Comparison of decision tools to improve the nitrogen management in irrigated maize under Mediterranean conditions in Spain

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Abstract
Recent studies at watershed scale indicate that the excessive use of nitrogen (N) fertilizer in irrigated maize is one of the major contributors to non-point nitrate pollution of waters in some agricultural areas of Spain. There is a need to provide relatively easy and practical decision tools to help farmers to increase N use efficiency in maize fields which simultaneously will increase crop profits and reduce environmental problems from excessive N use. Four field trials with different soil types were conducted in three different locations in Spain during the years 2010 and 2011 to compare three N fertilizer managements. These were (T1) a fixed N rate considering the crop potential of the zone, 200-250 kg N/ha, (T2) a variable rate of N depending on mineral soil N content before plant sowing, (T3) a variable rate of N depending of chlorophyll meter reading (CMR) at V15 stage. A control (T0) treatment without N application and an over fertilized treatment (T4) of 300 kg N/ha were also included. These five treatments were evaluated under 3 different initial soil nitrate concentrations (low, medium, and high), prior to sowing. Total N-fertilizer applied, grain yield and N-fertilizer use efficiency (NUEf) are presented and discussed. Our results showed that the two decision tools evaluated (T2 and T3) allowed for a reduction in total N fertilizer applied in two of the four experimental sites compared to the fixed N rate (T1) without yield penalties. In the other two sites the T3 treatment reduced the N applied but the soil criteria (T2) did not allow to reduce the N applications. The NUEf of the overfertilized plots (T4) was, in general, lower than in the N management treatments T1, T2 and T3. The use of the decision tools did not always significantly increase the NUEf compared with a reduced fixed dose of N fertilizer (T1). The methodology used should be refined to better adjust the N rates to different soil types and environments. However, results indicate that the use of soil tests before planting or chlorophyll meter readings at later vegetative stage can significantly improve the management of N in irrigated maize crops, reducing the negative effects of excessive nitrogen fertilizers use in agricultural areas.

Key Words
Maize, nitrogen fertilizer, sprinkler irrigation, non-point contamination

Introduction

Maize grown under irrigation in semiarid conditions is a very productive crop (15 Mg/ha of grain), but has a high N demand. Management of irrigation water and N fertilizer have been recognized as the main factors controlling N leaching risks and diffuse nitrate pollution of surface and ground water in irrigated semiarid areas (Isidoro et al, 2006). Data from surveys in the Ebro River Basin (Spain) indicate that farmers apply rates of 318 - 453 kg N/ha/yr every year (Cavero et al., 2003; Isidoro et al, 2006). Reducing N fertilizer rates and improving irrigation efficiency can decrease N leaching risks. However, due to lack of knowledge of maize N fertilizer requirements under field conditions, farmers often apply N fertilizer in amounts that exceed the N requirements of the crop to avoid yield losses. When an excess of N fertilizer is applied, a significant residual N can be left in the soil at harvest. This residual N can be leached during the intercrop period (October to April) (Moreno et al, 1996) and losses vary depending on rainfall distribution in this semiarid area, which can be very variable. Recent work also suggests that residual N can be lost at the start of the maize growing season when irrigation applied exceeds crop evapotranspiration (Salmeron et al, 2010). Although farmer knowledge of this problem is increasing due to both the social pressure and the rising cost of N fertilizer, there is little information available on how to improve the fertilizer management without compromising maize yields. It is necessary to provide farmers with practical decision tools to improve N fertilizer efficiency. These decision tools could be based on soil test results through estimation of soil available nitrogen, or on plant measurements that reflect the nutritional status of the crop and detect N deficiencies before yield is affected. The use of portable chlorophyll meters has been suggested as an easy tool to manage nitrogen in different crops. The objective of this work is to compare different strategies to manage nitrogen fertilizer applications to sprinkler irrigated maize in Spain growing under different initial soil nitrogen concentrations.

