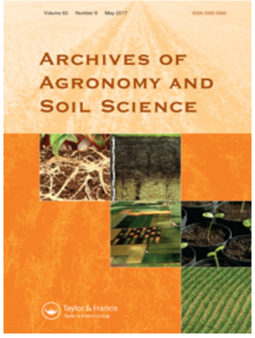

Archives of Agronomy and Soil Science

ISSN: 0365-0340 (Print) 1476-3567 (Online) Journal homepage: http://www.tandfonline.com/loi/gags20

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ARCHIVES OF AGRONOMY AND SOIL SCIENCE, 2017
VOL. 63, NO. 6, 870–882
http://dx.doi.org/10.1080/03650340.2016.1241391

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Modeling nitrogen mineralization at surface and deep layers of sandy soils

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ABSTRACT

We evaluated potential soil nitrogen mineralization of 46 sandy fields of the Pampas for determining the contribution of deep layers to mineralization and modeling its trend in depth as a possible tool for improving current existing mineralization models based on surface data. Mineralization, total and mineral nitrogen decreased with depth. A potential model fitted well to these variables (R^2 = 0.95–0.99), but mineralization showed a more stratified profile. Consequently, the fraction of total nitrogen mineralized decreased with depth despite soils had constant texture across the profile. Potential mineralization to 1 m depth could be estimated using data from the 0–0.2-m soil layer and the average curvature of the potential model (R^2 = 0.60) or linear regression methods (R^2 = 0.71). Another estimation of potential mineralization could be performed by developing a pedotransfer function which used as predictors total nitrogen and depth (R^2 = 0.62), without the need of laboratory incubations. Our results showed that for sandy soils, deep nitrogen mineralization account for 40% of soil mineralization and can be assessed using surface data or the total nitrogen content of the soils. Because surface soil mineralization and whole profile mineralization were highly correlated, it is improbable that field mineralization modeling may be improved using deep data in these soils.

ARTICLE HISTORY
Received 13 January 2016
Accepted 7 September 2016

KEYWORDS
Nitrogen mineralization; aerobic incubation; modeling in depth

Introduction

Nitrogen mineralization plays a major role in crop nutrition and its estimation allows calculating fertilizer needs by the nitrogen budget approach (Meisinger 1984; Neeteson 1995). In some soils, it had been demonstrated that as higher the potential mineralization evaluated *in vitro* the lower the response of crops to fertilizers (Khan et al. 2001; Mulvaney et al. 2001). Additionally, potential mineralization during laboratory incubations is a suitable tool for modeling field mineralization (Egelkraut et al. 2003; Alvarez & Steinbach 2011; Nyiraneza et al. 2012) and much work had been performed for generating methods adequate for nitrogen mineralization evaluation at both scales (Hart et al. 1994). Usually, potential mineralization had been assessed with surface soil but fertilizer needs or field mineralization would be better estimated in soils with contrasting mineralization patterns in depth if also subsurface and deep soil layers are evaluated. Consequently, the study of the relationships between mineralization potential at different soil layers becomes of relevance.

Soil mineralization is mainly regulated by organic matter content and texture. As total soil nitrogen increases mineralization increases too (Beauchamp et al. 2003; Li et al. 2008; Colman & Schimel 2013). Because total nitrogen and fine particle content of the soil are usually correlated at

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surface, some studies had founded greater mineralization in finer textured soils (Neil et al. 1997; O'Connell et al. 2003). This confounded effect has been overcome by using covariate models that showed lower nitrogen mineralization in clayed soils (Rasiah 1995; Cookson et al. 2006; Dessureault-rompé et al. 2010) or calculating the fraction of total nitrogen mineralized as a function of texture. By this latter approach, it has been observed lower mineralization ratios in finer soils because clay protects organic matter for microbial attack (Hassink 1994; Bechtold & Naiman 2006).

