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Optimisation of N application for a maize crop grown in a shallow, irrigated soil

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Abstract

A method of evaluating net nitrogen (N) mineralisation in shallow petrocalcic soils, based on N balances in non-fertilized plots, is proposed. During 1999, 2000 and 2001, estimated N mineralised in an irrigated maize crop (6.5 months) in Central Spain was: 73.3, 56.2 and 60.5 kg ha^{-1}, respectively. The relationship between EUF-Norg (organic nitrogen extracted from soil by electroultrafiltration) and mean mineralised N, in this experiment during the three seasons, was 1 mg EUF-Norg 100 g^{-1} soil equivalent to 30 kg N ha^{-1}. The calibration was applied to EUF-Norg values from soil samples analysed before sowing. These values, together with the mineral N, were used to estimate available N and consequently the optimal N rate. To evaluate the effect of N fertiliser rate on NO_3^- leaching and in N fertiliser-use efficiency (NFUE) three different rates of N were tested in 2000 and 2001: optimal N rate (N_O), conventional N rate (N_C) and a control no N (C). The N_O rates for the maize crop were 150 and 130 kg N ha^{-1} in 2000 and 2001, respectively. Nitrogen losses of nitrate due to leaching were lower with N_O than with the N_C rate of 300 kg N ha^{-1}. The NFUE values were higher for N_O at 78.8% and 83.5% in 2000 and 2001, respectively than for N_C at 48.7% and 49.3% in 2000 and 2001, respectively). However, in spite of the different levels of applied N, there was no difference in grain yield among treatments.

Additional key words: EUF, Mediterranean soils, N balance, optimal nitrogen rate.

Resumen

Optimización de la dosis de nitrógeno en suelos poco profundos, irrigados, bajo cultivo de maíz

Se propone una metodología para evaluar el nitrógeno (N) mineralizado en suelos petrocálcicos poco profundos, basada en los balances de N en parcelas no fertilizadas. Durante los años 1999, 2000 y 2001 el N mineralizado en un cultivo de maíz irrigado (6,5 meses) en la zona centro de España fue 73,3, 56,2 y 60,5 kg ha^{-1}, respectivamente. La relación observada en este experimento, entre EUF-Norg (nitrógeno orgánico extraído por electroultrafiltración) y el N mineralizado durante los tres periodos de cultivo (valores medios), fue 1 mg EUF-Norg 100 g^{-1} suelo = 30 kg N ha^{-1}. Esta calibración se aplicó a los valores de EUF-Norg correspondientes a las muestras de suelo tomadas antes del cultivo. Para evaluar el efecto de las dosis de fertilizante sobre la lixiviación de nitrato y la eficiencia del uso de fertilizante nitrogenado (NFUE), se determinó el N asimilable y la dosis óptima de N, en base a esta calibración, junto con el N mineral del suelo. Los tratamientos aplicados fueron los siguientes: dosis óptima de N (N_O), dosis convencional (N_C) y control sin fertilizar (C). Las N_O estimadas fueron 150 y 130 kg ha^{-1}, en 2000 y 2001, respectivamente. El nitrato perdido por lixiviación fue menor en la N_O que en la N_C de 300 kg N ha^{-1}. Los valores de NFUE fueron más altos para N_O (78,8% y 83,5% en 2000 y 2001, respectivamente) que para N_C (48,7% y 49,3% en 2000 y 2001, respectivamente). Sin embargo, a pesar de las diferencias en las dosis de N aplicadas en ambos tratamientos, no se observó ningún efecto sobre la producción de grano.

Palabras clave adicionales: balance de N, dosis óptima, EUF, suelos mediterráneos.