Methods

Four field experiments were carried out during the 2010 and 2011 growing seasons in two different irrigated maize production areas of Spain. Two experiments were located in the Middle Ebro valley (ZAR10 and ALM11) Aragón), and the other two in the south eastern end of the Central plateau (ALB10 and ALB11). The main site characteristics and key dates of the field trials are presented in Table 1. The climate of the Middle Ebro and Central plateau is Mediterranean-continental semiarid. The soils in both regions were clearly different with relatively deep and fine-textured soils in Aragón and shallow and coarse-textured soils in the Central Plateau. In all experiments the sprinkler irrigation was adjusted to satisfy crop requirements, according to FAO methodology, in order to minimize nitrogen leaching during the maize growing period.

Table 1. General description of field trials and soil characteristics.

Characteristic	ZAR10	ALB10	ALM11	ALB11
Location	Zaragoza	Albacete	Almudévar	Albacete
Number of plots	63	51	60	60
Plot size (m)	4.5 x 12	3.75 x 10	4.5 x 12	3.75 x 10
Sowing date	10 May	5May	12 April	28 April
Harvest date	7 Oct.	8 Oct	25 Oct.	25 Oct.
Plant density (plants/ha)	74,782	85,380	73,333	70,733
Irrigation + Rain (mm)	669	606	926	747
Crop Evapotranspiration (mm)	683	559	789	717
Soil Characteristics				
Soil depth (m)	1.20	0.60	>1.20	0.60
pH (ext. 1:2.5 H_2O)	8.42	8.55	7.8	8.16
Texture USDA	loam	sandy-clay-loam	silty-clay-loam	loam
Coarse portion (>2 mm, %)	0-20	40	< 1	40
Organic Matter (0-40 cm,%)	1.47	1.9	2.09	1.46
Carbonates (%)	37	48	35	35
P Olsen (0-40 cm)	11	22	24	26
K_2O (Amon Ac), mg/kg	106	328	300	309

Each experiment included three different initial available soil mineral N (High, Medium and Low) concentrations and each one had a control treatment (T0) with no nitrogen fertilizer, an overfertilized treatment (T4), and three different N management treatments in a random block design with four replications.

The three N management treatments, or decision tools, evaluated were defined as:

(1) T1 (fixed rate): A fixed optimal rate according to the expected yield in the area, split into three applications of 50 kg N/ha at pre-planting, half of the remainder applied at V6 and the other half applied at V15.

(2) T2 (N min): A simplified N balance was performed (Eq. [1]) considering soil mineral N at sowing (Nmin) (0-0.6 m), N in irrigation water and N released by mineralisation as inputs, N extracted by the plant, considered as 21 kg N for each ton of grain yield (14% of humidity), as output and a efficiency of fertilizer (Nef) of 0.7.

$$Nrequirements = \frac{(Outputs - Inputs)}{Nef} \qquad [1]$$

Soil mineral N (0-0.6m) was measured at each experimental plot and the *N requirements* were applied as 50 kg N ha^{-1} at sowing,2/3 of the remainder at V6 and 1/3 at V15.

(3) T3 (SPAD): In this treatments N rate was corrected at V15 stage. N was applied in fixed amounts of 50 kg N/ha before planting and 100 kg N ha^{-1} at V6 and a further application was applied depending on relative SPAD chlorophyll meter readings (CMr). The CMr was obtained in V15 stage at each plot from 30 SPAD readings in the ear leaf relative to the average SPAD reading in the overfertilized treatment (T4) in each zone. If CMr > 95% no N was applied, if 90%< CMr < 95% then 50 kg/ha were applied and if CMr < 90% then 100 kg N ha^{-1} were applied.

To create the three different available soil mineral nitrogen levels, three zones of the field were differentially managed the previous season in relation to nitrogen fertilizer. Table 2 shows that in the four sites there were significant differences in soil nitrate in the upper part of the soil profile between zones, this variation representing the range of soil mineral N often found in commercial maize fields.

Table 2. Soil nitrate concentration (mean ± standard error, mg N/kg) before maize planting in the [1,2]upper part of the soil profile at the four experimental sites.

