Furrow and ridge soil nitrogen mineralization in a surface irrigated artichoke field

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Abstract

Quantitative knowledge of soil organic nitrogen net mineralization (NNM) in field conditions is crucial to optimize N fertilization of crops. In a field fertilization trial of artichokes 48 PE tubes were inserted to 20 cm depth in the soil in plant row and irrigation furrows and soil samples were periodically taken during two and a half months to determine NNM. A parallel essay with disturbed samples from the same procedence was carried out in the laboratory at 25ºC and 10 kPa soil water tension. Soil sample position (ridge and furrow) did not significantly determined NNM in the laboratory essay. Although NNM (obtained from laboratory incubation and corrected to field soil temperature and moisture monitored during the experimental period) overpredicted measured field NNM, matching of both was better than those reported in other studies. NNM rate for the 76 days period of incubation predicted from lab data was 22.9 kg N/ ha x 0.1 m while corresponding field values corrected by Br^- or Cl^- mass balance were 10% and 20% lower respectively in ridge position and under 40% lower by either method in furrow position.

INTRODUCTION

Direct quantitative measurement of soil net N mineralization in agricultural soils under field conditions has not been widely used (Kolberg *et al*., 1997). To natural soil spatial variability, traffic and irrigation patterns in the field may complicate the estimation of N mineralization rates within an acceptable confidence interval. However, field validation of laboratory predictions made with altered soil samples are needed to promote N-use efficiency by crops (Honeycutt, 1999; Hatch *et al*., 2000).

This paper shows results of soil organic nitrogen net mineralization (NNM) obtained in laboratory incubation of altered soil samples at constant moisture and temperature compared with in situ NNM measured in the field.

The objectives of this research were:
a) To evaluate NNM in field topsoil in plant row and irrigation furrow positions and the merit of two methodologies (Cl^- or Br^- mass balance) to account for mineral N flux in the soil.
b) To match NNM in the field with the NNM determined in laboratory incubation with disturbed and homogenized soil samples from the same field.

MATERIAL AND METHODS

Two parallel essays on NNM were simultaneously carried in the laboratory and in a field located at Vinalesa (39º 32' N, 0º 22' W) in Valencia, where a long term N fertilization trial of cash crops in the second year to artichokes was in progress (Khayyo *et al.*, 2003). In a reconnaissance study on mineral N variability in the field, N0

treatment (no chemical fertilizers applied) showed minimum variability. Llorca *et al*. (1993) found in a nearby field that over 80% of total NNM in 120 cm depth of soil was contributed by the 20 cm plough layer. Therefore, we selected N0 field treatment plots and the surface topsoil as the most favourable and significant population to deal with. Soil texture, selected soil properties and bulk density measured at the end of the experiment are presented in Tables 1 and 2.

Surface soil sample (0-10 cm) from N0 treatment plots were separately collected from plant row (ridge) and irrigation furrow, gently passed humid through a 4 mm sieve, compounded and homogenized in two samples (ridge and furrow) and stored for two days at 4ºC till laboratory incubation started. Subsamples of 10 g of dry weight equivalent were placed in 250 mL Erlenmeyer flasks, carried to 10 kPa water tension by adding water, covered up with rubber stoppers and incubated in a dark chamber at 25ºC. Twice a week flasks were uncorked for aeration and water was added to compensate any loss of weight, whenever observed by weighing periodically the flasks. Soil mineral nitrogen was biweekly extracted, in three flasks for each position, during one hour with 100 mL of 2 M ClK and soil separated by centrifugation. Nitrate and nitrite nitrogen was determined by colorimetric reaction with 1 nafthilamide, after reduction of nitrates in a cadmium column, in a FIA system (Tecator, AN5201). Ammonium nitrogen was determined colorimetrically with bromocresol green indicator, as ammonium volatilized in a basic solution through a semipermeable membrane in a FIA system (Tecator, AN5226).

