed to create a map from the images. A system of software was developed to quantify weed cover in fallow fields in digital images and to simplify and automate the most challenging tasks that non-GIS professionals confront in creating and using maps derived from a large number of images. A GIS file of image locations is created with inexpensive consumer software. Images are classified, a GIS file is generated and the map is displayed in a simple GIS viewer with free software we developed. A map can be generated from 1000 images and 5000 GPS coordinates in 30 min, including image classification. The classified and original images for all locations can be viewed together easily from the map application. The accuracy of estimating weed cover was evaluated using images collected in 15 fields under natural light with a consumer grade camera mounted on an ATV driving 8–11 km h^{-1}. Weed cover was estimated with 96% accuracy for images, regardless of the amount of crop residue, unless part of the image was shaded by the camera. In those images, accuracy was 90% or better. This system will work with many professional and consumer digital cameras and GPS units and the classification algorithm can be easily modified for other applications.

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1. Introduction

Vegetative cover can be quantified in color digital images by identifying the proportion of an image that is green vegetation using the three color bands of individual pixels (Meyer and Neto, 2008; Panneton and Brouillard, 2009). Researchers have measured the cover of weeds and crops using inexpensive consumer cameras and this method of image classification (Booth et al., 2006; Rasmussen et al., 2007; Richardson et al., 2008). If GPS coordinates are recorded for each image location, a map of vegetative cover could be created from the classification results.

Maps of vegetative cover over large areas can provide valuable information about the spatial and temporal variability of vegetative cover for managers of agricultural fields (Shaw, 2005; Booth and Cox, 2008). For example, maps of spatial variability can be used to detect areas where the crop is stressed or weed pressure is greatest. Time-series maps can depict the variability of crop yield within a field, grazing impacts on rangelands, the spread of invasive weeds and the effectiveness of weed management. However, most managers lack the expertise and specialized software that researchers use to create maps from a set of images and GPS coordinates. The goal of this project was to simplify and automate the process of creating and using maps of weed cover in fallow fields.

The potential to reduce herbicide use with site-specific weed management has motivated research to overcome the difficulties of image analysis to map weed cover or density (Hague et al., 2006; Nieuwenhuizen et al., 2007; Burgos-Artizzu et al., 2009). These difficulties include differentiating weeds from crops and accurately estimating cover when crop residue is present or when lighting is not controlled or supplemented. However, no one has addressed how a typical grower will create a map from a set of images and use it for management decisions.

Currently, creating a map of vegetative cover is time-consuming and requires specialized software and expertise. Algorithms to differentiate weeds from background in images have been implemented with sophisticated image analysis, mathematical or statistical software (Yang et al., 2003; Meyer and Neto, 2008; Panneton and Brouillard, 2009) and some require calibrating the algorithm for each field (Kavdir, 2004; Hague et al., 2006; Nieuwenhuizen et al., 2007). Creating the GIS file with cover estimates, and even using the map for management decisions, requires GIS software and expertise (Loghavi and Mackvandi, 2008). Most growers will want to view the map of vegetative cover with other spatial data and examine images at specific locations to consider other factors, such as plant species and size, that influence the

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choice of management. A grower's challenges are compounded by the need for large number of images to accurately describe weed cover with uneven distribution within a field (Rew and Cousens, 2001) and often just a short period of time to assess weed cover before making a decision.

Mapping vegetative cover during the fallow period, of dryland crop rotations could be practical as well as valuable if there was simple, inexpensive software to create and use the map. Growers in Colorado, US, typically make 3–5 trips across the field to control the multiple flushes of weeds during the fallow period, and a GPS unit and one or more cameras could be mounted on the tractor. Weeds are the only green vegetation present during the fallow period so the difficulty of differentiating crops from weeds is avoided, yet the maps may be used to predict weed distribution and plan management in all crops of the rotation because weed patches are nearly in the same location from year to year (Gerhards et al., 1997; Colbach et al., 2000; Krohmann et al., 2006). Species could be identified by viewing the images or by the date the images were collected because time of emergence varies among weed species in fallow fields (Anderson and Nielsen, 1996).

The goal of this project was to develop software for growers to map weed cover in fallow fields. These growers need software that classifies images collected under natural light from a moving vehicle, automatically generates a GIS file from a set of images and GPS coordinates, and displays the weed cover estimates in a simple GIS viewer. Further, a classification algorithm was needed that did not require field by field calibration yet was accurate enough for weed management decisions and a GIS viewer was needed that allowed the user to examine the classified and original images by selecting a location on the map.

