WEED SEEDLINGS DETECTION IN WINTER CEREALS FOR SITE-SPECIFIC CONTROL: USE OF UAV IMAGERY TO OVERCOME THE CHALLENGE

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ABSTRACT

Weed management is an important part of the investments in crop production. Cost of herbicides accounts for approximately 40% of the cost of all the chemicals applied to agricultural land in Europe. Although weeds are distributed in patches, herbicide treatments are usually broadcast over the entire field and there is potential for overapplication. The development of site-specific weed management strategies based on weed maps in which herbicides are only applied to the crop zones were weeds spread could remedy this situation. Moreover, most of these strategies should be implemented in early season, just when post-emergence herbicide treatments are applied. Until now, obtaining weed infestation maps in early season has been a great challenge due to the reduced size of the weed and crop seedlings, and the spectral and morphological similarities between weeds and crop. This article describes the complete workflow developed to achieve the weed patch mapping in wheat fields, as paradigm of winter cereals. The workflow can be divided in three main steps: 1) configuration of the UAV and design of the flight route to acquire a set of overlapped images of the wheat field, 2) mosaicking of these images to create a georeferenced ortho-image of the whole crop field, and 3) automatic object based image analysis (OBIA) procedure developed for generating weed patch maps and herbicide prescription maps accordingly. The described workflow was applied in two wheat crop parcels, and the prescription maps and herbicide savings are showed and discussed.

Keywords: OBIA, wheat, remote sensing, unmanned aerial vehicle, crop protection

INTRODUCTION

Weed management is an important part of the investments in crop production. Cost of herbicides accounts for approximately 40% of the cost of all the pesticides applied to agricultural land in Europe (ECPA, 2010). In order to increase the profitability of crop production and to reduce the environmental concerns related to chemicals application, it is needed to develop site-specific weed management strategies in which herbicides are only applied in the crop zones were weeds spread (Jurado et al., 2005; Timmermann et al., 2003). Moreover, these strategies should be implemented in early season, just when post-emergence herbicide treatments are usually applied. Until now, obtaining weed infestation maps in early season has been a great challenge due to the reduced size of the weed and crop seedlings, and the spectral and morphological similarities between weeds and crop (López-Granados, 2011). And this challenge has been especially hard in winter cereals, in which the narrow space between crop lines complicate the weed-crop discrimination. Today, this challenge can be overcome by the combined use of Unmanned Aerial Vehicles (UAV) and the Object-Based Image Analysis (OBIA). UAVs can fly at low altitudes, making possible to take ultra-high spatial resolution images (e.g., pixels of a few mm or cm) and to observe small individual plants and patches, which has not previously been possible with remote images captured by piloted airborne and satellite platforms (Xiang and Tian, 2011). Also, they allow a great flexibility in flight scheduling due to the reduced time needed for prepare, initiate and perform a flight. On the other hand, OBIA procedures can overcome limitations of pixel-based methods related with the spectral and morphological similarities of weeds and crop by adding new information to the analysis routine. OBIA methodology creates “objects” by grouping adjacent pixels with homogenous spectral values, and then combines spectral, topological, and contextual information of these objects to drastically improve the image classification accuracy (Blaschke, 2010). Position of the vegetation objects in the crop row structure has demonstrated to be the key feature when using UAV imagery for accurate weed detection and further design of herbicide prescription maps in wide row crops such as maize (Peña et al., 2013). Our hypothesis was that OBIA algorithms developed for weed detection in these kind of crops could be adapted to their utilization in narrow row crops such as wheat specially due to previous works of our research group had demonstrated the suitability of UAV images and OBIA for vegetation detection and crop rows mapping in wheat fields (Torres-Sánchez et al., 2014a; 2014b) .

Thus, once high spatial and temporal resolution UAV images of the crop could be available, and OBIA procedures potentially could deal with complex classification analysis, a complete workflow for weed patch mapping in early season wheat fields was defined in detail and adapted accordingly to the wheat crop. This article describes the required equipment and the whole workflow developed to achieve the weed patch mapping in wheat fields, as paradigm of winter cereal sown with narrow crop rows.