In situ NNM was evaluated in four microplots (1.25 x 0.8 m^2). A solution (5 L m^{-2}) of KBr (18.6 g L^{-1} for microplot 1 and 1.86 g L^{-1} for the rest) was applied to the microplots in order to use Br^- as a tracer of water fluxes. Thereafter, 12 polyethylene tubes (33 cm height; 8.3 cm i. d.) were inserted to 20 cm depth into the soil in each microplot, 6 in the north side of the ridge and 6 in the middle of the furrow (Fig. 1). Tubes were loosely covered to allow gas exchange and to avoid rainwater entrance. Soil moisture and temperature were monitored, in duplicate manner in each position, with a data logger connected to moisture capacitance sensors and thermistors, installed at 5 and 15 cm depths inside four additional laterally perforated PE tubes placed for that purpose in two ridges and two furrows.

Field soil samples were biweekly taken with 2 cm i.d. auger by punching in four places to 20 cm depth inside the PE tube. As nitrogen mineral content variability was expected to increase with time, 8 tubes (2 positions x 4 plots) were randomly sampled in the first two sampling dates, 10 tubes in the third and fourth sampling dates and 12 tubes in the last sampling. Samples obtained from three punches in each tube were compounded in two depths (0-10, 10-20 cm) and half of each was used for mineral nitrogen determination in the same manner described for laboratory incubated samples, and the other half was air dried and kept for bromide and chloride determination in 1:1 soil-water extract after one hour in a laboratory rotative shaker. Bromide concentration in the extract was potentiometrically determined by selective bromide ion electrode (Mettler-Toledo) with Ag/AgCl as a reference electrode. Chloride concentration was determined in the filtered (through a 45 μm porous membrane) extract by ionic chromatography. Soil sample from the fourth punch was used for soil moisture determination. The average soil surface moisture for each position allowed to calculate the water deficit to restore that layer to field capacity, which was added, in two separated half fractions, to the corresponding unsampled tubes.

NNM obtained in laboratory incubation at 25ºC and field capacity moisture were adjusted to average soil temperature and moisture registered in the field between two consecutive samplings by multiplying slope of zero-order kinetic equation by

appropriated correction factors. Correction factors for temperature (f_T), assuming negligible effect of fluctuating soil temperature during incubation on NNM as compared with mineralization produced at constant equivalent temperature (Stanford *et al.*, 1975; Das *et al.*, 1995), were calculated with the exponential Q_{10} relationship (Stenger *et al.*, 1995; Das *et al.*, 1995):

$$f_T = \frac{K_T}{K_{25°C}} = Q_{10}^{\left(\frac{T-25}{10}\right)} \tag{1}$$

The value of $Q_{10} = 2.5$ used was within the range found in previous work in our laboratory when soil sample from the same field were incubated at four temperatures between 15ºC and 30ºC and close to that found by other authors, 2.4 to 2.26, (Stenger *et al.*, 1995) with soil of the same texture (sandy loam) incubated in a range of temperatures slightly lower (2ºC to 22ºC). Correction factors for soil moisture were calculated by a logarithmic equation of the type used by Rodrigo *et al.* (1997):

$$f_\theta = \frac{\log(-0.932/\psi)}{\log(-0.932/-0.01)} \tag{2}$$

where the value of – 0.932 MPa was obtained in our laboratory by incubating soil samples at 25ºC and four different soil water matric potential, ψ in MPa is the average measured potential in each sampling interval, and -0.01 MPa is the corresponding value of that potential at field capacity moisture.

Predicted NNM in laboratory incubation under field ambient conditions (θ_i, T_i) during "i" sampling interval of Δt_i duration in days was calculated by:

$$N_{\min Li}(\theta_i, T_i, \Delta t_i) = N_{\min Li-1} + K_i \cdot \Delta t_i \tag{3}$$

where

$$K_i = K_{25} \cdot f_{\theta i} \cdot f_{Ti} \tag{4}$$

and $N_{ninLt_{i-1}}$ is the nitrogen mineral content at the beginning of the time interval "i". Mineral nitrogen content variation in a field layer during a given time interval (Δt_i) is due to NNM = Organic N mineralized – N inmobilized – N denitrified – NH_4 nitrogen volatilized + N fixed, plus loss or gain of mineral nitrogen produced by mass flow of soil solution out or into that layer, since we disregarded the unlikely mineral nitrogen extraction by roots inside PE tubes as well as ion diffusion. Water flux through a 10 cm deep plane in the topsoil layer (J_{w10}) was estimated, during a time interval $\Delta t_i = t_i - t_{i-1}$, by mass balance of two unreactive ions like native chloride or added bromide, generically written as C:

$$C_{flux,10} = C_{10,i-1} - C_{10,i} \tag{5}$$

$$J_{w10} = \frac{C_{flux,10}}{[C_{10,i,i-1}]} \tag{6}$$

where $$C_{20,i,i-1} = \frac{\left[C_{0-10,i}\right]+\left[C_{0-10,i-1}\right]+\left[C_{10-20,i}\right]+\left[C_{10-20,i-1}\right]}{4} \qquad (7)$$

is obtained by averaging the concentration [ ] of ion in the adjacent layers to the plane of interest (10 cm) at the times defining the sampling interval. Two independent estimations of J_{w10} were made by using either ion in expressions (5) and (6). Nmin flux through a 10 cm deep plane was calculated as:

$$N\min flux_{10,i} = J_{w10} \left[\overline{N\min}\right]_{10,i} \qquad (8)$$

where average concentration of mineral N at 10 cm depth during time interval i is obtained in a analogous manner as in (8).

RESULTS AND DISCUSSION

ANOVA of soil mineral nitrogen content in laboratory incubated samples showed no significant difference respect to field position (ridge to furrow) sample procedence. Therefore, a single regression equation was adjusted to experimental data for mineral nitrogen as a function of time (Fig. 2), assuming as do other authors (Addiscott, 1983; Honeycutt, 1999) a zero order kinetics for nitrogen mineralization overall reactions.

Field soil temperature increased from about 12°C in March at the beginning of the essay up to 25°C in June at end of it, while soil moisture fluctuated around values under and over field capacity (taken as 10 kPa soil water tension) (Fig. 3 and 4). NNM obtained in the laboratory were adjusted to field measured temperature and moisture by using the correction factors (Table 3) calculated with equations (1) and (2). Measured increments of Nmin in the field were corrected for gains or losses of Nmin flux calculated in (8) and compared to predicted lab NNM (Fig. 5).

There was significant correlation (at 99% confidence level) between lab adjusted (x) and field corrected (y) NNM, as in Fig 5. When data are correlated together, regardless of position, it was found:

$$y = -1.56 + 0.94 \, x \qquad (r^2 = 0.56)$$

ANOVA of corrected field NNM showed significant difference (99% confidence level) between ridge and furrow, in the last three sampling intervals. However, both source of NNM were not only better correlated in ridge than in furrow but the former had also a regression slope coefficient closer to 1 than that in furrow. In furrow, lab NNM always overpredicted measured NNM in the field, except in one sampling interval (the 4th) and in one of the methods used to correct field data. A tentative explanation of the lower NNM in furrow is that the slightly larger compaction of topsoil brought about by more intensive traffic and flooding irrigation water in furrow could have favoured anoxic conditions and consequent larger nitrate N loss by denitrification.

In relation with the two methods used to estimate water and associated mineral N fluxes to correct field NNM observed increments, applied trace bromide showed to be stronger than the more variable native chloride. When data from each method were analyzed individually regression coefficients were larger for Br- (0.51) than for Cl- (0.46), while the slope of regression lines were closer to 1 in Br- method (1.07 in ridge and 0.87 in furrow) than in Cl- method (0.82 and 0.78, respectively). The reported deviations between lab and field NNM are considerably lower than the ones found

between disturbed and undisturbed soil samples in laboratory incubations (Stenger *et al.*, 1995) or between disturbed soil samples in lab and relatively undisturbed field cores with exchange resins in the field (Honeycutt, 1999), where the slopes of regression line were about 0.5.

CONCLUSIONS

NNM rates determined in laboratory incubation of disturbed soil samples were closer to field measured rates than what has been reported in other studies.

