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Research Paper

Multi-temporal imaging using an unmanned aerial vehicle for monitoring a sunflower crop

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The objective of this study is to determine the capability of an unmanned aerial vehicle system carrying a multispectral sensor to acquire multitemporal images during the growing season of a sunflower crop. Measurements were made at different times of the day and with different resolutions to estimate the normalised difference vegetation index (NDVI) and study its relationship with several indices related to crop status with the aim of generating useful information for application to precision agriculture techniques. NDVI was calculated from images acquired on four different dates during the cropping season. On two of these dates, two images were acquired to determine how the time of day when the images were taken influences NDVI value. To study the influence of image resolution on NDVI, the original images were resampled to 30 × 30 and 100 × 100 cm pixel sizes. The results showed that the linear regressions between NDVI and grain yield, aerial biomass and nitrogen content in the biomass were significant at the 99% confidence level, except during very early growth stages, whereas the time of day when the images were acquired, the classification process, and image resolution had no effect on the results. The methodology provides information that is related to crop yield from the very early stages of growth and its spatial variability within the crop field to be harvested, which can subsequently be used to prescribe the most appropriate management strategy on a site-specific basis.

1. Introduction

Precision agriculture (PA) is a production method that takes into account the spatial variability of conditions that affect crop production (e.g., soil characteristics, land elevation and weed infestation) and uses the information related to this variability to determine the most effective management strategy (Brisco, Brown, Hirose, Mcnairn, & Staenz, 1998; Moran, Inoue, & Barnes, 1997). The main steps of PA are data collection, field-variability mapping, decision-making, and

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the application of the management practices (Zhang and Kovacs, 2012). Remote sensing techniques can be used in the first three steps of the workflow (Copenhaver, 1998; Lan, Thomson, Huang, Hoffmann, & Zhang, 2010; Stafford, 1999; Warren & Metternicht, 2005), especially when the field variability maps are elaborated or updated to aid farmers to adapt the appropriate strategy that is based on variable management practices within a field according to the site conditions. The information needed to apply PA is provided by new technologies, such as geographic information systems (GIS), global positioning system (GPS), remote sensing, yield monitoring devices, and machinery that is able to apply the inputs in a variable-rate manner (Seelan, Laguette, Casady, & Seielstad, 2003). Gathering the required information is one of the key issues in PA that needs to be addressed to design appropriate decision systems and to recognise significant temporal variations (Lan et al. 2010; McBratney, Whelan, & Shatar, 1997).

To gather information for PA, several sensor platforms, including satellites and aircraft, have been used. Nevertheless, the platforms are not wholly adequate to provide information at the required spatial and time resolutions, as the images taken from them are expensive, and they can be affected by weather conditions such as clouds (Ehsani, Sankaran, Maja, & Camargo Neto, 2014; Hunt et al., 2014). Even the latest generation of very high resolution satellite images (e.g., GeoEye-1 and WorldView-2) is not able to provide high frequency data for critical situations such as monitoring nutrients or water stresses, diseases, or pest attacks. Moreover, manned airborne platforms are limited because of their high operational complexity, cost and the long time needed to deliver the images (Rango et al. 2009).

Unmanned aerial vehicles (UAV) have undergone a remarkable development in recent years and are now powerful sensor-bearing platforms for various agricultural and environmental applications. A limited amount of research on UAV applications for PA has been published. For example, Hunt, Cavigelli, Daughtry, McMurtrey, and Walthall (2005) used an unmanned helicopter with an image acquisition system to estimate biomass and nitrogen status for corn, alfalfa, and soybeans crops. Berni, Zarco-Tejada, Suarez, and Fereres (2009) acquired thermal and narrow band multispectral images taken from an unmanned helicopter to estimate biophysical parameters that were strongly correlated with leaf area index, chlorophyll content and water stress. Swain, Thomson, and Jayasuriya (2010) used a radio-controlled unmanned helicopter platform to acquire quality spatial and temporal resolution images to estimate grain yield and total aerial biomass of a rice crop. Linear regressions between these parameters and the normalised difference vegetation index (NDVI; Rouse, Hass, Schell, & Deering, 1973), estimated from images, yielded significant regression coefficients of 0.728 and 0.760, respectively. Agüera, Carvajal, and Saiz (2011) found a good correlation between applied nitrogen and NDVI that was estimated from images acquired from a quadrocopter flying at 70 m altitude over a sunflower crop.

Baluja et al. (2012) employed a UAV equipped with a multispectral sensor and a thermal camera to assess the water status of a commercial rain-fed vineyard of Tempranillo cv. (*Vitis vinifera* L.). Zarco-Tejada, Gonzalez-Dugo, and Berni (2012) demonstrated the ability to track stress levels in a citrus crop using thermal and hyperspectral imagery acquired from a UAV. García-Ruiz et al. (2013) used a UAV equipped with a multispectral camera to identify a citrus greening disease affecting citrus orchards. Recently, Hutn et al. (2014) used a sensor mounted on a UAV to collect imagery of a potato crop in near-infrared (NIR), red and green bands. From these images, they calculated the NDVI and green normalized difference vegetation index (GNDVI) and their relationship with leaf area index, plant cover and chlorophyll content over the growing season.

Because UAVs fly at low altitudes, ultra-high spatial resolution images can be obtained at a low operational cost, and the images can be acquired as frequently as necessary and analysed in quasi-real-time (Agüera et al. 2011; Hardin & Hardin, 2010; Xiang & Tian, 2011). Thus, it is necessary to study the application of images from UAVs for PA.

The objective of the present study is to determine the capability of a system composed of a UAV carrying a multispectral sensor (red, green and near infrared bands) to acquire multitemporal images during the growth season of a sunflower crop at different times of the day and with different resolutions to estimate the normalized difference vegetation index (NDVI) and study its relationship with several indices related to crop status with the aim of generating useful information that can be applied to precision agriculture.

2. Materials and methods

2.1. *Field experiment*

The experiment was conducted at the Agricultural Research Centre of Córdoba (37°51′22″ N, 4°48′19″ W), southern Spain. The soil is a deep sandy-loam, classified as Typic Xerofluvent (Driessen & Dudal, 1991). Córdoba has a Mediterranean-type climate with high temperatures in the summer, and most of the rainfall is concentrated between the autumn and spring.

A PR64E71 sunflower (*Helianthus annuus*, L.) hybrid crop was sown on 23 February 2012 with a plant density of 7.1 plants m^{-2}, which is a plant population widely used by local farmers.

The field was 30 × 30 m (Fig. 1), and two perpendicular strips divided the field into four blocks, each with a different irrigation treatment: full irrigation, which covered 100% of the crop's water need (I1); full irrigation until anthesis and no irrigation afterwards (I2), which simulated a typical sunflower season in this area; half irrigation (I3), which covered 50% of the crop's water needs; and no irrigation (I4). The irrigation treatment began on 25 May 2012. Each of these four blocks was divided into eight elemental plots of 7 × 3.4 m^2 (11 rows with 17 plants each), corresponding to eight nitrogen treatments, and which resulted in 32 elemental plots. The nitrogen application rates were 0, 20, 40, 60, 80, 100, 120 and 140 kg [N] ha^{-1}; half was applied on the sowing date, and the second half was applied on 20 May 2012. The experimental design was not intended to study the influence of irrigation or nitrogen application on crop yield. Rather, the objective was to simulate a high variability of growing conditions to study the relation of NDVI with several indices related to crop status. A