Introduction

In irrigated soils the mineralization of soil organic N during the growing season must be taken into account to determine available N and improve fertilizer efficiency. In these soils, net N mineralization is often very high in summer, due to soil moisture and temperature conditions. Even in soils with a low organic matter content, net N mineralisation can be high. Sánchez *et al.* (1998) estimated a net mineralization of 165 kg N ha^{-1} during a maize (*Zea mays* L.) growing season from

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an irrigated sandy loam under Mediterranean climatic conditions. Quantification of net mineralised N under field conditions is difficult, although methods based on mineral N balance during the growing season for consecutive years have given useful results (Sánchez *et al.*, 1998). Sánchez *et al*. (1998) determined N balance using: nitrate leaching, N mineral exchange in the soil during crop growth and crop N uptake. However, the method needs revision for stony and/or shallow soils. A high soil stone content or the presence of a petrocalcic horizon complicates the installation of the ceramic candles, which are necessary to measure nitrate leaching by this method. When stones are in contact with the ceramic candles a vacuum is not maintained during sampling and water is not collected in the candle. These complicated soils occupy large areas, especially in Mediterranean countries, where there is often a petrocalcic horizon close to the soil surface. Net N mineralization has not been determined for these soils.

Various soil tests have been proposed to estimate N available (N_{av}) for a crop, such as incubation (Stanford, 1982), or soil extraction methods (Németh, 1979; Houba *et al*., 1986; Mengel, 1991; Khan *et al*., 2001). The electro-ultrafiltration (EUF) extraction method proposed by Németh (1979) gives reliable information on different soil N forms. By applying an electric field, inorganic ions (NO_3^- and NH_4^+) and organic N compounds (mainly peptides and proteins) are desorbed from soil colloids. Satisfactory relationships between analyses of EUF extracts (Total EUF-N in extracts, EUF-NO_3^-, EUF-NH_4^+ and EUF-N_{org}) and plant N uptake have been reported (Wiklicky and Németh, 1981; Wiklicky *et al.,* 1983; Fürstenfeld and Németh, 1984; Poletschny and Fabian, 1989; Ziegler *et al.,* 1992). To estimate N_{av}, Wiklicky and Németh (1981) proposed the equation:

$$N_{av} = (\text{EUF-}NO_3^-) \times a + (\text{EUF-}N_{org}) \times b \qquad [1]$$

The N_{av} is the crop available N, in kg N ha^{-1}. The EUF-NH_4^+ was included in the EUF-N_{org} fraction to calculate available N. The parameter *a* is used to obtain the amount of NO_3^- in the upper part of the soil in kg N ha^{-1},while *b* estimates kg N ha^{-1} from organic matter. A relationship has been observed between *b* and mineralized N from organic matter (Nemeth, 1979). Wiklicky and Németh (1981) estimated a value of *b* of 50 for a sugar beet crop (*Beta vulgaris* L.) in a loess in Austria. The results of numerous recent field experiments showed that *b* differed with growing season, geographical region, management practices and soil type. Theoretically, for each combination of these factors, a separate calibration is necessary (Appel and Mengel, 1998). Spanish soil conditions are very different from central European soils where most of the calibrations estimating available N using the EUF method were obtained.

The aims of this study were: i) to assess mineralised N in calcareous soils with a petrocalcic horizon at 50 cm under a Mediterranean-climate, based on the N balance of non-fertilized plots under field conditions; ii) to calibrate the EUF method for these soils, and iii) to assess the optimum N rate by means of the available soil N calculated from the sum of mineralised N and mineral N.

Material and Methods

Soil characteristics

The experiments were conducted on an irrigated maize crop at Las Tiesas Field Station (5 km East of Albacete, Spain) in 1999, 2000 and 2001. The soil (*Calcic Xerosol*) is shallow. Soil depth was 50-55 cm, below which there was a 1-3 m thick petrocalcic horizon. This horizon gave a high degree of soil stoniness (20-30%). The soil pH was basic, with a high carbonate level and a bulk density of 1.30. It was a sandy loam.

Experimental design

Three N fertilizer treatments were evaluated in a randomized block design with three replicates. The experiment occupied 100 m^2 in 2000 and 2001. Treatments were: a non-fertilized control (C), conventional N rate (N_C, 300 kg N ha^{-1}) in three split applications of 100 kg N ha^{-1} (NH_4NO_3 33.5% N) and an optimal dose (N_O) applied as a single application 40 days after sowing, with the same fertiliser. The conventional rate is the mean rate used by farmers in the region. The optimal dose was estimated by difference between plant N uptake and available N. The available N was calculated by the EUF technique [Equation 1] using the previous year's results. In 1999, three plots were used to estimate mineralised soil N in an unfertilised soil (C) during the maize cropping season, from 20 April to 30 October. The data were used to calculate the optimal N rate for 2000. Data from control plots in 2000 were used to estimate mineralised N in 2001. The value of *b* in Equation 1 was then recalibrated for the next experimental year with mineralised N from the previous year. The N_O rates for the maize crop were 150 and 130 kg N ha^{-1} in 2000 and 2001, respectively.