NNM in ridge was significantly larger than in furrow and was predicted better from laboratory incubation data than that of furrow. NNM rate for the 76 days period of incubation predicted from laboratory essay was 22.9 kg N/ ha x 0.1 m, while corresponding field rates corrected by Br⁻ or Cl⁻ mass balance were 10% and 20% lower respectively in ridge position and under 40% lower by either method in furrow position.

If agreement between field and laboratory determined NNM is used as a criterion, the method of applying Br⁻ as a tracer to estimate water flux and associated mass flow of mineral N through a soil layer was better than that of using native chloride.

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Tables

Table 1. Topsoil (0-20 cm) physicochemical properties of the soil used in the experiment.

Texture			Class	CaCO$_3$	Org. C.	Org. N.	C/N ratio	pH	C.I.C.
Sand	Silt	Clay							
g·kg^{-1}				g·kg^{-1}				(1:2,5w)	cmol$_c$ kg^{-1}
625	250	125	Sandy loam	317	9,5	1,1	8,6	8,12	8,8

Table 2. Field soil bulk density determined in six samples from each position at the end of the experimental period.

Depth cm	Ridge		Furrow	
	ρ$_b$ (g·cm^{-3})	st. dev.	ρ$_b$ (g·cm^{-3})	st. dev.
0 – 5	1,45	0,24	1,57	0,15
5 – 10	1,58	0,09	1,54	0,06
10 – 15	1,52	0,06	1,56	0,04
15 – 20	1,65	0,07	1,62	0,07

Table 3. Correction factors applied to slope of equation (1) for adjusting to field average soil moisture and temperature recorded at different time intervals.

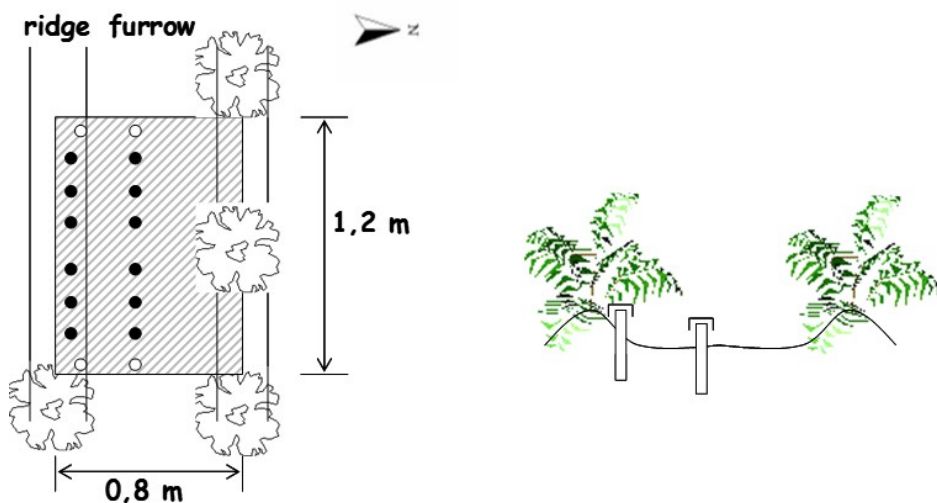| Incubation time (days)	Ridge		Furrow	
	f$_T$	f$_\theta$	f$_T$	f$_\theta$
0-14	0,315	1,000	0,319	0,799
14-28	0,381	0,947	0,390	0,584
28-48	0,499	1,000	0,528	0,783
48-62	0,660	0,779	0,723	0,626
62-76	0,892	0,415	0,983	0,544