2. Materials and methods

2.1. Collection of images and GPS coordinates

Sets of images and GPS coordinates, as growers might collect in fallow fields, were needed for development and testing of the classification algorithm and other components of software. Fifteen sets of 400–1200 images were collected in natural light and without stopping in eight fallow fields in eastern Colorado (Table 1) using an all terrain vehicle. The fields were managed with minimum tillage and proso millet (*Panicum miliaceum* L.), wheat (*Triticum aestivum*), or corn (*Zea mays* L.) residue was present. Images were collected 1–2 days prior to farmer's weed control, and most images were collected between 9 am and 2 pm.

Images with sufficient quality for classification were collected using a Canon EOS 10D camera[1] (6.3 effective megapixels) with an EF24 mm f/2.8 lens.[1] The camera was operated in shutter priority mode (the camera adjusts the aperture for a fixed shutter speed) with the shutter speed set at 1/4000 s and with automatic settings including 1600 ISO, autofocus, evaluative metering, and automatic white balance setting. A UV filter was used to protect the lens. Images were 2048 × 1360 pixels and stored in JPEG format with low compression on a compact flash card. Image acquisition was controlled with an inexpensive remote control (Canon TC-80N3[1]) that can trigger the camera at intervals as short as 1 s.

The camera was mounted on an all terrain vehicle so that it was 1.2 m above the ground with an unobstructed nadir view (Fig. 1). When collecting images, driving speed was 8–11 km h^{-1} and images were acquired every 4 s so images represented approximately 1.0 m^2 (0.36 mm^2 $pixel^{-1}$) and were taken 8–16 m apart.

[1] Mention of a trade name or proprietary product does not constitute a guarantee or warranty by the US Department of Agriculture and does not imply approval to the exclusion of other products that may be suitable.

Table 1
Accuracy of estimating weed cover was assessed using 150 images from 15 sets of 400 to 1200 images collected in eight fields with different types of crop residue.

Field	Year	Crop residue[a]	Dates	Percent of images with low weed cover	
				⩽5% Cover	⩽2.5% Cover
1[b]	2003	Proso millet	May 23	86	47
2[b]	2003	Wheat	June 26	22	14
3[b]	2005	Corn	June 29	92	55
			August 8	67	55
4[b]	2005	Corn and wheat	June 16	90	68
			July 21	97	89
5	2006	Corn	May 17	86	73
			June 28	82	73
			July 24	6	1
6	2006	Proso millet	May 17	43	12
			July 24	84	55
7	2006	Corn	June 16	81	63
			July 21	11	2
8	2006	Corn and wheat	June 1	94	79
			July 12	86	47

[a] Proso millet (*Panicum miliaceum* L.), wheat (*Triticum aestivum*), and corn (*Zea mays* L.).
[b] Seventy of the 3390 images collected in these fields were used for development of the image analysis algorithm but were not used in the accuracy assessment. These images were selected to be representative of varying degrees of overexposure, underexposure, shadow, crop residue, weed species.

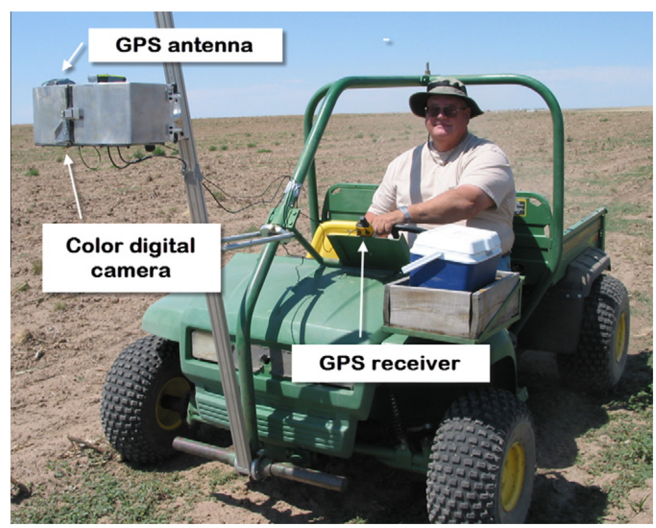

Fig. 1. Images were collected in fallow fields with a camera mounted on an all terrain vehicle. Images were acquired every 4 s using a remote control with an interval timer and the GPS unit was operated continuously with coordinates collected every 2 s.

GPS coordinates were collected continuously at 2 s intervals while images were collected. We used an external recreational grade GPS receiver (Garmin GPS60[1]) that has WAAS-enabled mode and an external antenna. The GPS unit was mounted in front of the driver so vehicle speed could be monitored and the external GPS antenna was located on top of the camera mount. No connection between the GPS unit and camera was required.

2.2. Classification algorithm

The classification algorithm and software were developed with cooperation of an information technology specialist and a computer programmer associated with the US Geological Survey, Fort Collins Science Center. This image classification algorithm was