Crops and irrigation management

Maize cv Pregia was sown at 86,580 seeds ha^{-1} into the previous year's stubble on 25 April 1999, 8 May 2000 and 30 April 2001. The seedbed in all plots was fertilized with calcium superphosphate and potassium sulphate at 87 kg P ha^{-1} and 85 kg K ha^{-1}. Plots were treated with a combination of 48% Alachlor (3 L ha^{-1}), 33% Pendimetaline (3 L ha^{-1}) and 24% Bromoxynil (0.75 L ha^{-1}), pre-emergence for weed control. Methyl-chloropyriphites (48%) and Cypermetrine (10%) were applied in irrigation water (dissolved in 70 m^3 ha^{-1}) to control European corn borer *(Ostrinia nubilalis* Hübner*)*. Crops were harvested in October.

Plots were watered periodically (9 irrigations in 1999, 10 in 2000 and 12 in 2001) depending of crop evapotranspiration (ETc). The amounts of irrigation water each year are included in Table 2. Crops were irrigated with an overhead mobile-line sprinkler system. Crop ETc was estimated via the crop coefficient Kc using the Penman-Monteith model (de Juan *et al.*, 1996) with data from a meteorological station situated in the experimental field. The Kc was 0.40 for the first 70 days. It increased to 1.20 to maturity (130 days), and was 0.70 at harvest.

A year prior to the start of the experiment, a system for monitoring soil water-content in real time, using semipermanent multisensor capacitance probes (EnviroSCAN, Sentek Pty Ltd, South Australia) was installed (Buss, 1993). Four of the nine experimental plots were fitted with probes (50 mm interior diameter) to 50 cm depth, the N_O and N_C treatments had 1 probe and there were 2 probes in C. Sensors were located in the probes at 5, 15, 35 and 45 cm depth (Fig. 1). The frequency signal (FS) from the apparatus was converted into a measure of the volumetric moisture content (θv) using the calibration equation of Paltineau and Starr (1997) from a soil with similar texture. Measurements were taken hourly throughout crop growth in each year. Data was recorded on a data logger. Drainage was calculated from the water content curves from the EnviroSCAN (Sentek, 2000) data during crop growth. The EnviroSCAN system made it unnecessary to install tensiometers to determine the direction of soil water-flux, as this information was provided by the system. To calculate drainage the decrease in water reserve curves corresponding to sensors located near the drainage zone (45 cm depth) were used. Drainage (D) was calculated through the water balance of the soil profile (Arauzo *et al.*, 2003) by:

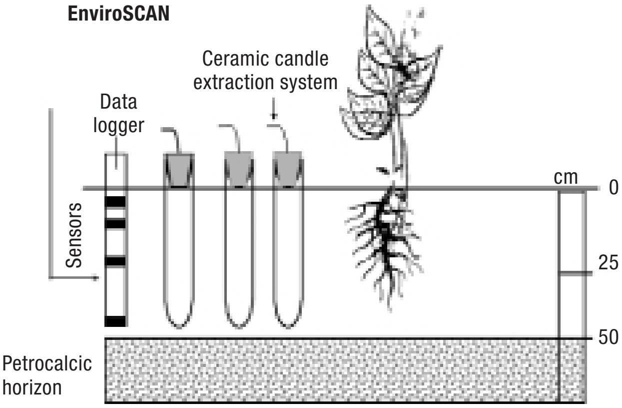

Figure 1. Equipment installed in experimental plots.

$$D = R + I - ET \pm \Delta S \qquad [2]$$

where R is rainfall (mm), I is irrigation (mm), ET evapotranspiration (mm) and ΔS changes in soil water (mm) from 0 to 50 cm depth.

