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A new model for water balance estimation on lettuce crops using effective diameter obtained with image analysis

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ABSTRACT

Digital processing and analysis of vegetation cover images allow a precise calculation of some parameters related to crop development, which are linked to the estimation of irrigation requirements of the plants. In this paper, a new methodology for visual monitoring of horticultural crops and computation of the corresponding water needs is presented. The proposed approach is based on the concept of effective diameter, defined as the equivalent diameter of a plant biomass as seen from a top view. It has been applied to a 'Little Gem' lettuce crop. The percentage of green cover (PGC), computed by means of a digital processing of captured coverage images, is used to provide accurate estimates of the effective diameter of the plants. Then, this value can be precisely related with some important parameters in agronomy such as root depth, height of the plants, and crop coefficient *Kc*. Since *Kc* is an essential parameter in most existing methodologies for water balance estimation, an extensive comparative study on the accuracy of the proposed approach with respect to two alternative methods has been conducted. The first approach is based on PGC and crop density data, while the second is exclusively based on image analysis. The proposed method behaved significantly better in all cases, yielding a coefficient of determination, R^2, to the actual *Kc* values obtained with a Bowen station always above 0.95, and a maximum relative error of only 2.1%. Moreover, the proposed methodology also produced accurate estimates of root depth with R^2 values above 0.986 and maximum error below 9%. This approach not only leads to a reduction of water consumption compared to traditional estimation methods, but it also simplifies the required computations and field equipment.

1. Introduction

Precise knowledge of the water needs of crops makes it possible to achieve proper management of irrigation resources with a maximum efficiency (Fereres, 1987). The computation of water balance can be used to estimate the hydric demand of cultures during the cropping cycle (Sánchez et al., 2012), being based on the quantification of the inputs and outputs of water in the soil profile explored by the root system of plants.

The use of coverage images of crops to estimate water needs is based on the determination of the fraction of ground covered by the plant canopy (Escarabajal-Henarejos et al., 2015a; Fernández-Pacheco et al., 2014). In particular, the percentage of green cover (PGC) – also referred by some authors as the fraction of vegetation or ground cover – allows estimating the water needs of crops since it is directly related to the evapotranspiration (*ETc*), which is computed as the product of the crop coefficient (*Kc*) by the reference evapotranspiration (*ETo*) (Allen et al., 1998), that is: $ETc = Kc \cdot ETo$. Therefore, *Kc* integrates in a single value the real influence of soil evaporation and crop transpiration, in relation with the reference *ETo*. So an accurate estimation of this parameter is essential to achieve a precise and efficient water management.

A large number of methods to compute *Kc* can be found in literature, many of which are extremely labour-intensive, destructive and costly in terms of time and money. For these reasons, many alternative techniques have been proposed to estimate it by modelling its relationship with other biological magnitudes, such as the Leaf Area Index (LAI) (Kirk et al., 2009), the Normalized Difference

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Vegetation Index (NDVI) (Rahimi et al., 2015), and the fraction of vegetation cover (López-Urrea et al., 2009) among others, being achieved great advances in this regard.

Specifically, Allen and Pereira (2009) proposed a method for estimating *Kc* from data of PGC, a crop density coefficient, *Kd*, and the average plant height, *h*. Moreover, Fernández-Pacheco et al. (2014) developed another method for estimating *Kc* based on digital image processing for determining PGC. In contrast with the approach of Allen and Pereira (2009), the latter methodology requires no direct measurement of the height of the crop, but it makes an estimate using the available values of PGC, in order to provide the value of *Kc*. This procedure greatly simplifies data collection and facilitates automation of the process.

Another important variable of the vegetative growth of crops, directly involved in hydric balance computation, is the depth of the root system of the plants. Its role in water balance is determined by the need to know the profile of soil explored by the roots, in which it is necessary to maintain optimum moisture conditions for the proper development of the crop (Rincón and Sáez, 1997). In crops of lettuce, Escarabajal-Henarejos et al. (2015b) successfully achieved to correlate this parameter with the PGC, and developed a way to obtain prediction models of the root depth using top-view images of the crops.

The aim of the present research is to describe a significant advance in the estimation of water requirements of lettuce crops (*Lactuca sativa* L. cv. Little Gem) using visual data, introducing the concept of effective diameter. This parameter can be defined as the average diameter of plants in a crop, as seen from top view images. Instead of making predictions based directly on the PGC, the proposed approach obtains the effective diameter in first place; then, crop coefficient, plant height and root depth are correlated with this diameter by using allometric functions. PGC is estimated applying digital photography and automatic image processing techniques. This proposal is complemented with an experimental validation of the accuracy of the proposed method, as compared to the previous methodologies presented by Allen and Pereira (2009) and Escarabajal-Henarejos et al. (2015a).