Figures

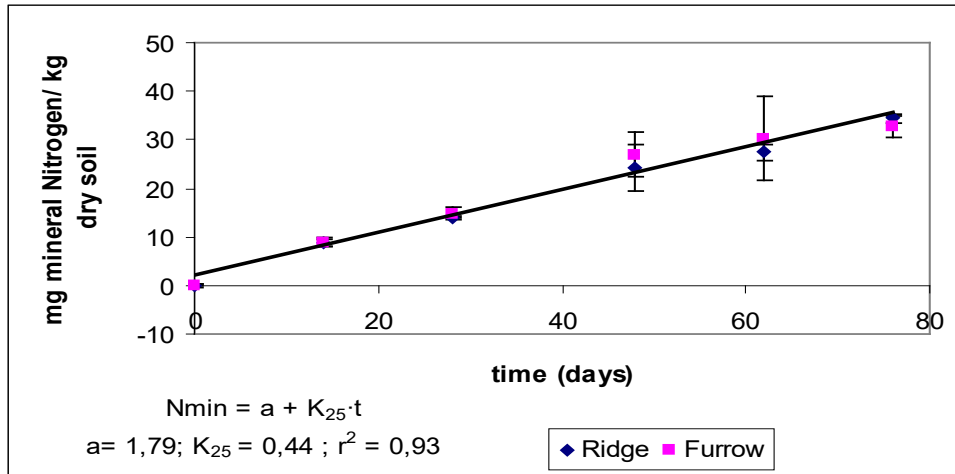Fig. 1. Details of experimental field and PE tubes placement in a microplot.

Fig. 2. Nitrogen mineralization in disturbed soil samples at 25ºC and 10 kPa as a function of time.
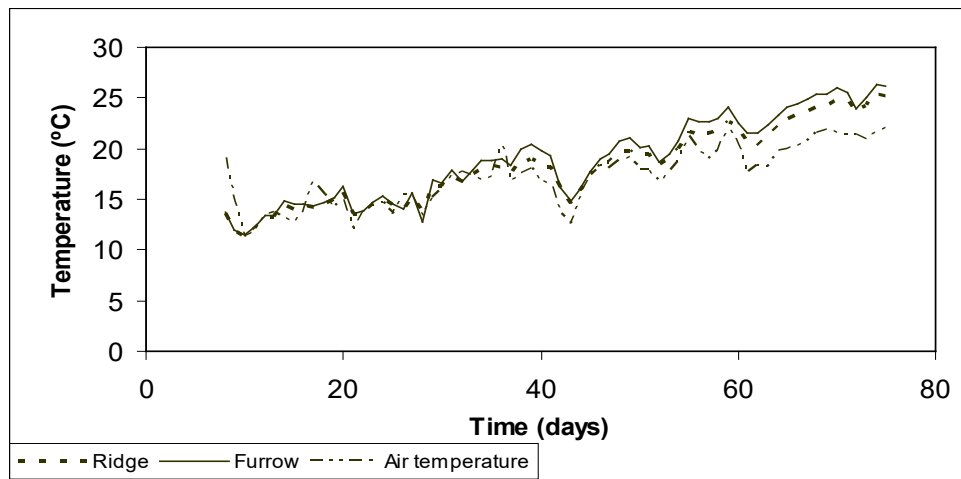

Fig. 3. Soil temperature at 5 cm depth and air temperature during the soil experimental period. Time 0 = March 25th, 2003.
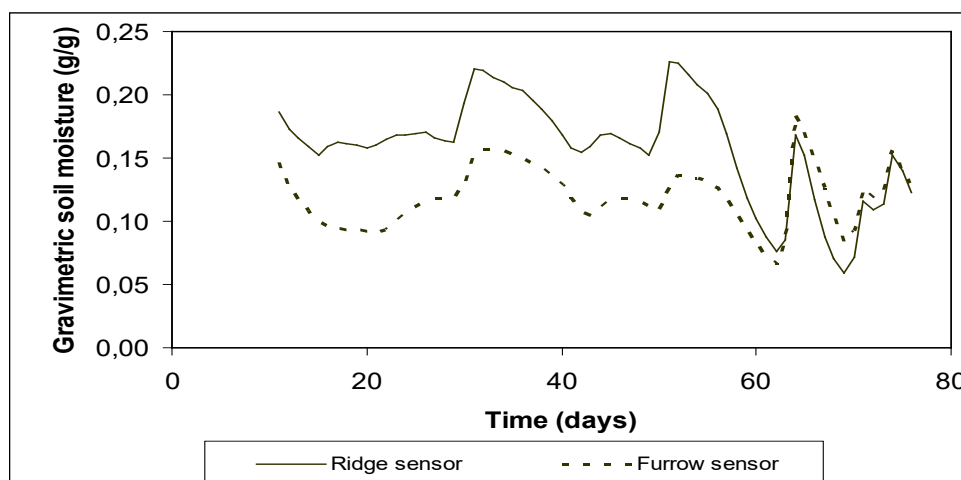

