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Spatial variability in orchards after land transformation: Consequences for precision agriculture practices

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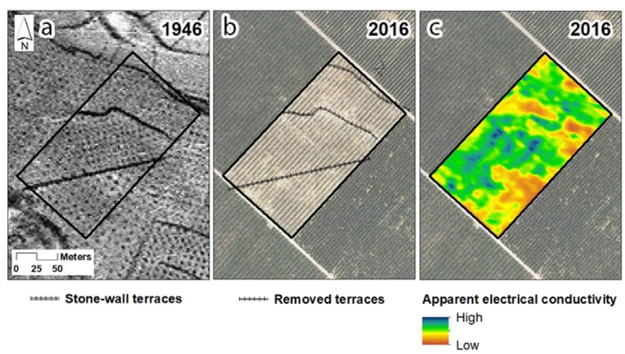
HIGHLIGHTS

- Land transformations alter the spatial distribution and continuity of soil properties.
- Apparent electrical conductivity (ECa) and NDVI were used to map consequences.
- Differential management of orchards is proposed on the basis of ECa and NDVI.

GRAPHICAL ABSTRACT

Comparison of situations before (a) and after (b) land transformation, and (c) effects in the spatial variability of apparent electrical conductivity were stone-wall terraces were removed.



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ABSTRACT

The change from traditional to a more mechanized and technical agriculture has involved, in many cases, land transformations. This has supposed alteration of landforms and soils, with significant consequences. The effects of induced soil variability and the subsequent implications in site-specific crop management have not been sufficiently studied. The present work investigated the application of a resistivity soil sensor (Veris 3100), to map the apparent electrical conductivity (ECa), and detailed multispectral airborne images to analyse soil and crop spatial variability to assist in site-specific orchard management. The study was carried out in a peach orchard (*Prunus persica* (L.) Stokes), in an area transformed in the 1980 decade to change from rainfed arable crops to irrigated orchards. A total of 40 soil samples at two depths (0–30 cm and 30–60 cm) were analysed and compared to ECa and the normalised difference vegetation index (NDVI). Two types of statistical analysis were performed between ECa or NDVI classes with soil properties: a linear correlation analysis and multivariate analysis of variance (MANOVA). The results showed that the land transformation altered the spatial distribution and continuity of soil properties. Although a relationship between ECa and peach tree vigour could be expected, it was not found, even in the case of trees planted in soils with salts content above the tolerance threshold. Two types of management zones were proposed: a) zones delineated according to ECa classes to leach salts in the high ECa zones, and b) zones delineated according to NDVI classes to regulate tree vigour and yield. These strategies respond to the alteration of the original soil functions due to the land transformation carried out in previous years.

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1. Introduction

Since the mid-twentieth century, and particularly since the 1980s–90s, traditional agriculture is undergoing a change to a more modern, mechanized and technical agriculture. In many cases, these changes have involved land transformation, with land use alteration and intensification (Richter, 1984). This has been the case of cash crop development by the market-oriented agriculture. It is a global phenomenon that has promoted the expansion of hazelnut, rubber, fruit, and tea in developing tropical and subtropical countries (Xiao et al., 2015); citrus in Brazil (Moraes et al., 2017); or vineyards, almonds, olive and fruit trees in the Mediterranean Europe (García-Ruiz, 2010; Martínez-Casasnovas et al., 2010a), among others.

This intensification of agriculture has supposed the alteration of landforms and soils, with significant ecological consequences (Xiao et al., 2015). Some works have reported specific examples of those effects. For example, local hydrology (Yi et al., 2014), soil profile dismantlement (Laudicina et al., 2016; Öztekin, 2013), acceleration of soil erosion (García-Ruiz, 2010; Ramos and Martínez-Casasnovas, 2010; Xiao et al., 2015), fragmentation of traditional landscapes (De Oliveira et al., 2017), increase of CO_2 emissions (Carlson et al., 2013), elimination of traditional soil conservation measures and increase of soil spatial variability (Laudicina et al., 2016; Martínez-Casasnovas and Ramos, 2009; Su et al., 2016; Xiao et al., 2015). Another major problem is the effect of topsoil removing on plant growth. Reduced growth may occur on the fill areas (Martínez-Casasnovas et al., 2010b), although the exposure of subsoil in the cuts is usually a more serious problem (Öztekin, 2013). Moreover, many of these land transformations have been supported by subsidies, as happens in the Mediterranean Europe, where many orchards planted in the last decades were also supported by the European Agricultural Policy in response to market demand (Cots-Folch et al., 2009; Nainggolan et al., 2012).

Although there have been attempts to document the process of cash crops expansion, the effects of induced soil variability due to land transformations and the subsequent implications in crop management have not been sufficiently investigated. However, this is of particular interest to fruit growers since, due to the soil-plant interaction, fruit trees development and their potential production are affected by the spatial variability of soil properties (Khan et al., 2016; Panda et al., 2010; Pedrera-Parrilla et al., 2016). Then, changes produced by land transformations can become a main constraint to consider when planning orchard management operations (Fulton et al., 2011). On the other hand, field size should not be considered as a limitation for precision agriculture applications in fruticulture since, even in small orchards, there may be differences in soil properties affecting tree growth and fruit quality (Käthner and Zude-Sasse, 2015; Zude-Sasse et al., 2016).

