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Reducing background effects in orchards through spectral vegetation index correction

Jonathan Van Beek[a,*], Laurent Tits[a], Ben Somers[b], Tom Deckers[c], Pieter Janssens[d], Pol Coppin[a]

[a] KU Leuven, Department of Biosystems, M3-BIORES, Willem de Croylaan 34, Leuven BE-3001, Belgium
[b] KU Leuven, Division Forest, Nature and Landscape, Celestijnenlaan 200E, Leuven BE-3001, Belgium
[c] Pcfruit Research Station, Fruittuinweg 1, Sint-Truiden BE-3800, Belgium
[d] Soil Service of Belgium, Willem de Croylaan 48, Leuven BE-3001, Belgium

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ABSTRACT

Satellite remote sensing provides an alternative to time-consuming and labor intensive in situ measurements of biophysical variables in agricultural crops required for precision agriculture applications. In orchards, however, the spatial resolution causes mixtures of canopies and background (i.e. soil, grass and shadow), hampering the estimation of these biophysical variables. Furthermore, variable background mixtures obstruct meaningful comparisons between different orchard blocks, rows or within each row. Current correction methodologies use spectral differences between canopies and background, but struggle with a vegetated orchard floor. This background influence and the lack of a generic solution are addressed in this study.

Firstly, the problem was demonstrated in a controlled environment for vegetation indices sensitive to chlorophyll content, water content and leaf area index. Afterwards, traditional background correction methods (i.e. soil-adjusted vegetation indices and signal unmixing) were compared to the proposed vegetation index correction. This correction was based on the mixing degree of each pixel (i.e. tree cover fraction) to rescale the vegetation indices accordingly and was applied to synthetic and WorldView-2 satellite imagery. Through the correction, the effect of background admixture for vegetation indices was reduced, and the estimation of biophysical variables was improved ($\Delta R^2 = 0.2$–0.31).

1. Introduction

Precision agriculture in orchards requires accurate, reliable and continuous information at high spatial and temporal scales (Pinter et al., 2003), sensitive to stress-related biophysical variables such as chlorophyll content (Zarco-Tejada et al., 2004), water content (Govender et al., 2009) and leaf area index (LAI). In situ measurements of these biophysical variables are time-consuming and labor intensive, while technological advances in remote sensing provide non-destructive, time efficient and cost beneficial alternatives (Dorigo et al., 2007). For precision farming in deciduous orchard growing regions, the high cloud cover requires a near-to-daily revisit time to provide consistent information throughout the growing season (Moran et al., 2003). Furthermore, the high spatial variability in orchards (Perry et al., 2009) requires high spatial resolution imagery to provide accurate information essential for steering precision farming management schemes. Currently, this combination of both high spatial and temporal resolution data is feasible from high spatial resolution satellite sensors with off-nadir viewing capabilities, such as GeoEye-1, Quickbird, Pleiades or WorldView-1 and WorldView-2.

Despite the relatively high spatial resolution of these satellite sensors, remote sensing imagery over orchards will contain mixtures of canopies and backgrounds (i.e. soil, grass and shadow). Even at sub-meter spatial resolution, this mixture of canopies and background will be present (Stuckens et al., 2010). Furthermore, the combination of satellite imagery with a high spatial resolution (i.e. 2 m) and orchard geometry (i.e. row planting distance) will also cause variable background mixtures, obstructing meaningful

* Corresponding author. Tel.: +32 1632 8146; fax: +32 1632 2966.
E-mail addresses: jonathan.vanbeek@biw.kuleuven.be (J. Van Beek), laurent.tits@biw.kuleuven.be (L. Tits), ben.somers@ees.kuleuven.be (B. Somers), tom.deckers@pcfruit.be (T. Deckers), pjanssens@bdb.be (P. Janssens), pol.coppin@biw.kuleuven.be (P. Coppin).

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comparisons between different orchard blocks, rows or within each row. Moreover, the background will be influenced by geological differences, slopes, presence or absence of vegetation and weed species distribution, causing a high spatial variability within one orchard.

In the past, several methods were constructed to remove the influence of the background components. An established way to diminish soil background effects is the use of soil-adjusted vegetation indices combined with TCARI (Transformed Chlorophyll Absorption in Reflectance Index) (Haboudane et al., 2002; Zarco-Tejada et al., 2004). Another technique to minimize or remove background effects in orchards is signal unmixing models (Somers et al., 2009; Tits et al., 2013b), which often require large databases of background spectra to correct imagery and account for spatial variability. However, both these approaches were based on the spectral differences between soil and vegetation, rendering them less usable in orchards with vegetative orchard floors or backgrounds.

Mixture effect could also be avoided by the application of a spatial filtering or smoothing of reflectance or vegetation index values, e.g. Acevedo-Opazo et al. (2008). This approach requires a uniform background and a similar row and tree spacing in order to present similar canopy and background mixtures throughout the orchard. However, both spectral information and spatial variability might be lost due to the smoothing algorithm and comparisons between orchards with different row or tree spacing would cause inaccuracies.

