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Delineation of site-specific management units for operational applications using the topographic position index in La Pampa, Argentina

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ABSTRACT

In this work we propose the use of the topographic position index (TPI), which takes into account the local topography for a given neighborhood, to delineate management units (MU) for site-specific systems. This study was performed in the province of La Pampa, in central Argentina, an area with sandy soils where the main limiting condition for crops is soil moisture. Usually, multi-annual yield maps are used for the delineation of MU. However, those are strongly influenced by issues that could be related to uncalibrated data and previous agronomical practices. Thus, there was a need for a methodology based on stable and unbiased parameters. The methodology was developed for a representative 100 ha field. The average size and orientation of the topographic structures were characterized applying the autocorrelation function on the topographic data, which was then used to determine an optimum neighborhood size for the TPI. TPI performed better than the topographic map to characterize the variability of the field. The correlation between yield and TPI was higher ($r = 0.74$) than that between yield and topography ($r = 0.54$). The resulting management units were delineated using an unsupervised classification approach on the TPI maps. From the confusion matrices, the overall accuracy was higher for the TPI derived maps than for the topography derived maps (62% against 47%) when compared to a yield map used as reference. We estimate that this methodology could be used for operational applications, the only requirement being topographic data for a given field, since it is simple, the algorithms used are unbiased and it could be performed using free software.

1. Introduction and background

In Argentina site-specific management, also known as Precision Farming, started to be developed around 1990, promoted by the National Agricultural Technology Institute (*Instituto Nacional de Tecnología Agropecuaria* (INTA)) (Bragachini et al., 2011). The number of yield monitors increased significantly from 2004 to 2010, with some 9600 units in 2014. Since 2007, variable rate technology (VRT) equipment has been rapidly increasing with approximately 2600 units in 2014 (Méndez et al., 2014). Some statistics show that 87% of all site specific management adopters use yield maps to some extent and 66% use satellite imagery. Most of them use yield data for visualization (83%) and some of them to delimit management zones (77%). The percentages are lower for the application of VRT for seeds and fertilizers (33% and 44% respectively). There is no statistical information regarding the use of topographical data or Geographic Information Systems (GIS) (Melchiori et al., 2013).

The province of La Pampa is situated in central Argentina between approximately 35° S and 39°11' S, and 63°23' W and 68°17' W. Rainfed agriculture is one of the major economic activities of the province which is implemented in the northeastern part where the soil and climate conditions are appropriate (Fig. 1). The main crops are soybean (*Glycine max* L. Merr.), maize (*Zea mays* L.) and sunflower (*Helianthus annus*), with 1,000,000 hectares sown in the agricultural campaign 2014–2015 (MAGyP, 2015) mostly under no-till management.

The average precipitation is around 700 mm/year (APA, 2015) and the main constraint for crop development here is the low water retention capacity of the soil (INTA, 2004). Given these limiting conditions for crops, the adoption of site specific management strategies has a good potential to enhance crop yields by a better use of natural resources.

Site-specific management promotes the identification and management of areas, called management units (MU), within a given

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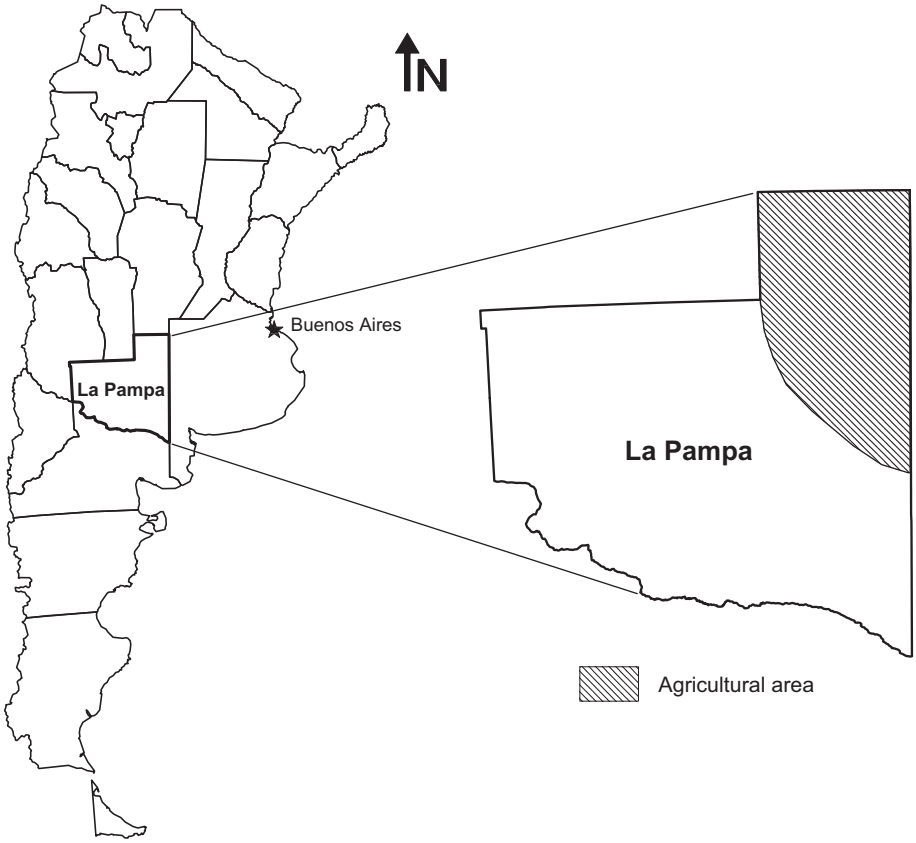

