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Using site-specific nitrogen management in rainfed corn to reduce the risk of nitrate leaching

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ABSTRACT

Managing nitrogen (N) to achieve yield potential and limit losses to the environment is challenging due to the temporal and spatial variability in crop N uptake which affects the distribution of soil-N. Nitrogen fertilization using site-specific management (SSM) is one of a number of strategies that can improve the efficiency of N use and reduce the losses of N to the environment from cropping systems. The aim was to assess: (i) corn (*Zea mays* L.) grain yield and N uptake; and (ii) soil residual- and potentially leachable-N, and its relationship with N and water use efficiency using SSM vs. uniform management (UM) strategies in high-(HP) and low-(LP) productivity zones on soils of the Inland Pampas of Argentina. Differences in soil residual- and potentially leachable-N, corn grain yield, N uptake, water and N use efficiency were compared between treatments. In HP-zones, corn grain yield and total biomass were 2.7 and 4.2 Mg ha^{-1} higher with SSM than UM, and corn grain N uptake and total N uptake increased by 21% and 18% with SSM when compared to UM. Soil residual-N at field-scale was reduced by 18% with SSM. Marginal differences in potentially leachable-N among treatments were observed throughout the soil profile; the highest nitrate concentration was 6.6 mg kg^{-1} in LP-zones with UM within the 210–240 cm soil layer. Overall corn water use efficiency in total biomass was 16% higher with SSM than with UM in both LP- and HP-zones. Using SSM in the LP-zones increased corn N use efficiency in grain and total biomass by 50% and 43% respectively. In this context, SSM can be considered as a conservation practice that optimizes N and water use efficiency by corn under dry conditions.

1. Introduction

Globally, application of nitrogen (N) fertilizer has increased dramatically in recent decades and is projected to exceed 186 million Mg N yr^{-1} by 2050. An average 10–30% of total N inputs in cropping systems are typically lost due to nitrate leaching (Schepers and Raun, 2008) which has led to environmental contamination and concerns regarding use of N fertilizers (Hatfield and Prueger, 2004; Li et al., 2007; Rimski-Korsakov et al., 2004). Therefore, development of alternative N management strategies is vital for sustainable cereal-based cropping systems. Managing N to achieve yield potential and limit losses to the environment is challenging due to the temporal and spatial variability in crop N uptake which affects soil residual- and potentially leachable-N (Delgado et al., 2005). Nitrogen leaching losses have been found to be larger for corn (*Zea Mays* L.) than for other cereals (St. Luce et al., 2011). It is assumed that nitrate content in the top 150 cm of the soil profile is available to corn roots. Below the rooting depth there is no active N uptake by roots and there is the potential for N to leach downwards to the aquifer (Follet et al., 1994; Delgado et al., 2005). The amount of nitrate accumulated in the lower layers of the unsaturated zone in the soil profile is useful for predicting potential N leaching losses (Costa et al., 2002; Rimski-Korsakov et al., 2004). In long-term experiments with corn crop on soils of the Pampas Region, the mean leaching losses of nitrate-N at 150 cm soil depth from eight consecutive seasons increased as the N fertilizer rate increased, and were 20, 38 and 56 kg ha^{-1} for the three N rates of 0, 100 and 200 kg N ha^{-1} respectively. This indicates that in order

Abbreviations: HP, high productivity; LP, low productivity; SSM, site specific management; UM, uniform management.

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to minimize N losses to the environment, it is vital to adequately adjust the N fertilizer rates (Aparicio et al., 2008).

Nitrogen fertilization using site-specific management (SSM) is one of a number of strategies to reduce the risk of N leaching in cropping systems (Khosla et al., 2002; Delgado et al., 2005). The benefit of implementing SSM is in the ability to adjust N fertilizer application to match crop requirements by identifying and managing homogeneous areas within a field. These areas are commonly termed as management zones and are defined as sub-regions having similar limiting factors for crop grain quality and yield (Moral et al., 2011; Peralta et al., 2015a,b). Site-specific fertilization rates can be determined upon zone-based yield potential from analysis of multi-year yield maps (Khosla et al., 2002). The general principles of the SSM technology are transferable but the specific fertilization strategy for a given field requires development using locally-based climate, soil and production variability information (Bramley, 2009).

The Pampas Region is considered one of the most suitable areas for grain crop production in the world (Hall et al., 1992) and is divided into four sub-regions (León, 1992; Fig. 1) mainly due to their contrasting soil attributes, relief and climatic conditions. The dominant soil type in the Pampas are temperate Mollisols (Soil Survey Staff, 2014), representing 35% of Argentinean area. These soils have an aeolian origin, and are comparable to other loess-derived soils of the main cropping regions of the world (e.g. United States, China, Ukraine). The Inland sandy Pampas sub-region is characterized by contrasting landscape systems with coarse texture soils that vary considerably in crop yield potential within relatively small distances. In cropping soils of the Inland Pampas with significant topographic gradients, grain yields of the major cereals (corn, wheat, soybean) in the lowland positions can be 2–3 times the yields in the upland positions (Niborski et al., 2004; Urricariet et al., 2011). Consequently, water and N availability for crop production in the Inland sandy Pampas is affected by highly variable soils that can be found at the field-scale. Increasing corn water use efficiency can improve N use efficiency, being the latter dependent on crop response to both N and water availability during the crop growing season (Hatfield and Prueger, 2004).