The determination of NO_3^- leaching required the method to be adapted to the soil type. Three ceramic candles (63 mm interior diameter) were installed in each plot at a soil depth of 45 cm to obtain soil solution samples. To ensure a vacuum it was necessary to ensure there was no contact between the ceramic candle and the petrocalcic horizon. Water samples were taken weekly from the ceramic candles and nitrate concentration determined. Leaching of NO_3^- was calculated as the product of drained water and NO_3^- concentration in the soil solution (Díez *et al.*, 1996, 2000).

Soil sampling and analysis

In March, in each year, soil samples were taken from control plots to characterize the soil and establish N mineralised by N balance. Fresh soil samples were air-dried and sieved through a 2 mm. Soil characteristics are shown in Table 1.

Soil pH was determined in water by a calomel glass electrode (ISO 10390, 1994). Soil organic matter content was determined following ISO 14235 (1998). Carbonates were measured by gasometry (ISO 10693, 1995). Particle size distribution was measured using a Robinson pipette (ISO 11277, 1998). Total N (N_t) in the EUF

Table 1. Physicochemical properties of the soil at the start of the experiment in the ploughed soil layer (Mean ± SD)

pH (H_2O)	7.7 ± 0.1
Bulk density ($Mg\ m^{-3}$)	1.30 ± 0.02
C ($g\ kg^{-1}$)	8.70 ± 0.03
Organic matter ($g\ kg^{-1}$)	15.0 ± 1.2
Carbonate ($g\ kg^{-1}$)	350 ± 14.0
Clay (%)	38
Silt (%)	42
Sand (%)	20

extracts was determined by UV radiation digestion and subsequent oxidation with potassium persulphate in an alkaline medium (Díez, 1988). The N determination in extracts was done colourimetrically using an AAII Autoanalyzer (Technicon Hispania, Madrid) with N1-naphthylethylenediamine. Analysis for NH_4^+-N was performed using the same device but with nitroprussiate. The EUF-N_{org} was estimated as the difference between EUF-N and EUF-(NO_3^- plus NH_4^+).

The EUF method used was that of Németh (1979). Samples were taken from the ploughed soil layer (0-30 cm) in March. A 5 g sample of air-dried soil (< 1 mm) was weighed and introduced into an EUF cell (Vogel S-724).

The soil profile was divided into two sections (0-30 cm and 30-50 cm) to determine N balance. In the first section, samples were taken at 15 cm for EUF extraction of $N_{initial}$ and N_{final}. The level of NO_3^-, NH_4^+ and organic N were also determined. The second section was sampled at 40 cm. Samples were dried, passed through a 2 mm sieve and extracted with 2M KCl 1:5 solution/soil ratio and shaken for 2 h. Samples were centrifuged and NO_3^-, NH_4^+ were analysed. There was little organic matter at this soil depth.

Nitrogen balance

Nitrogen balance was measured, in the control plots, to estimate mineralised N and thus estimate *b*. The balance was calculated following Sánchez *et al*. (1998):

$$N_{min} = (N_i - N_f) + N_{leached} + N_{taken\ up} \quad [3]$$

where N_{min} = mineralised N, N_i= soil initial mineral N content and N_f = soil final mineral N content. Initial and final refer to the soil N before sowing and after harvest, respectively.

The mineral N level in the 0-30 cm soil section was obtained by the EUF method. Values for the 30-50 cm section were obtained through extraction with 2M KCl solution. The values N_{min}, $N_{leached}$ and $N_{taken\ up}$ refer to the crop growth period. Denitrification and volatilisation were not considered as they are generally negligible in Mediterranean climates from non-fertilised soils (Arcara *et al.,* 1999; Sánchez *et al.,* 2001).

Plant N uptake (aboveground biomass) was measured in 10 randomly selected plants, from a 5 m strip of two adjacent rows in the middle of each plot. Samples were divided into: stalk, leaf, bract, cob and grain, and oven-dried for 24 h at 60ºC and 2 h at 80ºC to determine crop dry matter (DM). Nitrogen concentration in plant fractions was measured by the Kjeldahl method (AOAC, 1990). Samples were pre-treated with a solution of salicylic and sulphuric acids (Bremner, 1965). Plant N uptake was calculated by multiplying plant fraction yields by their N concentration. Grain yield was calculated at the standard grain moisture content of 14%.

The value of *b* [Equation 1] was calculated by dividing N_{min} by N_{org} extracted by EUF. With this method, N available in the following year was determined using a recalibrated *b*.