Soil information is often not available at a spatial resolution intrinsically needed for precision agriculture or other site-specific soil uses and management purposes (Mertens et al., 2008); and specifically is not available after land transformations. One approach to obtain detailed spatially distributed soil data is the non-invasive measurement of the apparent electrical conductivity (ECa). Soil sensors for on-the-go ECa mapping are increasingly used for this purpose (Corwin and Lesch, 2003; Fulton et al., 2011; Mertens et al., 2008), and to delineate management zones according to the concept of precision agriculture (Moral et al., 2010; Peralta and Costa, 2013). In orchards, ECa has been used for the analysis of soil variability, and some researchers have found correlations between ECa, generative tree growth, fruit development and fruit size (Käthner and Zude-Sasse, 2015; Zude-Sasse et al., 2016). In this respect, it was pointed out that fruit development and soil ECa were well correlated. However, quality parameters, although very variable, are spatially less stable and may be poorly related to the ECa as indicated Aggelopoulou et al. (2010) in apple tree plantations. Regarding the interpretation of the ECa signal, some authors have highlighted the difficulty to determine the soil properties that most affect the variability of ECa in a particular field (Uribeetxebarria et al., 2018). Because of that, they proposed the use of multivariate analysis of variance (MANOVA) to better interpret which soil properties are behind the variation of the electrical conductivity signal. This was particularly useful in orchards affected by previous parcelling (Uribeetxebarria et al., 2018).

Additionally, site-specific management zones (SSMZ) can also be delimited based on remote sensing data. In this respect, the most frequently used vegetation index is the Normalised Difference Vegetation Index (NDVI) (Rouse Jr et al., 1974), which is feasible in low-chlorophyll fruits and canopy imaging. NDVI is correlated to plant vigour and has strong interaction with yield and sometimes quality parameters (Zude-Sasse et al., 2016). Different authors have used spectral indices to estimate orchard variables. For example, Peña-Barragán et al. (2004) developed a methodology to determine tree cover in olive groves using aerial images and different spectral indexes. González-Dugo et al. (2013), using high resolution airborne thermal imagery, assessed the heterogeneity in water status in commercial orchards (almond, apricot, peach, lemon and orange), as a prerequisite for precision irrigation management. Other authors (Noori and Panda, 2016) also studied the relationship between vegetation indexes (SAVI, NDVI and Vegetative Vigour Index) with field environmental data including soil and tree structure attributes in an olive orchard, suggesting that these relationships would help in Site Specific Crop Management (SSCM) of orchards. Other works used airborne hyperspectral imagery for predicting yield in citrus crops (Ye et al., 2009), or more specifically, to quantify fluorescence emission in a commercial citrus orchard as well (Zarco-Tejada et al., 2016). In the latter, the objective was to track photosynthesis at different phenological and stress stages throughout the season to suggest its operational use in precision agriculture.

Despite these findings and advances, there are not many examples of practical application of SSCM in commercial fruit orchards (Noori and Panda, 2016). However, emerging research knowledge in this field demonstrates clear advantages of precision agriculture tools in fruit production management. In this respect, different authors suggest the combination of ECa with spectral vegetation indices to help in the delineation of SSMZ (De Benedetto et al., 2013; Ortega-Blu and Molina-Roco, 2016; Panda et al., 2010). This approach allows identifying homogenous sub-field areas related to the intrinsic properties of soil and, above all, differentiated crop response. This is because ECa, by itself, may not be a good estimator of the most commonly measured soil properties and, under irrigation and fertigation conditions, the vegetation status may be more affected by water and nutrient management than by soil properties (De Benedetto et al., 2013).

ECa and/or spectral vegetation indices have been mainly applied in field crops and vineyard (Priori et al., 2013), but fewer studies refer to their use in fruit orchards, and even less in Mediterranean latitudes. One important reason could be the small sized orchards usually have there. Nevertheless, and as pointed out by Käthner and Zude-Sasse (2015) and Arnó et al. (2017), even in small orchards there may be differences in soil properties affecting tree growth and fruit quality.

As showed above, precision agriculture applications in tree crops are rather limited in the literature (Aggelopoulou et al., 2011). Moreover, as suggested by Öztekin (2013), after land transformations, some site-specific management practices should be taken into account to regain productivity and improve homogeneity in soil properties. However, to the best of our knowledge, there are no works addressing the implications of land transformations in precision agriculture. In this context, the aim of the present work was to investigate the effects of land transformations in soil variability and crop development in a peach orchard (*Prunus persica* (L.) Stokes) located in Lleida (Catalonia, NE Spain). The area suffered land transformations in the 1980 decade to enlarge fields and changed from rainfed crops to irrigated orchards. The hypothesis was that land transformations aimed to enlarge fields, instead to create more homogeneous areas, alter the spatial distribution and continuity of soil properties, with consequences in crop vigour. This opens an opportunity to precision agriculture techniques to assist in site-specific orchard management.