Fig. 1. Political map of Argentina showing the location of the province of La Pampa and Argentina Capital City (Buenos Aires). In the map of the province the agricultural area situated in the NE is indicated in diagonal pattern.

field, which represent subfield regions with homogeneous characteristics, such as texture, topography and nutrient levels (Moral et al., 2010). Each management unit is obtained by grouping the pixels of the layer used to characterize the spatial variability of the field (for example a yield map) applying some decision rule defined by the user. This process is usually known as classification or segmentation. Different types of layers can be used to generate the MU. Examples using yields maps can be found in Brock et al. (2005), Flowers et al. (2005), Jaynes et al. (2005) and Milne et al. (2012). Other types of layers used are topographic and electrical conductivity maps (Kweon, 2012; Fraisse et al., 2001), and soil fertility maps (Ortega and Santibáñez, 2007). Regarding the segmentation methods, various techniques have been proposed, for example Cordoba et al. (2013) used a methodology based on cluster analysis from spatial principal components and Zhang et al. (2016) developed a method for the delineation of rectangular management zones based on semivariograms. Other researchers used various clustering algorithms (Haghverdi et al., 2015; Brock et al., 2005; Fraisse et al., 2001; Li et al., 2007), segmentations based on image processing algorithms (Pedroso et al., 2010) and geostatistical techniques (Moral et al., 2011). In Argentina, some methodologies for the delineation of MU using yield maps can be found in (Justo et al., 2011). Peralta and Costa (2013) use the apparent electrical conductivity (ECa) as an estimator of the soil properties and for the delimitation of homogeneous areas in the province of Córdoba, Argentina. In La Pampa, much of the development was performed by farmers and private contractors that, probably due to its availability (Melchiori et al., 2013), use multi annual yield maps for the delineation of management units for VRT applications (personal communication). The situation observed in that case is that once variable rates of seeds and fertilizers are applied, the resulting yield is not only affected by the natural variation (i.e., the variation that would arise without VRT) but becomes entangled with the VRT strategy applied. Thus, there is a need to use some other variable, relatively invariant for the time scale of the agronomical practices, as estimator of the natural spatial variability of a field. One option is to use the topography, given its relationship with textural soil parameters and water availability. In the literature, some studies regarding the yield-topography relationship in Illinois and Indiana in the US can be found in Kravchenko and Bullock (2000); they show that elevation is the single most influential variable on yield. Also Marques da Silva and Silva (2008), for irrigated maize fields in Portugal, found that average yield presented a strong dependency on topography, as well as on derived parameters (slope and topographic indices) that reflect water availability (for example the wetness index and the distance to flow accumulation lines). Kweon (2012) used a fuzzy logic system using soil properties obtained from on-the-go electrical conductivity (EC), organic matter (OM) sensors and topographic attributes (slope and curvature). In Argentina, Franco et al. (2012) analyzed the relationship between topography and some primary as well as secondary characteristics and yields in the SE of the province of Buenos Aires. In the agricultural establishment where the present study was carried out, management units were generated by segmentation of the topographic maps for VRT applications of seeds and fertilizers since 2008 (Mieza et al., 2014). Also pilot studies regarding the optimum rates of seed and fertilizers for those management units have been performed (Ghironi et al., 2012).

From the analysis of yield maps on representative areas, it was observed that yield variability seems to correlate better with local minima and maxima topographic values rather than with the