Because total nitrogen decreases with depth and clay content rises in soils with B horizon, this leads to sharp decreases of nitrogen mineralization in the deeper layers of fine-textured soils (Groot & Houda 1995). In sandy soils, B horizons are usually not founded but nitrogen mineralization as a fraction of total nitrogen may also drop below 30 cm, possible because of the chemical protection of organic matter (Dodd et al. 2000). Nevertheless, in some cropped coarse-textured soils, it had been reported that ca. 50% of total mineralization is produced in the 0.18–1.08-m layer (Cassman & Munns 1980). This may have a strong effect on crop nutrition as it can be estimated, using the model of Jackson et al. (1996), that ca. 50% of crop roots are allocated in this layer. Consequently, the evaluation of nitrogen mineralization in deep soil layers may be of interest for soil fertility evaluation in sandy soils. As deep soil sampling is difficult and time consuming, so is performing mineralization test on many samples, this in time may raise interest in the development of methods for estimation of mineralization in deep soil layers.

Potential mineralization is assessed by aerobic or anaerobic methods but conflicting results can be found in the literature when comparing both techniques. In some regions, results obtained by both alternatives are fairly correlated (Barrios et al. 1996; Wang et al. 2001) but not in others (Curtin & McCallum 2004; Kader et al. 2013). This makes necessary to test the most suitable incubation methods for the soils under study.

The Pampas of Argentina has been considered as one of the main cropping areas in the World (Satorre & Slafer 1999). The balance sheet method had been adjusted in this region as a fertilizer rate estimation method for humid (González Montaner et al. 1997; Alvarez et al. 2004) and semiarid (Romano et al. 2015) environments. For assessing *in situ* soil nitrogen mineralization, the quantification of nitrogen mineralization during 2-week aerobic incubations of surface samples has been identified as an useful predictor, both for corn (*Zea mays*) and wheat (*Triticum aestivum*) in fine and coarse soils (Alvarez & Steinbach 2011; Romano et al. 2015). Potential mineralization during this short incubation was used as predictor in multiple regression models or artificial neural networks for estimation field mineralization over the whole growing season joined to other soil and climate variables. Results of these models suited well to field mineralization estimated by the mass balance approach at multiple sites (Alvarez & Steinbach 2011; Romano et al. 2015). Anaerobic short incubations had also been proposed for assessing the soil nitrogen supply capacity to both crops in fine-texture soils of the region (Sainz Rozas et al. 2008; Reussi Calvo et al. 2013) but these methods had not been tested in the coarser soils of the Semiarid Pampa. The stratification pattern of mineralization has been also poorly studied in the region. In 35 production fields of humid areas with clayed B horizons, mainly Typic Argiudolls (Luvic Phaeozems), aerobic potential mineralization has been assessed (Giambiagi & Kraljev 1973). The integration of these data showed that 70% of the nitrogen mineralized in the upper 1 m of the profile became from the 0–0.3-m layer (Alvarez & Steinbach 2012). Conversely, in the Semiarid Pampa, that accounts for around 50% of the Pampas, only in one soil, an Entic Haplustoll (Haplic Kastanozems), it was measured nitrogen mineralization along the soil profile (Bono & Alvarez 2013). In this soil, 50% of the net mineralization was produced below 0.25 m depth. As in this area, main crop roots explore soils and extract much water in depth (Dardanelli et al. 1997), the evaluation of mineralization in subsurface soil layers became of special interest. Different nitrogen mineralization patterns in depth between soils would determine different contribution of the deep soil layers to the soil nitrogen supply capacity and would made it necessary to develop methods for evaluating or estimating deep mineralization in order to improve models base at present solely on surface mineralization. Our objectives were (1) to compare methods of determining potential mineralization using aerobic and anaerobic incubations and their relationships with soil nitrogen pools in sandy soils of the Semiarid Pampa, (2) to evaluate nitrogen mineralization potential at surface and deep layers for assessing the contribution of deep soil layers to the overall mineralization and (3) to determine the correlation between potential mineralization at different sampling depths and to develop simple estimation methods of mineralization at the whole profile scale without the need of deep sampling and extensive laboratory work.

Materials and methods

Experimental area

The Pampas of Argentina is a plain of ca. 60 Mha located between 28 and 40°S and 57 and 68°W. Mean annual rainfall varies from 500 mm in the West to 1200 mm in the East and mean temperature ranges from 14°C in the South to 23°C in the North. Most common soils are Mollisols (mainly Phaeozem and Kastanozem) formed on loess-like materials, under graminaceus vegetation (Hall et al. 1992). Around 50% of the region is under semiarid climate with an annual rainfall lower than 700 mm. This area has sandy textured soils, in some cases presenting a petrocalcic horizon within the upper 1 m of the soil profile (Alvarez & Lavado 1998; Berhongaray et al. 2013). Soil pH varies usually between 6 and 7 in well-drained soils which are devoted to agriculture (Berhongaray et al. 2013).

