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Optimum nitrogen fertilization rates for second-year corn succeeding alfalfa under irrigation

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ABSTRACT

The N contribution of alfalfa (*Medicago sativa* L.) to the succeeding corn (*Zea mays* L.) crop (FYC) is widely recognized. However, there is less information regarding the optimum N fertilization rates (ONR) for a second-year corn (SYC) following alfalfa. Thus, the objective of this study was to evaluate the response of SYC after alfalfa to N fertilization under irrigated semiarid conditions. Three field experiments of SYC following alfalfa were conducted between 2007 and 2009 in Northeast Spain. Treatments included the combination of six N rates applied to FYC (0, 50, 100, 150, 200, and 300 kg N ha^{-1}) with four N rates applied to SYC (0, 100, 200, and 300 kg N ha^{-1}). In one of the three fields, high SYC yields (16.8 Mg ha^{-1}) were obtained in plots that remained unfertilized during two consecutive years after alfalfa. On the other two fields, 81–100% of the maximum corn yields were obtained with application of 200 kg N ha^{-1} to SYC. Results suggest that the typical N fertilizer rates applied to SYC after alfalfa in irrigated semiarid areas (300 kg N ha^{-1}) could be reduced by at least 100 kg N ha^{-1}, with small or no economic penalties and important reductions in N losses.

1. Introduction

In irrigated semiarid conditions of Northeast Spain, corn (*Zea mays* L.) grain yields at the farm level can easily exceed 10–14 Mg ha^{-1}. The corn N requirements to achieve these productions are also quite high, ranging from 200 to 400 kg N ha^{-1} (Berenguer et al., 2009; Cela et al., 2011). In order to avoid risks of yield losses, farmers usually match up N-fertilization rates with corn-N uptake, leading to an over fertilization of corn with N (>300 kg N ha^{-1}) (Alvaro-Fuentes and Lloveras, 2003; Sisquella et al., 2004).

One way of optimizing N fertilization of corn is considering the residual-N effect of a preceding legume crop. In many areas of the world, corn is frequently grown after alfalfa (*Medicago sativa* L.) to take advantage of the N mineralization of alfalfa residues (Bruulsema and Christie, 1987; Kelner et al., 1997). Different studies have shown that the N credits of alfalfa for the subsequent crop can be as high as 180 kg N ha^{-1} (Kurtz et al., 1984; Hesterman et al., 1987). Previous studies have reported that the optimum N fertilization rate (ONR) for first-year corn (FYC) after alfalfa ranged from 0 to 50 kg N ha^{-1} under rainfed conditions (Bruulsema and Christie, 1987; Bundy and Andraski, 1993; Morris et al., 1993; Lawrence et al., 2008) and ranged from 0 to 150 kg N ha^{-1} under irrigated conditions (Carter et al., 1991; Ballesta and Lloveras, 2010; Cela et al., 2011). However, there is little information regarding the response of second-year corn (SYC) following alfalfa to N fertilization. Some authors indicated that N applications to a second crop after alfalfa under rainfed conditions could be reduced from 20 to 56 kg N ha^{-1} (Kurtz et al., 1984; Fox and Piekielek, 1988). However, Harris and Hesterman (1990), working in Michigan, reported that alfalfa residues did not provide significant amounts of N to a second-year barley crop sowed after alfalfa. These authors suggested that the C/N ratio of alfalfa roots and crowns can affect the rate of root decomposition and, in consequence, the availability of N to subsequent crops.

Most of the information concerning the response of SYC following alfalfa to N fertilization has been obtained in rainfed areas. Nevertheless, alfalfa yields, corn yields and corn-N requirements are usually higher under irrigation and long growing seasons than under rainfed conditions and short growing seasons. This suggests that the ONR for SYC following alfalfa under irrigation could be different than those previously reported in the literature for rainfed areas. To our knowledge, only a few studies (Rehm et al., 2008; Ballesta and Lloveras, 2010) evaluated the effect of alfalfa

Abbreviations: FYC, first-year corn succeeding alfalfa; SYC, second-year corn succeeding alfalfa; ONR, optimum N fertilization rate; SMN, soil mineral N (NO_3–N); FNUE, fertilizer nitrogen use efficiency.

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Table 1
Field, soils, and crops information for the three trials. SYC: second-year corn following alfalfa.

Abbreviation Field	GIM Gimenells	ALM Almacelles	LAT La Tallada d'Empordà
Fields			
Year of alfalfa ploughing	2005	2006	2007
Year of SYC sowing	2007	2008	2009
Latitude	41°39′N	41°43′N	42°40′N
Mean temperature (°C)	13.8	14.1	14.8
Rainfall (mm)	277	385	626
Irrigation			
Method of irrigation	Flood	Sprinkler	Furrow
Amount (mm^1)	550	650	480
Frequency (days)	14	1–2	7–9
Soils			
Type	Petrocalcic Calcixerept	Typic Xerochrept	Xerofluvent Oxiaquic
Depth (cm)	<60	>90	>90
Textural class	Loam	Loam	Sandy loam
pH (0–30 cm)	8.3	7.8	8.3
OM (g kg^{-1}, 0–30 cm)	28	26	17
Second-year corn			
Hybrid	DKC5542	PR33P67	PR33B51
FAO cycle	500	600	600
Number of replicates	4	3	4

on a second-year crop under irrigated conditions. In Minnesota, Rehm et al. (2008) reported N credits from alfalfa to SYC of at least 67 kg N ha^{-1}. Ballesta and Lloveras (2010) working with a two-year-old alfalfa crop, reported fertilizer replacement values of alfalfa of 76 kg N ha^{-1} to a second-year wheat crop.