The rest of this paper is organized as follows. First, in Section 2 the materials used in the present study, the proposed estimation approach and the alternative methods are presented. Then, Section 3 describes the experimental results and the comparison of the different methodologies. Finally, the main conclusions and future research lines are exposed in Section 4.

2. Materials and methods

This research was conducted on lettuce crops with low vigor (*Lactuca sativa* L. cv. Little Gem), located in the region of San Javier, in the province of Murcia (latitude 37°47′04″N, longitude 0° 49′34″W and altitude 15 m), Spain. In order to avoid statistical dependence on the experiments described in Section 3, different sets of experimental data were collected. Particularly, for the comparison of methodologies, three commercial plantations of lettuce were used, all belonging to the autumn-winter season, taking place during the months from October to December of the years 2011–2013. Lettuce seedlings were obtained in seedbeds apart and transplanted in October, during the three seasons (2011–2013), with a planting density of 16.5 plants m^{-2}. The total duration of the cultures was 9 weeks. Other cropping cycles in spring 2013 and autumn 2014 were also used for some additional experiments, with similar planting conditions.

For image processing, four small subparcels with an area of 1.8 m^2 (1.8 m × 1.0 m) were delimited by frames in each plot (as shown in Fig. 1), being representative of the culture and randomly distributed, far from the edges of the plot to avoid the edge effect. This procedure was included in the data gathering methodology described by Escarabajal-Henarejos et al. (2015b). The photographic monitoring of vegetation cover was performed at intervals of 2–3 days, with a compact Sony digital camera model DSC-HX400 and a Nikon Coolpix S3300. No especial field equip-

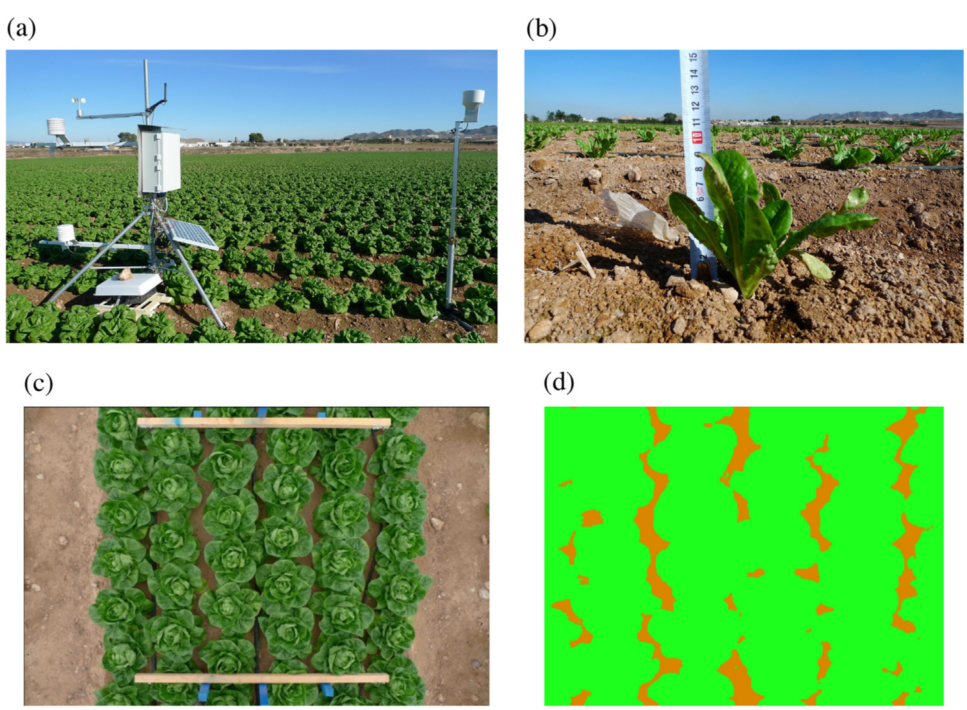

Fig. 1. Some sample images of the lettuce crop and the monitoring process. (a) A global view of the crop and the Bowen station used to obtain ground-truth values of *Kc*. (b) Manual process for measuring plant height. (c) A top view of a sample plot with the area of interest delimited. (d) Result of the automatic plant/soil segmentation, producing a PGC of 89.04% in this case.

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