Nitrogen fertiliser-use efficiency (NFUE) was determined for each treatment and each year (Garabet *et al*., 1998).

$$\begin{aligned}\text{NFUE} = (&\text{N uptake in fertilised plot} - \\ &- \text{N uptake in control plot})/(\text{applied N}) \times 100\end{aligned} \quad [4]$$

Results

Mean cumulative drainage during crop growth was 158, 119 and 78 mm in 1999, 2000 and 2001, respectively. This was 28.5%, 15.1% and 9.6% of total water applied. Table 2 shows the water balance for each year and also rainfall and irrigation for the three years of the experiment. Water NO_3^-, concentration in irrigation water was < than 3 mg L^{-1}.

The NO_3^- concentration in solutions from the ceramic candles were generally low (Table 3), especially

Table 2. Water balance during the experiment (mm). Drainage calculated by EnviroSCAN (Sentek, 2000)

	1999	2000	2001
Rain	198	18	66
Irrigation	554	765	690
Drainage	158	119	78
ETc	602	668	683

Table 3. Mean nitrate concentration[1] [NO_3-N] (mg L^{-1}) at 45 cm depth and N leached (kg ha^{-1}), during maize growth during 1999, 2000 and 2001

Treatments[2]	1999		2000		2001	
	[NO_3^--N]	NO_3^--leached	[NO_3^--N]	NO_3^--leached	[NO_3^--N]	NO_3^--leached
C	5.7 ± 5.2	3.2± 0.5	4.8^{a} ± 4.8	2.6 ± 0.3	0.94^{a} ± 1.2	1.65 ± 0.04
N_C			18.1^{b} ± 16	7.9 ± 0.6	17.0^{b} ± 7.5	14.30 ± 2.3
N_O			6.6^{ab} ± 6.6	5.5 ± 0.2	1.1^{a} ± 1.8	1.70 ± 0.05

[1] Mean ± standard deviation. Data based on 7 samples in 1999 and 2000 and 11 samples in 2001 with nine replicate extraction cups per fertiliser. [2] C: control; N_C: conventional nitrogen rate; N_O: optimal nitrogen rate. ^{a,b}: in each column [NO_3^--N], mean values followed by the same letter are not significantly different ($P > 0.05$, Duncan test).

in the control and N_O treatment plots. The N_C plots had higher NO_3^-, levels due to the higher applied N. The low soil NO_3^- concentration and a control of irrigation diminished NO_3^- leaching. Average crop season NO_3^- losses during 2000 and 2001 were 2.1, 11.1 and 3.6 kg N ha^{-1} for the C, N_C and N_O treatments, respectively.

Table 4 shows the N balance of non-fertilised maize plots during crop growth. Variations in soil mineral N for the maize were negative, at –22.1 kg N ha^{-1} in 1999, –43.9 kg in 2000 and –23.5 in 2001. This suggests that available N reserves were decreased in the soil during crop growth. This was mainly due to N uptake by the maize, whereas leaching losses were small.

Table 5 shows: ΔN (Table 4), N leached (Table 3), crop N uptake, mineralised N [Equation (3)], EUF-N_{org} and *b* values, corresponding to each year's crop in which N balance was monitored.

Data for grain production and N absorbed in each treatment for each year is shown in Figure 2. In 2000 there was a decrease in both absorbed N and grain production in control plots (Table 6), due to a N deficit. In the same year there were significant differences ($P < 0.01$) in N absorbed between the N_O and N_C treatment plots. However, this did not translate into differences in grain production. This means that the N_C plants had «luxury» N absorption. In 2001 these results were repeated, i.e., there were no significant difference in

Table 4. Nitrogen balance in un-fertilised maize plots during crop growth, 1999, 2000 and 2001

