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Research Note

Estimation of ground canopy cover in agricultural crops using downward-looking photography

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Fast and accurate estimates of canopy cover are central for a wide range of agricultural applications and studies. Visual assessment is a traditionally employed method to estimate canopy cover in the field, but it is limited by the costs, subjectivity and non-reproducibility of the produced estimates. Digital photography is a low-cost alternative method. In this study we tested two automated image classification methods, the first one based on a histogram-analysis method (Rosin), the second one based on a combination of a visible vegetation index and the $L^*a^*b^*$ colour space conversion (LAB2), which have both been previously tested in forestry, and a supervised image classification method (Winscanopy), to estimate canopy cover from downward-looking images of agricultural crops. These methods were tested using artificial images with known cover; this allowed exploring the influence of canopy density and object size on canopy cover estimation from photography. The Rosin method provided the best estimates of canopy cover in artificial images, whose accuracy was largely unaffected by variation in canopy density and object size. By contrast, LAB2 systematically overestimated canopy cover, because of the sensitivity of the method to small variations of chromaticity in artificial images. Winscanopy showed good performance when at least two regions per class were manually selected from a representative image. The results were replicated in real images of cultivated aromatic crops. The main findings indicate that digital photography is an effective method to obtain rapid, robust and reproducible measures of canopy cover in downward-looking images of agricultural crops, including aromatic plants.
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1. Introduction

Accurate estimates of ground canopy cover (hereafter abbreviated as canopy cover or cover), also called fractional vegetation cover, defined as the fraction of ground area covered by the vertical projection of foliage (Walker & Tunstall, 1981), are strongly required for a wide range of studies, including hydrology, carbon and nutrient cycling, and

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global change (Angelini, Corona, Chianucci, & Portoghesi, 2015; Fathizadeh et al., 2017). As canopy cover is a major determinant of vegetation reflectance from optical satellite data, this variable is also required to calibrate remotely-sensed vegetation indices and to indirectly estimate leaf area index from radiative transfer theory (Ahmed, Franklin, Wulder, & White, 2015; Asner, Martin, Anderson, & Knapp, 2015; Pfeifer, Korhonen, Wheeler, & Rautiainen, 2017).

A major challenge in estimating canopy cover is that no 'direct' method is applicable to measure this variable in the field. Visual assessment is a widely used method, but its drawbacks are well-known, and include the bias between operators (Luscier, Thompson, Wilson, Gorham, & Dragut, 2006; Richardson et al., 2001), the inability to distinguish between cover intervals smaller than 10% (Hahn & Scheuring, 2003) and the unsatisfactory ability to reproduce measurements. As an alternative to visual assessment, indirect optical methods have long been used to estimate canopy cover in vegetation ecosystems (Chianucci, 2016; Song, Mu, Yan, & Huang, 2015). For example, the AccuPAR ceptometer (Decagon, Pullman, WA, US) and the LAI-2000 Plant Canopy Analyzer (Li-COR, Lincoln, NE) have often been used to estimate vertical gap fraction (and its complement canopy cover) from radiation transmittance at the zenith or nadir (Rautiainen, Stenberg, & Nilson, 2005). However, these methods are limited by the cost of the instruments, and some constraints related to their use in short canopies, like agricultural crops (e.g.: minimum distance between target and sensor, sampling size; Chianucci & Cutini, 2012).

Thanks to recent technological developments, digital cameras are becoming increasingly affordable and promote the use of digital photography to indirectly estimate canopy attributes. Canopy photography has been mainly used in forestry and, to a less extent, for agricultural crops (e.g., Jannoura, Brinkmann, Uteau, Bruns, & Joergensen, 2015; Liu, Mu, Wang, & Yan, 2012; Liu, Pattey, & Admiral, 2013; Liu et al., 2016; Mora et al., 2016; Patrignani & Ochsner, 2015; Ramirez-Garcia, Almendros, & Quemada, 2012; Roth & Streit, 2018; Song et al., 2015), while no application has been tested before on wild or cultivated aromatic plants. Use of visible-vegetation indices allows extracting green vegetation pixels from true colour (red, green, blue) images taken from above the canopy looking downward, thus supporting the use of digital photography to estimate canopy cover in agricultural crops. However, poor studies have tested the accuracy of canopy cover comparing estimates from photography against known values. The majority of previous studies have used estimates of gap fraction from indirect methods, to obtain indirect estimates of leaf area index via a theoretical gap fraction formula, and these estimates are then validated against direct measures of leaf area index (Alivernini, Fares, Ferrara, & Chianucci, 2018; Chianucci, Cutini, Corona, & Puletti, 2014; Macfarlane, Grigg, & Evangelista, 2007; Ryu et al., 2010). However, there is potential for compensating errors in the process of indirect leaf area index estimation, which can result in approximately accurate leaf area index estimates despite inaccurate estimates of some intermediate quantities employed in the theoretical gap fraction formula (e.g. getting both the leaf inclination distribution function wrong, and the clumping index wrong can still yield an approximately correct leaf area index; Macfarlane, 2011). Therefore, the comparison of indirect versus direct leaf area index can't allow a firm conclusion to be drawn on the performance of indirect methods on estimating canopy cover (Macfarlane, Ryu, Ogden, & Sonnentag, 2014).

The objective of this study was to test the accuracy of digital photography to estimate canopy cover from downward-looking images over agricultural crops. For the purpose, estimates obtained from photography were compared with those obtained from artificial images with known canopy cover; this allowed evaluating the influence of canopy cover and mean object (leaf/background) size on indirect canopy cover estimation. Results were also compared with real images of agricultural crops.

2. Materials and methods

2.1. *Artificial canopy cover images*

The idea of measuring an artificial target to calibrate canopy cover measures has been proposed by various authors (Chianucci, 2016; Macfarlane et al., 2014; Song, Doley, Yates, Chao, & Hsieh, 2014). However, previous studies mainly employed two-coloured (black and white) targets, which are suitable for binary classification of upward-facing images into sky/canopy. An ideal artificial target for downward-facing images should be representative of the chromatic and spectral variability of vegetation and soil background. For this reason, we generated 200 artificial images with known canopy cover, and we coloured them using wide colour palettes. First, an R routine (R Core Development team, Vienna) was used to randomly fill blank 1000 × 1000 pixel images with dark circles (representing the canopy) with a radius of 1 pixel. The artificial canopy cover ranged from 0.01 to 0.80, representing a realistic range of canopy cover occurring in real crops. We then created two colour ramps, the first representing vegetation objects and the other representing soil objects (background pixels). Each ramp was obtained by combining 6–7 default colours, which have been arbitrarily selected as representative of vegetation (Hexadecimal codes: "#B4EEB4", "#CAFF70", "#7FFF00", "#00FF7F", "#2E8B57", "#006400") and soil ("#EED5B7", "#FFF68F", "#DAA520", "#DEB887", "#CDAD00", "#A52A2A", "#000000"). Vegetation pixels and non-vegetation pixels were then recoloured by randomly selecting colours from respectively the vegetation and soil colour ramps. The artificial images contain about 400,000 different colours from the two produced colour ramps, as measured from a colour cube analysis. To explore the influence of object size on canopy cover estimation, eight 1000 × 1000 pixel images were further generated by applying a checkerboard (black and white) pattern (canopy cover of 0.5) and arbitrarily varying checkerboard size (simulating object size) from 0.1% to 10% of the image area. The black and white pixels were then recoloured by randomly selecting colours from respectively the vegetation and soil colour ramps.

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