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Discrimination of sterile oat (*Avena sterilis*) in winter barley (*Hordeum vulgare*) using QuickBird satellite images

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ABSTRACT

Site-specific weed management implies detecting the location of weeds in order to generate maps of their spatial distribution. This information facilitates a more accurate application of herbicides, spraying them in the exact areas of weed growth and in the required doses. In order to explore the potential of commercial satellites to discriminate and map weeds, we used the information contained in high spatial resolution images acquired by the QuickBird satellite to assess the density of sterile oat (*Avena sterilis*) present in a winter barley field at two different dates (March and June). Our results confirmed the potential of using satellite images in the spectral discrimination of weed patches in infested fields. The results of binary logistic regressions showed that the best matches in the classification of three categories (low, medium, or high sterile oat densities) corresponded to the March image. QuickBird's March image provided reliable estimates of sterile oat patches in barley crops when weed density was relatively high (between 86% and 94% of agreement between predicted and observed densities). However, when weed densities were lower than 10 plants/m^2 there were serious difficulties to distinguish them from weed-free zones (between 72 and 75% of global agreement in the classification) with large underestimation of medium density weed patches (10 plants/m^2). This is a potential limitation considering than the thresholds used for herbicide application decisions are generally close to this density. However, the information obtained may still be useful for producing field maps to describe the spatial distribution of this weed. Moreover, these studies have provided valuable information on the best spectral regions and/or vegetation indices for approaching discrimination between sterile oat and cereal crops and the most suitable period for it.

1. Introduction

In conventional agriculture, individual fields are considered as uniform areas. Therefore, the same inputs (fertilizers, herbicides, fungicides, etc.) are applied at the same doses over the entire area. However, a single field can vary enormously in terms of soil fertility and of the composition, abundance, and spatial distribution of weeds and other pest organisms. Over the last few decades, the concept of precision crop protection has been used to adjust pesticide inputs to the real needs of each land unit. Applied to weed control, this concept implies detecting the location of weeds in order to generate maps of their spatial distribution. This information facilitates a more accurate application of herbicides, spraying them in the exact areas of weed growth and in the required doses (Thompson et al., 1991; Stafford and Miller, 1993; Brown et al., 1995). This would result in a decrease in herbicide use, leading not only to a reduction in costs for farmers, but also to a decrease in negative environmental effects (Timmermann et al., 2001; Swinton, 2005).

Weeds generally grow in well-defined areas (weed patches). This spatial pattern favors the use of remote sensing to obtain information on the location, type, and density of weeds present in cropland (Moran et al., 1997; Zwiggelaar, 1998; Lamb and Brown, 2001). Most researchers have used different classification algorithms to delimit weed patches, basing them on spectral differences amongst the soil, crops, and weeds. These classification algorithms are effective at detecting weeds during the pre-emergence stage of crops since the spectral response of bare soil is different than that of weeds (Lamb and Weedon, 1998). However, accurately discriminating weeds from crops in post-emergence is more complex since the both plants may have similar spectral characteristics (Lamb and Brown, 2001). Another problem arising from applying remote sensing to weed discrimination is the soil effect. When the percentage of vegetation cover is low or

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intermediate, the interaction between the reflectance from the vegetation cover and the soil alter the spectral response. Unfortunately, it is precisely this period when it is more useful to generate weed maps so they can be used for planning post-emergence herbicide applications.

Although various studies have demonstrated the possibilities of using conventional color and/or color-infrared aerial photographs to identify weed patches (López-Granados et al., 2006; Peña-Barragán et al., 2006), the use of satellite images for weed detection has been limited to studies over extensive areas (e.g. rangelands, semi-natural areas) where the level of detail in the data gathered was scarce (Lass et al., 2005). However, the placement in orbit of new, very high spatial resolution sensors (less than 1 m pixel size) has considerably broadened the range of applications in weed science. This new generation of satellites, usually sponsored by private companies, has allowed the introduction of remote sensing in markets so far reserved for aerial photography. The first high spatial resolution commercial satellite, IKONOS, operated by GeoEye (http://www.geoeye.com), was launched in December 1999 and became the first commercial satellite with sub-meter spatial resolution acquiring images with a pixel size of 4 m in multispectral mode and 0.8 m in the panchromatic band. Another commercial high spatial resolution satellite is QuikBird, owned by DigitalGlobe (http://www.digitalglobe.com) and launched in October 2001. This satellite can acquire images with a spatial resolution of 2.60 m in the multispectral mode and 0.65 m in the panchromatic band.