Corn is one of the most important contributors to groundwater pollution in irrigated areas as a consequence of its high N requirements (Cavero et al., 2003; Isidoro et al., 2006). A better adjustment of N fertilization of SYC following alfalfa under irrigated semiarid conditions may help increase corn profitability and reduce the risk of water pollution by nitrates. The objective of this study was to evaluate the ONR for SYC after alfalfa under irrigated semiarid conditions.

2. Material and methods

2.1. Experimental design

Three field experiments with corn were conducted between 2007 and 2009 in Northeast Spain: Almacelles (ALM), Gimenells (GIM), and La Tallada d'Emporda (LAT). Table 1 summarizes the main characteristics of each experiment. At each field, corn was planted during two consecutive years following alfalfa in rotation. This study was focused on SYC succeeding alfalfa; results for FYC were reported by Cela et al. (2011). The preceding alfalfa crops were 4–5 years old, which is the typical age when alfalfa is plowed in the region, and presented a good plant-stand density (from 39 to 60 plants m^{-2}).

The experiments were arranged in a split-plot design replicated three times at ALM and four times at GIM and LAT. The main plot factor was N fertilization of FYC after alfalfa, with 6 levels: 0, 50, 100, 150, 200, and 300 kg N ha^{-1}. The subplot factor was N fertilization of SYC after alfalfa, with four levels: 0, 100, 200, and 300 kg N ha^{-1}. Corn was seeded between late March and early April at a density of 8 plants m^{-2}. The plots were hand-fertilized with ammonium nitrate (33.5%), placing the fertilizer between the corn rows in two sidedress applications (V2-3 and V5-6 grow stages). The subplot size was 33.6 m^2 (5.6 m × 6 m). Mineral P and K fertilization was applied prior to corn seeding at rates of 60 and 200 kg ha^{-1}, respectively, in order to avoid deficits in either of these elements. Except for N, P, and K fertilization, the corn crops were managed by the farmers following their conventional practices. The amounts and the frequency of irrigation were managed by each farmer following the typical schedule of the region (Table 1). The method of irrigation was sprinkler, flood, and furrow irrigation at ALM, GIM, and LAT, respectively.

2.2. Soil and plant analysis

Soil NO_3^-–N content ($SMN_{0–90\,cm}$) was determined before SYC sowing and after SYC harvest by taking 5 soil samples per plot in the upper 30 cm and 3 soil samples to a depth of 90 cm, in 30 cm increments. Soil nitrate was extracted using deionized water and were measured using test strips with a Nitrachek® device calibrated according to the standard procedure (Bischoff et al., 1996). Concentration of ammonium in the soil was considered negligible compared to nitrate concentrations and was not measured (Villar-Mir et al., 2002).

Corn-grain yield was measured in late-September to early-October by harvesting the 2 central rows of each plot (8.4 m^2). Grain moisture was determined for each plot from a 300 g sample, and grain yield was adjusted to 14% moisture content. Corn aboveground-biomass (plant biomass) was determined close to physiological maturity by cutting the plants at the ground level in the 4 m of a row. Whole plant moisture content was determined by chopping three entire plants per plot and oven-drying them at 60 °C for 48 h. The dry plants were ground and its N content was determined by near infrared (NIR) spectroscopy, using a previously calibrated 500 Infrared Analyser (Bran + Luebbe, Norderstedt, Germany). Nitrogen uptake in aboveground biomass was calculated as the product of plant biomass by its N concentration. At ALM, plant biomass and N uptake could only be calculated on plots in which FYC after alfalfa received 0 and 300 kg N ha^{-1}.

2.3. Nitrogen balance

A N balance was calculated for all treatments at GIM and LAT fields, and on plots in which FYC received 0 and 300 kg N ha^{-1} at ALM. Mineralization (Nmin) was estimated from the SYC unfertilized treatments by applying the equation Nmin = residual SMN + plant-N uptake − initial SMN (Sexton et al., 1996) and assuming that N losses from unfertilized plots were unimportant. Nitrogen losses (Nlost) were estimated from the N balance for the fertilized plots (Angás et al., 2006; Berenguer et al., 2009) by the following expression:

$$\text{Nlost} = \text{residual SMN} + \text{N uptake} - \text{intial SMN} - \text{Nmin} - \text{N fertilizer} \quad (1)$$

which considers Nlost as the sum of N lost by leaching, volatilization, denitrification, and unaccounted-for processes. A negative value of Nlost indicates a N loss from the soil–plant system.

The average fertilizer nitrogen use efficiency (FNUE) was calculated as following:

$$\text{FNUE}_{Ti} = \frac{(\text{N uptake}_{Ti} - \text{N uptake}_{T0}) \times 100}{\text{Applied N}_{Ti}} \quad (2)$$

where N uptake is total SYC N uptake (grain + plant) in treatment *i* (*Ti*) and at the 0 N rate (*T*0), and applied N_{Ti} is the N fertilizer applied to SYC in treatment *i*.

2.4. Net economic return from nitrogen fertilization

The net economic return from N fertilization of SYC was calculated as following:

$$\text{Net return } (\text{€ ha}^{-1}) = (\text{yield } Ti - \text{yield } T0) \times \text{grain price} - (\text{N applied } Ti \times \text{N price}) \quad (3)$$