The major soil types of the Inland sandy Pampas are Typic Hapludolls in the uplands and Entic Hapludolls in the lowland landscape positions (Niborski et al., 2004). Since the in-field soil heterogeneity in the Inland Pampas can lead to great variability in corn yields (Nosetto et al., 2009), corn N uptake can be spatially variable within fields (Urricariet et al., 2011). In this context, an N fertilization strategy accounting for in-field variability such as SSM, is needed. However, most of the agricultural production is still conducted in regular fields under the assumption that the optimal practice is to use a single UM strategy (Bramley, 2009). In highly variable soils, N applications based on UM strategy can result in under- and/or over-fertilized areas within a field. In the latter case, there is a greater risk of nitrate leaching losses (Delgado et al., 2005). Nitrogen fertilization technologies using SSM have been shown to be more efficient than UM by increasing corn N use efficiency (Khosla et al., 2002) while sustaining maximum crop grain yield (Delgado et al., 2005).

In Argentina, 35% of the cultivated area has adopted Precision Agriculture tools, with SSM one of the main and most explored areas. However, there is still a need for the development of understanding of the factors affecting crop yield variability and N uptake to efficiently adopt SSM technology (INTA, 2013). Despite the increasing interest in Argentina, to date there are no studies that have reported the use of SSM to reduce the risk of nitrate leaching losses to the environment. This study aims to assess: (i) corn grain yield and N uptake; and (ii) soil residual- and potentially leachable-N, and its relationship with corn N and water use efficiency using SSM vs. UM strategies in high and low productivity zones.

2. Materials and methods

2.1. The study site

The study was conducted in Vedia, Province of Buenos Aires (34° 23′ S, 61° 35′ W) located in the Inland sandy Pampas sub-region (Fig. 1) on corn producing fields under no-tillage system. The crop

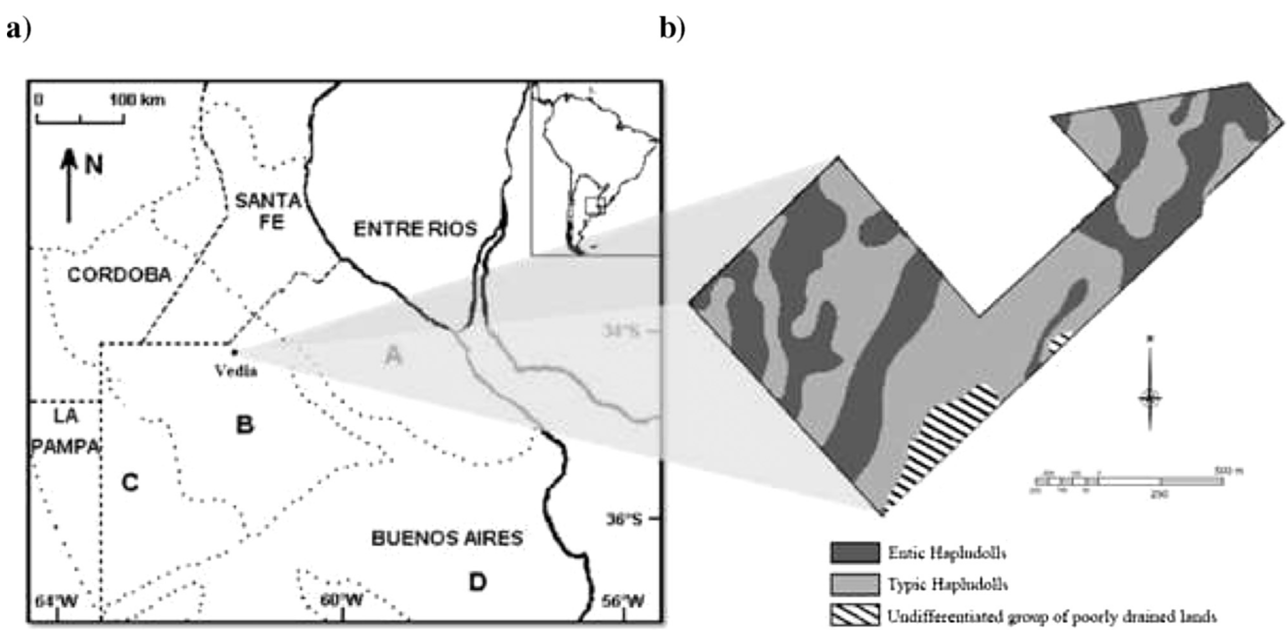

Fig. 1. Location of the study site in Argentina within South America and sub-regions of the Pampas (a). Dotted lines (• • •) indicate the boundaries of the sub-regions of the Pampas (León, 1992). A: Rolling Pampas, B: Inland sandy Pampas; C: Western Inland Pampas, D: Flooding Pampas. Dashed lines (–) indicate provincial boundaries. The right panel (b) shows the map soil at 1:20,000 scale of one the fields (area = 295 ha) representing the soil types (Soil Survey Staff, 2014) identified at field-scale. This map was generated by conventional methods from photo-interpretation of panchromatic photograms (1:20,000 scale). A preliminary map was developed using geomorphologic and physiographic integrated criteria. The final soil map was developed after checking for soil limits in the field. Soils were characterised by open-pits in which samples were collected and analysed in the laboratory. The approximate density of field observations was one pit every 35 has.