MATERIALS AND METHODS

UAV and sensor

A multi-rotor platform with vertical take-off and landing (VTOL), model md4-1000 (Microdrones GmbH, Siegen, Germany), was used to collect the sets of aerial images at three flight altitudes over the experimental crop-fields (Fig. 1). The vehicle is equipped with four brushless motors powered by a battery and can fly by remote control or autonomously with the aid of its Global Position System (GPS) receiver and its waypoint navigation system. The VTOL system makes the UAV independent of a runway, so it can be used in areas with rough terrain. A still point-and-shoot camera, model Olympus PEN E-PM1 (Olympus Corporation, Tokyo, Japan), was mounted on the UAV and used to acquire the images. This camera acquires 12-megapixel images in true colour (Red, R; Green, G; and Blue, B, bands) with 8-bit radiometric resolution and is equipped with a 14-42 mm zoom lens. The images were acquired fixing the objective at 14 mm focal length. The camera's sensor is 4,032 × 3,024 pixels, and the images were stored in a secure digital SD-card. Detailed information about the configuration of the UAV flights and specifications of the vehicle and the camera used can be found in (Torres-Sánchez et al., 2013).

Figure 1. UAV taking off over the wheat crop field.

Workflow description

Mission planning

The first step in the weed mapping workflow is to define the parcel that will be analysed. Once the coordinates of the field are known, they are used to design the flight route with the aid of the software provided by the UAV manufacturer. Flight altitude defines the spatial resolution of the images, and the overlapping is needed to stitch them to generate a complete image of the whole field. Thus, flight altitude and overlapping between images must be defined in this step.

UAV flight and image acquisition

Once the flight route is designed, it is transferred to the UAV. After the manual take-off of the vehicle, the automatic flight is switched on, and the image triggering is activated by the UAV according to the programmed flight route. At the moment of each shoot, the on-board computer system records a timestamp, the GPS location, the flight altitude, and vehicle principal axes (pitch, roll and heading). When the flight ends, the UAV is manually landed by the pilot.

Image mosaicking

After the landing, the images are downloaded from the camera memory card to a personal computer. An important task prior to image analysis was the combination of all these individual and overlapped images by applying a process of mosaicking in order to generate a complete crop map in the whole study area. The images were collected with 30% side-lap and 60% forward-lap in order to allow correct image mosaicking. Agisoft PhotoScan Professional Edition (Agisoft LLC, St. Petersburg, Russia) was employed in this task. The resultant ortho-mosaicked image must be geometrically interoperable and must shows an accurate crop row matching between both sides of overlapped borderline images, which guarantee good performance of the subsequent image analysis.

OBIA analysis

The OBIA algorithm designed for the weed mapping tasks was developed using the commercial software eCognition Developer 8.9 (Trimble GeoSpatial, Munich, Germany). It was preliminarily based on the algorithm for weed mapping in broad row crops fully described in previous works of our research group (Peña-Barragán et al., 2012; Peña et al., 2013). This OBIA procedure was redefined to adapt it to the specific characteristics of narrow row crops such as wheat (Torres-Sánchez et al., 2014a). The OBIA analysis algorithm combines object-based features such as

