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Delineation of management zones to improve nitrogen management of wheat

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ABSTRACT

Site-specific management of N (NSSM) is an attractive and intuitive approach to increasing N fertilizer use efficiency (NUE) of agricultural systems by adjusting fertilizer rates to the soil characteristics. The objective of this study is to assess: whether delineating of management zone (MZ) within fields improves NUE in wheat (*Triticum aestivum* L.). This research was carried out at 5 commercial fields (between 26 and 84 ha), located in the south-eastern portion of the Province of Buenos Aires, Argentina. The MZ were delineated by using georeferenced measurements of apparent soil electrical conductivity, terrain elevation and soil depth. Spatially referenced wheat yields were recorded with a yield monitor equipped with DGPS. The interaction effect was significant ($p < 0.05$) in most fields, thus indicating that the response to N fertilization is different among MZ. Also, NUE was significantly different ($p < 0.05$) among MZ. The detection of soil spatial variability and the delineation of MZ are now possible on a commercial scale. The delineation of MZ affords the opportunity of variable rate application of N fertilizers on Typic Argiudolls and Petrocalcic Paleudolls, and the minimization of pollution risk due to an excessive application of resources.

1. Introduction

Worldwide, the average efficiency of N fertilizer use in cereal crops is 33% (Raun and Johnson, 1999). The Argentine Humid Pampas region is one of the world's best regions for grain crop production (Satorre and Slafer, 1999). The major soil types that compose this region are Typic Argiudolls, with a loam texture at the surface layer, loam to clay loam at subsurface layers, and sandy loam below 110 cm deep, and Petrocalcic Paleudoll, which presents discontinuous layers of a petrocalcic horizon between 50 and 100 cm and greater clay contents at subsurface layers than Typic Argiudolls. Because of this, agricultural fields in south-eastern Pampas frequently have multiple soil map units within them, despite their sometimes relatively small size, and wide range of soil textures and properties, causing high soil spatial variability (Peralta et al., 2013a). As a result, spatial variability of the different soil processes that determine soil N supply and crop response to N fertilizer between and within fields (Ruffo et al., 2006; Jaynes et al., 2011) is generated. The dominant practice for farmers is to apply the same rate of N fertilizer over whole fields and even whole farms. In fields with spatially variable N needs, this practice leads to frequent mismatches between N fertilizer rate and crop N need. Over-application of N increases the probability of NO_3–N leaching below the root zone (Aparicio et al., 2008; Barbieri et al., 2008) while underfertilization limits yields and may restrict economic returns (Scharf and Lory, 2002). Efficient N fertilizer management is critical for profitable crop production and long-term soil and environmental quality. One of these is to use precision farming methods to apply N fertilizers at variable rates across a field rather than at a uniform rate (Raun and Schepers, 2008; Jaynes et al., 2011). Site-specific management of N (NSSM) is an attractive and intuitive approach to increasing fertilizer use efficiency of agricultural systems by adjusting fertilizer rates to the soil characteristics. Delineation of different management zones (MZ), i.e., zones that may differ in factors such as the type of soil, topography, water and nutrient availability (Bullock et al., 2009).

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Efficient techniques to accurately measure within-field variations in soil properties are very important to define an MZ (Peralta et al., 2013a). Traditional soil sampling is costly and labor-intensive. This traditional method is not viable from an MZ perspective, because it needs a large number of soil samples in order to achieve a good representation of soil properties and nutrient levels. The geospatial measurement of apparent electrical conductivity (ECa) is an efficient ground-based sensing technology that is helping to take MZ from concept to reality (Kitchen et al., 2003, 2005). ECa can be intensively recorded in an easy and inexpensive way, and provides an indirect measure of soil physical and chemical properties that can have a dominant influence on plant growth and yield (Kitchen et al., 2003; Peralta et al., 2013a). Terrain elevation, also provide useful information for to delineate MZ, because it plays an important role in the hydrological response of rainfall catchment and has a major impact on water availability for crop production in rainfed agriculture (Kitchen et al., 2003). In Pampean soils cultivated with grain crops, the depth of the petrocalcic horizon, is also a useful variable for MZ delineation (Peralta et al., 2013b; Córdoba et al., 2013). The delineation of management zones is an approach to the application of different N rates within the field (Ruffo et al., 2006; Bullock et al., 2009). In this regard, Wollenhaupt and Buchholz (1993) found a potential for improved profitability with NSSM, especially when applied to fields with contrasting texture, topography and soil depth. Mulla (1993) calculated the recommended N rates for three MZ for a winter wheat (*Triticum aestivum* L.) field in Washington based on soil organic matter content. He found that the recommended N rates for each MZ (37, 45, and 28 kg N ha^{-1}) were significantly different from the grower's uniform N rate of 73 kg N ha^{-1} in the year of the study. In contrast, Robert et al. (1996) developed MZ based on soil depth for winter wheat in France. They found yield components not to be significantly different between NSSM and a uniform rate. Bhatti et al. (1998) compared uniform N application on wheat with variable rate application based on crop productivity patterns and found no difference in grain yield, while the site-specific approach used less total N. These inconsistent results may be due to complex interrelationships between wheat and soil characteristics.