Fig. 4. Gravimetric soil moisture in the field as a function of date and position of measurement during the soil experimental period.
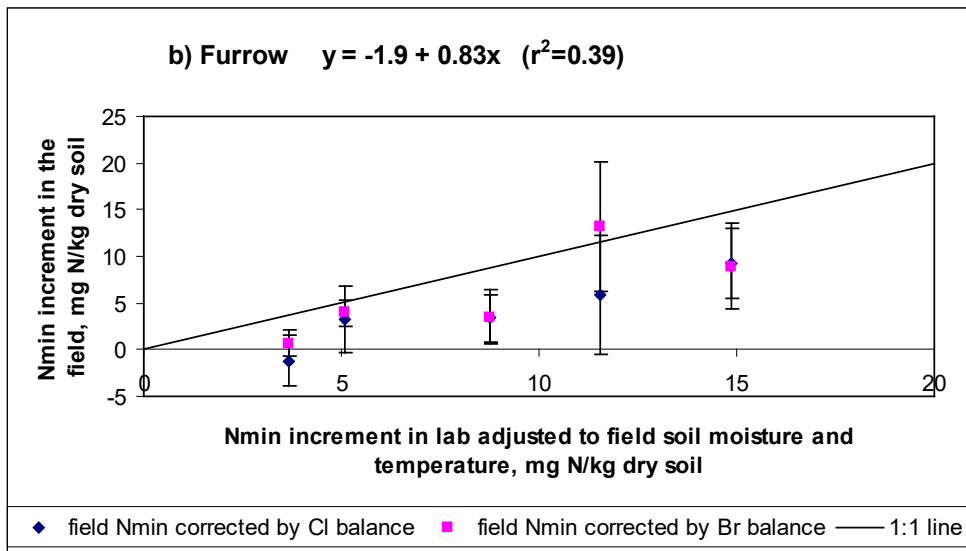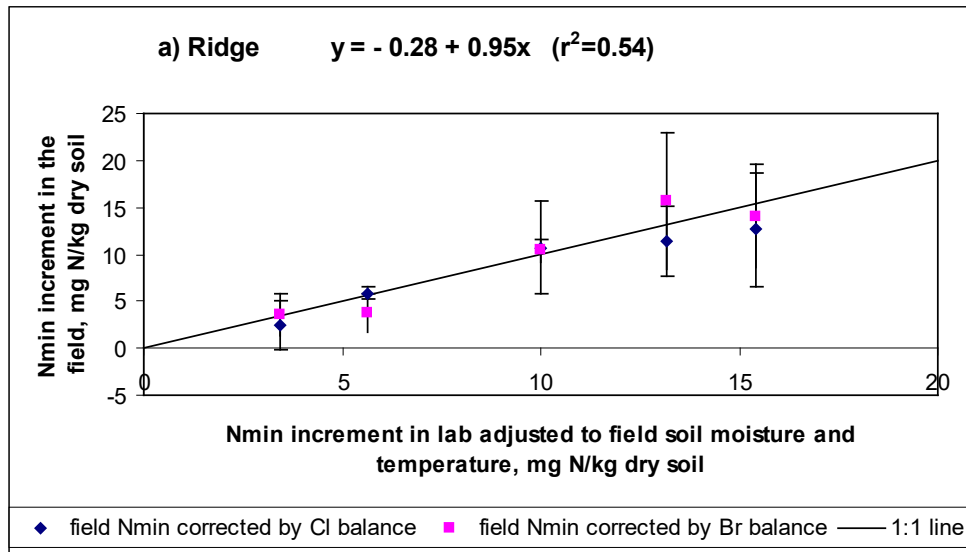
Fig. 5. Comparison on NNM derived for adjusted laboratory data and field data.