Zone	[1]ZAR10 (n=21)	[2]ALB10 (n=16)	[1]ALM11 (n=20)	[2]ALB11 (n=20)
Low N	6.1 ± 0.7	4.9 ± 0.3	13.2 ± 0.5	8.5 ± 0.6
Medium N	8.6 ± 0.7	16.6 ± 1.9	19.2 ± 1.0	16.9 ± 0.6
High N	22.6 ± 1.6	37.1 ± 3.4	25.9 ±1.9	30.9 ± 2.6

[1] 0-60 cm; [2] 0-40 cm

Maize grain yield was obtained by manual harvest of the two central rows of each plot (about 15 m^2) and expressed as t ha^{-1} at 14% of humidity. For a given site and zone, the nitrogen fertilizer use efficiency ($NUEf_x$) in each plot "Px" was calculated Eq 2.

$$NUEf_X = \frac{Grain\ yield(P_X) - Average\ Grain\ yield\ (T0)}{Napplied} \quad [2]$$

Weeds and pests were controlled according to standard agricultural practices at each site. No limitations of water or other nutrients were observed in the experiments.

Results and discussion

Grain yields in the non fertilized plots (T0) were significantly lower ($P<0.05$) than in the rest of treatments in "Low N" and "Medium N" zones, but not when the initial soil nitrate was high (Table 3). Using decision tools T2 and T3 N rates applied were lower than the fixed rate (T1) at ZAR10 and ALM11 sites. However, at ALB10 and ALB11 only chlorophyll meter readings (T3) allowed for application rates lower than the fixed rate (T1) in the "High N" zone. In these two sites, with the T2 treatment there was no reduction in N fertilization applied to any zone (Table 3).

Table 3. Average total N applied (kg N/ha) and maize grain yield (t/ha) for the different treatments and zones of initial soil N in the four sites. For yield data, values following by the same letter were not significantly different (P > 0.05) for a given site and zone.

Zones	Treat.	Total N applied (kg N ha^{-1})				Maize grain yield (t ha^{-1}, 14%)			
Soil initial N		[1]ZAR10	[1]ALB10	ALM11	ALB11	ZAR10	ALB10	ALM11	ALB11
Low N	T0	-	-	-	-	3.3 a	4.0 a	9.9 a	8.6 a
	T1	225	200	250	200	9.5 b	14.1 b	15.9 b	15.6 b
	T2	209	306	142	306	9.3 b	15.7 b	15.2 b	16.0 b
	T3	210	225	150	150	8.8 b	14.6 b	14.9 b	15.7 b
	T4	400	300	300	300	[1]10.0	[1]17.1	15.1 b	14.6 b
Medium N	T0	-	-	-	-	5.6 a	10.7 a	13.3 a	14.2 a
	T1	225	200	250	200	11.0 b	16.8 b	15.3 a	16.1 b
	T2	203	269	96	269	10.6 b	15.4 b	15.8 a	16.4 b
	T3	200	213	150	150	10.7 b	16.0 b	16.5 a	16.6 b
	T4	400	300	300	300	[1]11.8	[1]16.5	15.9 a	15.9 b
High N	T0	-	-	-	-	12.4 a	15.2 a	13.2 a	15.4 a
	T1	225	200	250	200	12.3 a	16.4 a	14.5 a	15.7 a
	T2	83	220	64	233	12.5 a	17.0 a	13.8 a	16.0 a
	T3	160	188	163	163	12.4 a	16.7 a	14.4 a	15.4 a
	T4	400	300	300	300	[1]11.4	[1]19.2	14.0 a	16.2 a

[1] no replications in T4 treatments

These results indicate that maize requires a large supply of N to obtain high yields and generally should be fertilized to avoid yield penalties. As suggested in recent studies (Cela et al, 2011) under similar growing conditions, only in situations such as maize grown after alfalfa is it possible to avoid or to reduce drastically N fertilizer applications without yield reductions. For a given site and zone, there was no significant difference in maize yields between treatments T2 and T3 and the fixed dose (T1) and over fertilized (T4) treatments. The results showed that it was possible to improve current farmer N fertilizer practices without compromising maize yields.