Treatment	Depth (cm)	Mineral N		ΣN (0-50)	ΔN = Nf – Ni
		(mg N 100 g^{-1})	(kg N ha^{-1})		
1999					
Ni	0-30	1.35	52.6		
Ni	30-50	0.80	20.8	73.4	
Nf	0-30	0.75	29.2		
Nf	30-50	0.45	11.7	40.9	–32.5
2000					
Ni	0-30	1.10[a] ± 0.12	42.90		
Ni	30-50	0.70[b] ± 0.17	18.20	61.10	
Nf	0-30	0.32 ± 0.07	12.48		
Nf	30-50	0.25 ± 0.05	6.50	18.98	–42.12
2001					
Ni	0-30	0.92 ± 0.08	35.88		
Ni	30-50	0.60 ± 0.09	15.60	51.48	
Nf	0-30	0.55 ± 0.14	21.45		
Nf	30-50	0.25 ± 0.05	6.50	27.95	–23.53

[a] 1 mg N 100 g^{-1} = 30 (cm depth) × 1.3 (bulk density) kg ha^{-1}. [b] 1 mg N 100 g^{-1} = 20 (cm depth) × 1.3 (bulk density) kg ha^{-1}. Ni: initial N before sowing. N_f: final N, after crop growth.

Table 5. Nitrogen mineralised in unfertilised plots during growth of each crop, calculated from the N balance. Calibration of the *b* coefficient is relative to EUF-N_{org}

Year	ΔN (kg ha^{-1})	N leached (kg ha^{-1})	N uptake (kg ha^{-1})	N mineralised (kg ha^{-1})	EUF-N_{org} (mg 100 g^{-1})	*b*
1999	–32.5	3.2	102.6	73.3	2.50	29.3
2000	–42.1	2.6	95.7	56.2	2.00	28.1
2001	–23.5	1.6	82.4	60.5	1.82	33.2

ΔN (see Table 4); N leached (see Table 3); N uptake (Fig. 2). Mineralised N = ΔN + leached N + N uptake. b = N mineralised/EUF-Norg.

grain production between the N_C and N_O plots, despite the difference in applied N.

The results show that optimal dose of N (N_O) obtained by taking N mineralised into account (*b*) represents a better NFUE, 78.8 and 83.5 in 2000 and 2001, respectively, than the conventional N doses (N_C) which were 48.7 and 49.3 respectively for the same years.

Discussion

Table 2 shows that drainage was higher in 1999 (158 mm) due to rainfall of 198 mm. In this area, under conventional irrigation practice, drainage usually exceeds 20% of applied water (Román *et al.,* 1996). However, during crop growth in 2000 and 2001 drainage was < 20%.

The generally low NO_3^- concentration in this shallow soil (Table 3) can be explained because the high level of stones and the shallow soil depth may have stimulated maize roots to grow into all of the available soil above the limestone crust, removing NO_3^-.

The amount of mineralised N was similar over the three years at 73.3 kg N ha^{-1} in 1999, 56.2 kg in 2000 and 60.5 kg in 2001) (Table 5). This indicates that N mineralisation is characteristic of the soil under these weather conditions for maize in this area. The values are lower than that of Sánchez *et al.* (1998) for maize of 160 kg ha^{-1} in a deep (2 m) stoneless soil. A comparison of the two situations indicates that the soil volume involved in N mineralisation was less in this work because of the shallow, stony soil, typical of this area.

The parameter *b* [Eq. 1] was calculated from N_{min}: $b = N_{min}/\text{EUF-}N_{org}$. It varied between 27.2 in 2000 and 33.2 in 2001 (Table 5). In 2000, available N was calculated using the *b* value estimated from the previous year ($b = 29.3$, $N_{av} = 122$ kg ha^{-1}). An optimum dose of 150 kg N ha^{-1} was established, assuming an efficiency for N fertiliser of 70%, as estimated in previous experiments (Sánchez *et al.,* 1998). In 2001, available N was estimated from the previous year's N balance of the control plots ($b = 27$). The N optimal value (N_O) was 130 kg N ha^{-1}.