The NSSM in wheat has not been adequately described for regions with soils associations formed by h Typic Argiudolls and Petrocalcic Paleudoll, typical of many agriculturally important soils in Argentina and throughout the world. When ANOVA models do not take spatial autocorrelation structure into account estimated coefficients are biased and the variances can be inflated which in turn, affects the crops site-specific function responses such as profit analysis, leading to wrong conclusions (Bullock et al., 2009). This can be addressed by fitting ANOVA models under the Linear Mixed Model context which takes into account the correlation and heteroscedasticity problems encountered with soil and field variability. A proper model should accounts for within-trial spatial correlation, between-MZ heterogeneity, and includes random block effects or spatial correlations in the error terms (Casanoves et al., 2005).

The objective of this study is to assess whether delineating management zones with cluster analysis, using as input variable to ECa, topography and soil depth, improves N use efficiency (NUE) in wheat fields with multiple soil maps units within them.

2. Materials and methods

2.1. Experimental site

The study was performed, at five commercial production fields located in three experimental sites in the southeastern Pampas of the province of Buenos Aires, Argentina (Fig. 1). The five fields are composed of various soil series (Table 1), FA, FB and FE of the Tandil series (fine, mixed, thermic, Typic Argiudoll) and Azul series (fine, illitic, thermic Petrocalcic Paleudoll); F11, and F25 of the Semillero Buck series (fine, illitic, thermic Typic Argiudoll), Cinco Cerros series (fine, illitic, thermic, Lytic Argiudoll) and Azul series [Instituto Nacional de Tecnología Agropecuaria (INTA) 1970–1989]. These soils in surface and subsurface horizons present clay contents between 25% to 30% and 38% to 45%, respectively (Peralta et al., 2013a; INTA, 1989). Furthermore, these soils in surface and subsurface horizons present low values of electrical conductivity of the saturation extract (ECe) between 0.25 to 0.34 dS m^{-1} and 0.29 to 0.45 dS m^{-1}, respectively (Peralta et al., 2013a; INTA, 1989). Except for N fertilizer application rates, crop management and tillage practices varied between fields and were chosen by the farmer, but each farmer managing more than one field used the same practices on each field. Phosphorus fertilizer (Triple Super Phosphate, 0-46-0) was applied in all fields in the fall before wheat planting to avoid deficiencies. No-tillage (direct seeding) is widespread in the region and it was a feature common to all fields in this study.

2.2. Soil sampling, analysis and precipitation data

The precipitation data (monthly precipitation for June–December) were obtained from weather stations located at each farm. For all the experiments and MZ, a water balance was calculated according to Della Maggiora et al. (2002). Maximum and actual crop evapotranspiration (MET and AET) were estimated using crop coefficients as reported by Allen et al. (1998). The effective depth of the soil ranged from 132.2 and 59.6 cm, total soil wáter storage capacity (mm cm^{-1}) and available soil water (mm cm^{-1}) were calculated using the model of Travasso and Suero (1994). Maximum water storage limit and available water content were estimated as the product of soil depth by total storage capacity and available water, respectively (Travasso and Suero, 1994). Soil water content at the lower limit was 54% of total water content; actual soil water was determined by the balance between rainfall and AET. The physiological threshold was assumed as 50% of available water (Doorenbos and Kassam, 1979). When actual soil water content fell below this threshold, AET was less than the MET, and water deficit was estimated as the difference between MET and AET.

Soil sampling at sowing was done by randomly collecting eight 2-cm-diameter cores from each replication; samples were taken to 0- to 60-cm soil depth in 20-cm depth increments. Soils were oven dried (30 °C). Determinations of soil NO_3–N content (0–60 cm) was done by microdistilation (Bremner and Keeney, 1966).

2.3. Measurements to generate management zones

The following variables were recorded: georeferenced measurements of apparent electrical conductivity (ECa) taken at two depths: 0–30 (ECa30) and 0–90 cm (ECa90), elevation and soil depth. All variables were measured between April and June, prior to sowing winter crops (wheat, *T. aestivum*).

Soil ECa measurements were taken using Veris 3100® (Veris 3100, Division of Geoprobe Systems, Salina, KS). The sensor was pulled across the field in a series of parallel transects spaced at 15–20 m intervals, the appropriate spacing to avoid measurement errors and information loss (Farahani and Flynn, 2007). ECa was simultaneously measured and georeferenced with a Differential Global Positioning System (DGPS) (Trimble R3, Trimble Navigation Limited, USA) with sub-metric measurement accuracy and set up to record position once per second. Terrain elevation data were processed to obtain a vertical accuracy of about 3–5 cm. The soil depth was measured using a hydraulic penetrometer (Giddings