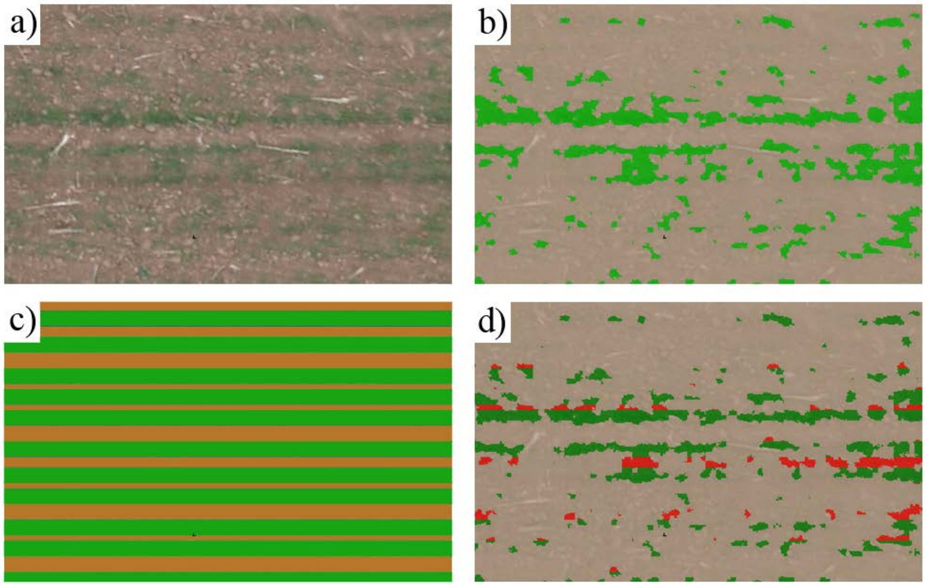

Figure 2. Different phases in the weed mapping algorithm: a) Original wheat field image without classification. b) Vegetation (weeds and crop) discrimination. c) Crop row (in green) and bare soil (in brown) detection. d) Classification as weeds of the vegetation objects located outside the rows (in red).

spectral values, position, orientation and hierarchical relationships among analysis levels, and it is mainly based on the fact that plants growing between crop rows are weeds. The algorithm is divided in four steps (Fig. 2):

1. Rotation of the ortho-mosaic to put the crop rows in horizontal position.
2. Vegetation (weeds and crop) and bare soil discrimination by applying an automated thresholding method to the values of a vegetation index.
3. Crop row detection using a dynamic and auto-adaptive classification process.
4. Classification of the vegetation objects outside the rows as weed plants.

After the discrimination of the weeds, infestation map is converted on a prescription map for spatially variable herbicide application machinery. The algorithm generates a grid of user-adjustable size and afterwards it estimates the weed coverage on every square of the grid. Finally, the decision of applying the site-specific weed treatment is taken on the basis of a weed coverage threshold in every grid.

Study site and flights

The described workflow was applied in two wheat fields located at the private farm La Monclova, in La Luisiana (Seville, southern Spain):field 1 (37.529º N, 5.315º W, datum WGS 84) , and field 2 (37.524º N, 5.318ºW, datum WGS 84)

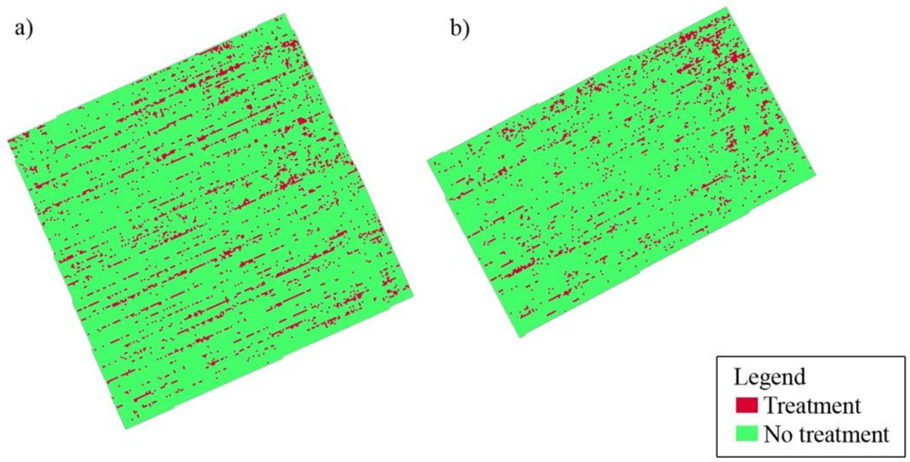

Figure 3. Prescription maps for both fields generated applying the weed-detection algorithm to the ortho-mosaics generated with the imagery from the 30 m altitude flight: a) Field 1. b) Field 2.