Some authors have reported *b* differed depending on growing season, geographical region, climatology, management practices and soil type (Table 6). Generally, high *b* values are associated with irrigated summer crops (e.g. maize) in hot climates (Sánchez

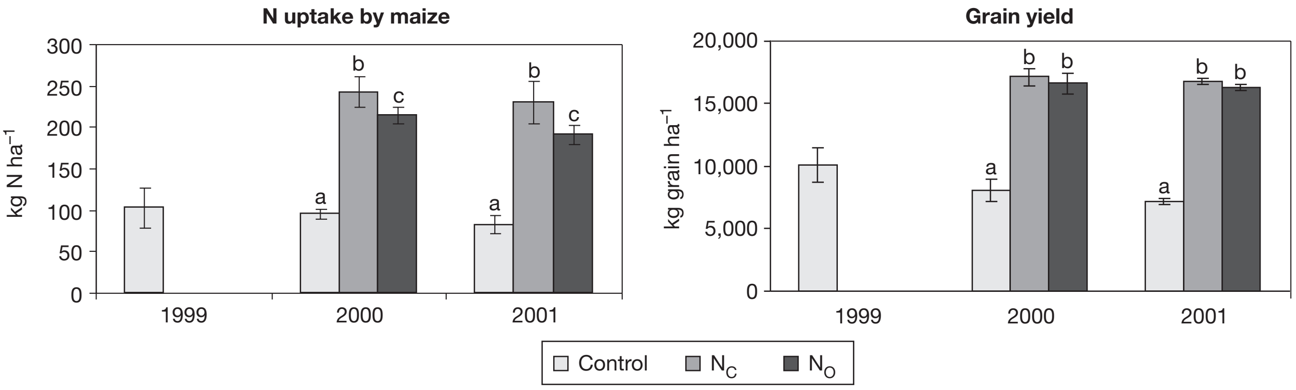

Figure 2. Nitrogen uptake and grain yield under different nitrogen treatments (± SD) in 1999, 2000 and 2001. Control: unfertilized; N_C: conventional N rate of 300 kg N ha^{-1}, and N_O: optimal N rate of 150 and 130 kg N ha^{-1} in 2000 and 2001, respectively. Different letters above bars indicate statistically different values ($P < 0.05$).

Table 6. Reported *b* values for different crops

Crop	Soil type	Country	Irrigation	Growth period	*b*	Reference
Sugar beet	Loess	Austria	No	Spring	50	Wiklicky and Németh (1981)
Maize	Xerofluvent	Spain	Yes	Spring-Summer	85	Sánchez *et al.* (1998)
Winter wheat	Xerofluvent	Spain	No	Winter	32	Sánchez *et al.* (1998)
Maize	Loess	Germany	No	Spring	47	Horn (1990)
Winter wheat	—	Germany	No	Winter	45	Steffens *et al.* (1990)

et al., 1998). Unirri-gated winter cereals (e.g. wheat, *Triticum aestivum* L.) give low *b* values (Steffens *et al.,* 1990; Sánchez *et al*., 1998). Unirrigated maize and sugar beet grown in central Europe, in summer, give intermediate *b* values (Wiklicky *et al*., 1983; Horn, 1990). This work gives a *b* value ≈ 30 (27.2 to 33.2), for the following combination of factors: a summer irrigated maize crop, grown in a shallow stony soil. The results show that shallow irrigated soil must be included as a factor which can affect *b*. These calibrations for *b* can be used in areas with the same irrigated crop and with similar climatic conditions.

The method proposed in this paper, based on N balance in unfertilised plots under field conditions, can determine net mineralised N in shallow irrigated soils. Net mineralised N during crop growth was similar over the three years, but was less than reported in deeper soils.

Soil tests based on the EUF method could be used to estimate available N and *b* in the Wiklicky and Németh (1981) equation recalculated for shallow soils. It was nearly 30 (1 mg EUF-Norg-N $100g^{-1}$ soil = 30 kg N ha^{-1}).

Optimal N (N_O) application gave a similar grain production to the conventional rate (N_C). This was despite an appreciable difference in the amount of fertiliser N applied. However, there were significant differences in absorbed N due to «luxury» absorption by plants in plots given the conventional 300 kg N ha^{-1}. Optimisation of N fertiliser application, based on determination of available N, reduces N losses leaching and improves the efficiency (NFUE) of the applied fertiliser. As soil mineralised N is low compared to N uptake by maize, in this agroecosystem it is common to fertilise with higher N rates than in deeper soils.

Over the two years 2000 and 2001, with N fertilisation, the N_O treatment gave higher NFUE values (79.1 and 58.2), than the N_C treatment (48.8 and 49.3 in 2000 and 2001, respectively). The NFUE usually ranges from 40 to 70 with an upper limit of 80 (Greenwood and Draycott, 1989).

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