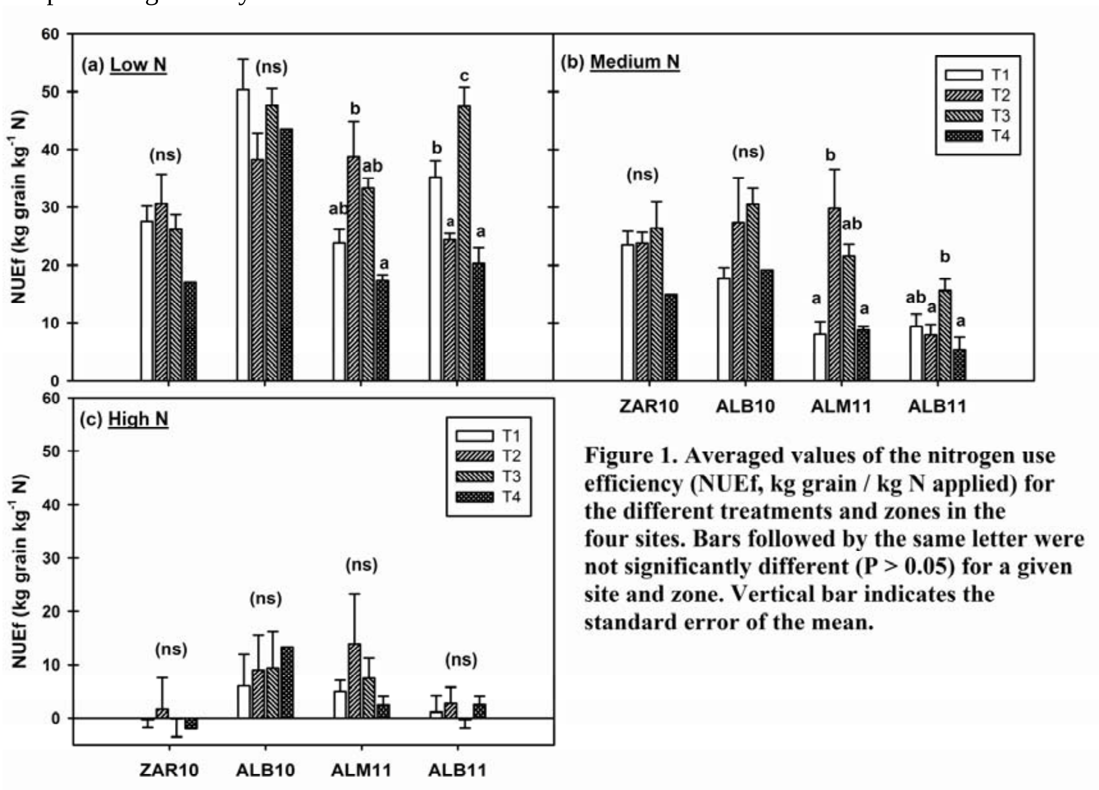

Figure 1. Averaged values of the nitrogen use efficiency (NUEf, kg grain / kg N applied) for the different treatments and zones in the four sites. Bars followed by the same letter were not significantly different (P > 0.05) for a given site and zone. Vertical bar indicates the standard error of the mean.

When the soil has high initial soil nitrate content (High N zone), the NUEf is much lower than in situations with lower available soil mineral nitrogen (Fig. 1). The NUEf of the overfertilized plots (T4) was, in general, lower than in the N management treatments T1, T2 and T3, although not always significantly. The use of the decision tools T2 and T3 did not always significantly improve the NUEf compared with a reduced fixed dose of N fertilizer (T1). This was particularly so at ALB10 and ALB11. It appeared that the methodology could be improved to better adjust the N rates in a wide range of soil N availability and soil types.

Conclusion

Given the actual rates of N fertilizer used by maize farmers in irrigated areas of Spain, this study suggests that there is a potential to reduce N fertilizer applications or using soil and plant indicators to evaluate more exactly the site specific maize N requirements. This could lead to increased profitability of maize cropping and reduce the environmental impacts of excessive N applications.

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