which had an average slope <1% and a surface about 0.8 ha and 0.5 ha, respectively. The wheat crops were sown by the end of November 2013 in rows 0.15 m apart. It was naturally infested by monocotyledonous and dicotyledonous weeds; these plants had an appearance very similar to wheat and an analogous phenological evolution, which complicates the weed-crop discrimination. At the moment of the flights, weed and crop plants were at the principal stage 1 (leaf development) from the BBCH extended scale (Meier, 2001).

UAV flights over the field 1 were performed the 12th January 2014, and the field 2 was overflown the next day. The UAV was programmed to acquire images of the whole fields at three flight altitudes (30, 60 and 100 m) in order to compare the prescription maps generated from ortho-mosaics with different pixel size. Images from 30, 60 and 100 m had spatial resolutions of 1.14, 2.28 and 3.80 cm/pixel respectively.

RESULTS AND DISCUSSION

Figure 3 shows the prescription maps generated applying the weed-detection algorithm to the ortho-mosaics created with the imagery from the 30 m altitude flight. A width of 0.5 m of the spray boom has been considered, and the weed coverage used as threshold for herbicide application was 10% for these prescription maps. With the described settings, the herbicide savings for both fields were about 90% (Table 1), i.e., only the 10% of the field must be treated for weed removal. Herbicide savings derived from the analysis of the ortho-mosaics generated with the imagery from the 60 and 100 m altitude flights were lower. This is because, at higher altitudes and consequently at lower spatial resolutions, the row detection was less accurate and the algorithm did not detect all the crop rows in the images, i.e., there were a number of vegetation objects incorrectly classified as weeds being really crop objects.

The results presented in this work must be considered as an example of a practical workflow for weed mapping and generation of herbicide prescription maps. These results could be different if other settings, such as grid size or treatment threshold, were taken into account since the algorithm is user configurable.

The presented workflow could be applied for weed detection in any row crop. The only requirements for the application of the OBIA algorithm are: 1) the rows must be clearly defined, if the crop plants occupy the inter-row area can be misclassified as weeds; 2) images must be taken before the crop covering all the soil surface between the crop rows for the same previous reason; 3) crop rows must be straight, without abrupt changes in their orientation. The first requirement is more important in narrow row crops (such as wheat or barley) than in broad row crops (such as sunflower or maize), because the inter-row area is smaller in the first ones and, consequently, the crop row delineation is harder. Next investigations of our group are currently devoted to debug the crop row orientation in different scenarios for a better discrimination of crop objects.

CONCLUSIONS

A set of overlapped images of a naturally grass and broadleaved weed infested wheat field was taken using an UAV equipped with a conventional RGB camera at early season at different flight altitudes in two fields. A robust and automated OBIA algorithm was applied for the automatic discrimination of weeds in georeferenced ortho-mosaics created from the overlapped images. Weed plants located in the inter-row area were distinguished from crop plants on the basis of

Table 1. Herbicide savings calculated for both fields applying the weed-detection algorithm to the ortho-mosaics generated with the imagery from the three flight altitudes.

Field	Flight altitude (m)	Herbicide savings (%)
1	30	90.12
	60	85.05
	100	84.65
2	30	91.08
	60	85.00
	100	77.06

their relative positions with respect to the crop rows. Finally, prescription maps were generated for both fields using a grid framework and a weed treatment threshold. The application of the described workflow allows the generation of herbicide prescription maps in wheat using UAV imagery, which has not been possible previously with traditional piloted airborne or satellite images. This technology can help in the implementation of the European legislation for the sustainable use of pesticides, which promotes reductions in herbicide applications. This objective can be achieved using site-specific herbicide control according to the weed maps.

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