All of the above-described methodologies were able to remove background effects in certain circumstances but did not provide a standard solution for the mixture problem. This lack of a generic solution to reduce background effects irrespective of background types (i.e. soil, grass and shadow) and the influence of variable background mixtures on vegetation indices require further investigation. Therefore, this study addresses the mixture problem in orchards presented in high spatial resolution space borne imagery. Through synthetic imagery, the mixture problem was demonstrated in a controlled environment for different background scenarios toward the estimation of biophysical variables (i.e. chlorophyll, water content and LAI). A vegetation index correction method, based on the canopy cover fractions, was tested in the virtual environment and afterwards implemented on space borne imagery of a commercial hedgerow pear orchard.

2. Materials

2.1. Synthetic images

Synthetic or simulated imagery provide a useful data source for improving our understanding of remotely sensed data and are frequently used to perform a preliminary evaluation of analysis techniques, e.g. Tits et al. (2013b). The advantages of synthetic data are the availability of the exact cover fractions, spectral signatures and the biophysical variables of the target crop. In this study, the simulations were used to demonstrate the mixed pixel problem in orchard crops, to visualize its effect on vegetation indices, to prove the necessity of a correction method and to quantify the improvements of the proposed correction algorithm.

A virtual orchard, developed by Stuckens et al. (2009), was modified and adapted for this study. The virtual orchard consisted of virtual citrus trees (*Citrus sinensis* L.), comprises triangular meshes (Weber and Penn, 1995), for which the leaf and stem optical properties and physical properties were based on field measurements (Somers et al., 2009; Stuckens et al., 2009). The virtual trees were arranged in a 3.5 m × 2 m grid with a row azimuth of 7°.

In the virtual orchard, three biophysical variables were investigated, i.e. chlorophyll, water and LAI. For each variable, several sections of the virtual orchard were modified to mimic stressed conditions. The leaf optical properties of these virtual trees were modified by extracting the biophysical variables from the unmodified spectra through the inversion of PROSPECT (Jacquemoud and Baret, 1990), and lowering the extracted variables to 50% and 75% of the original value for chlorophyll and to 70% and 85% of the original value for water content. Afterwards, the modified spectra were recalculated through PROSPECT with the modified variables (Stuckens et al., 2009). For LAI, the virtual trees were modified by randomly removing or adding leaves to represent 125% and 56% of the original LAI (Stuckens et al., 2009). An overview of the used biophysical variables is shown in Table 1, while the spatial distribution of each biophysical variable is represented in Fig. 1a, b and d.

Table 1
The mean, standard deviation (σ) and range of chlorophyll, water content and leaf area index for the unmodified trees used in the virtual orchard.

Biophysical variable	Mean value (±σ)	Range
Chlorophyll content (μg/cm^2)	38.69 (±10.55)	16.08–58.92
Water content (mg/cm^2)	18.81 (±2.35)	13.43–21.63
Leaf area index (cm^2/cm^2)	6.44 (±1.72)	3.20–10.97

From these virtual orchards, different images were made in a physically based ray-tracer (PBRT, Pharr and Humphreys, 2004), with a direct and diffuse illumination source (elevation of 79.2° and azimuth of 339.6°), corresponding to the position of the sun on Southern summer solstice on 22nd of December in 2007 at 13:00 h. The sensor was positioned in zenith, and combined with an orthographic projection to yield images without any geometric distortion. The spectral range of the synthetic image was 350–2500 nm with a spectral resolution of 10 nm, while the spatial resolution of the sensor was fixed at 2 m. The resulting canopy cover fractions within the 2 m pixels are shown in Fig. 1e.

The influence of different background types was investigated by varying the orchard floor or background through three different scenarios, while the position of the virtual trees remained identical for each scenario.

- Scenario 1 (S1), a uniform soil background, consisting of an Albic Leptic Luvisol soil (FAO, 1988), for which the reflectance was measured in situ (Somers et al., 2010). An RGB image of the orchard with the uniform soil background is shown in Fig. 1c.
- Scenario 2 (S2), a uniform weed background, consisting of *Phleum pratense* L. modeled with leaf reflectance obtained from the Leaf Optical Experiment database (Hosgood et al., 1994; Stuckens et al., 2009).
- Scenario 3 (S3), a variable weed background, consisting of a weed background with a chlorophyll gradient. The weed background was modified similar to the leaf reflectances, increasing the chlorophyll content from 75% to the reference value (i.e. uniform weed background). The spatial distribution of the variable weed background is depicted in Fig. 1f.

S1 was used to investigate the usefulness of existing background correction methodologies (i.e. soil-adjusted vegetation indices and signal unmixing), while S2 was used to link this to variable conditions (S3).

2.2. Study area and satellite imagery

Satellite imagery was acquired over an orchard, planted with Conference pear trees (*Pyrus communis* L. cv. 'Conference'), situated in Bierbeek, Belgium (50°49′34.59″ N 4°47′42.83″ E). The ±2.5 m high trees were planted between 1989 and 2010 in a 3.5 m × 1 m grid (row azimuth 41°) and trained into either a V-system with