A number of studies have been conducted on the analysis of field spectroscopy data in order to assess the potential of commercial multispectral sensors with high spatial resolution to discriminate different weeds and crops. López-Granados et al. (2008) and Gómez-Casero et al. (2010) analyzed the spectral discrimination of late-season grass weeds in wheat fields. Different statistical analyses were applied to spectral signatures taken on the field in the visible and near infrared part of the spectrum using a handheld spectroradiometer. Results showed the potential ability of broadband multispectral sensors such as the one on board QuickBird satellite to discriminate weeds and crops at specific phenological stages.

In spite of these interesting findings, extensive research on the effectiveness of multispectral data for the discrimination of grass weeds in winter cereal using satellite images is still limited. In this context, the main objective of this work was to explore the possibility of using very high spatial resolution images acquired by commercial sensors (QuickBird) to discriminate and map patches of sterile oat (*Avena sterilis* L.) present in winter barley crops. We were aware of the difficulty of this task considering that both species belong to the same botanical family, being quite similar from a morphological, phenological and physiological standpoint.

2. Materials and methods

2.1. Study area and experimental design

The study area was located on La Poveda Research Farm, Arganda del Rey, Madrid. A winter barley (*Hordeum vulgare* L.) crop was established in November on a 65 m × 65 m area with no previous sterile oat infestation. Sterile oat was seeded at various densities (0, 5, 50, 500 and 5000 seeds/plot) in order to generate a wide range of plant densities (0, 0.1, 1, 10 and 100 plants/m^2) in different plots. Individual plots (12 m × 20 m) were hand seeded immediately before crop planting, incorporating the seeds with a shallow cultivation. The experimental set-up was a randomized block design, with five treatments and three replications.

2.2. Image acquisition and ground-truthing

In order to discriminate the various sterile oat densities, the acquisition of two QuickBird images over our study site was planned. Those images were provided by Digitalglobe through out their local resellers. March and June were the selected acquisition periods as the purpose of this study was to test the potential of QuickBird images to discriminate weeds at different stages of crop development. March's image (Fig. 1, left) corresponded to the crop's tillering stage and coincided approximately with the date of herbicide application. Therefore, the results for this assessment should, in theory, allow an evaluation of the potential of this type of image in providing the necessary information for the selective application of herbicides. The June image (Fig. 1, right), in contrast, corresponded to crop maturity and it is not useful for planning herbicide applications in the current year. However, it could be useful for estimating patch distribution in the following year. The QuickBird satellite was chosen because offers a very high spatial resolution: from 0.65 m in the panchromatic band to 2.6 m in the multispectral bands. The spectral resolution is also suitable for this type of study since it has a band in each of the most significant portions of the electromagnetic spectrum: blue (450–520 nm),

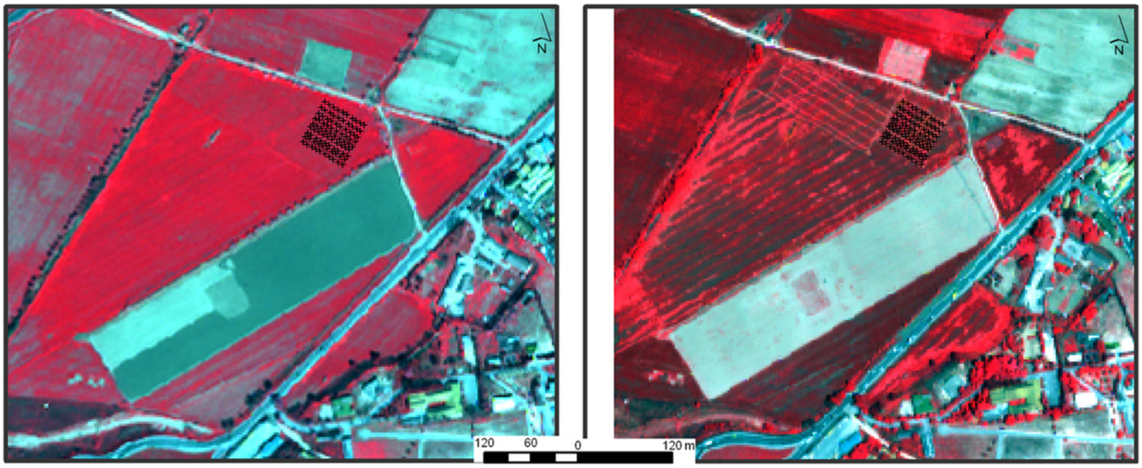

Fig. 1. False color composites of Quickbird images (March left, June right) acquired over La Poveda research farm. Bands 4, 3 and 2 have been applied to Red, Green and Blue color channels. Vegetation can be observed in red color and bare soil and infrastructures and buildings in blue. Sample points (black crosses) have been over-imposed (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)