Sampling and analytical methods

We sampled 46 different crop production fields within the Semiarid Pampa over and area of 15 Mha (Figure 1). Soil were classified as Typic Haplustolls (Haplic Kastanozem) (*n* = 36), Typic Ustipsaments (Haplic Kastanozem) (*n* = 9) and Entic Hapludoll (Haplic Phaeozem) (*n* = 1). Fields were selected because they were representative of common agricultural managements. Within each field, a plot of 200 m^2 was sampled randomly choosing six sites by plot. Samples were taken at each site with an auger by 0.2 m layers to 1 m depth in 33 fields and to the upper limit of a

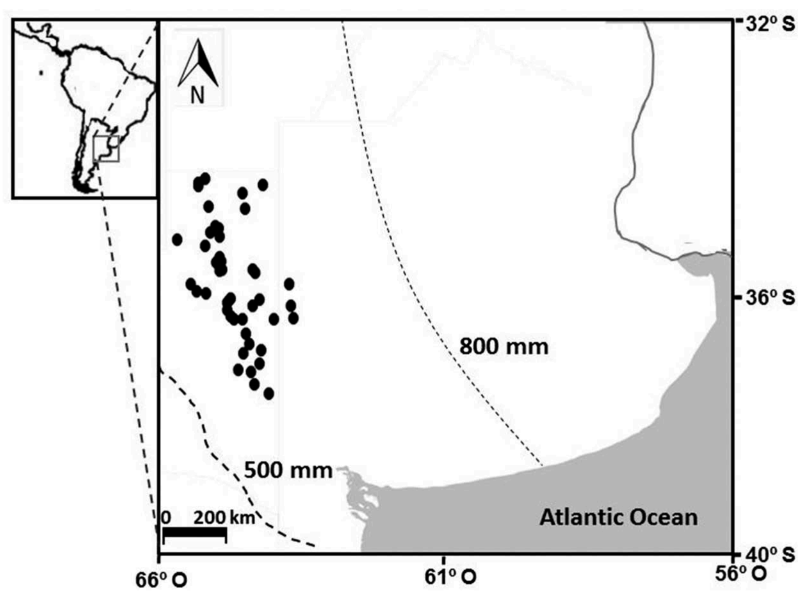

Figure 1. Map of the Pampas showing the location of the sampled fields.

petrocalcic horizon in 13 of the fields which had that type of horizon. The six samples by depth layer were mixed. This procedure generated 212 samples (46 fields × 1 plot/field × 1 sample/plot/depth × 3–5 depths, depending on the presence and depth of a petrocalcic horizon). Additionally, a pit was dug to 1 m depth in the center of each plot and samples for soil bulk density determination were taken from the four walls of the pit at the middle of the sampling depths. In fields with petrocalcic horizon, bulk density was measured in the soil layers above that horizon.

Soil bulk density was determined by the cylinder method (Blake & Hartge 1986) and values obtained with the four samples taken by soil and depth layer were averaged. The fresh samples taken for chemical and biological determinations were split; part of the samples was ground and sieved (2 mm) for ammonium and nitrate determination. The rest was air dried for the other soil analysis. After drying, samples were also ground (2 mm) and the textural composition was assessed by the Bouyuocos method (Gee & Bauder 1986).

Nitrate and ammonium nitrogen were extracted by 2 M KCl, determined by separating the steam distillation method (Mulvaney 1996) and summed (mineral N). Total nitrogen (total N) was assessed with an autoanalyzer (LECO Co., Truspec CN, USA). Nitrogen mineralization during aerobic incubations (aerobic N) was tested as an estimation of soil nitrogen mineralization potential. Aerobic N was defined as the nitrogen mineralized during aerobic incubation of 2 weeks duration under adequate conditions of temperature and water content from disturbed soil samples. The methodology had been used successfully in the past as one of the predictors of field mineralization for grain crops included in multivariate models in the Pampas (Alvarez & Steinbach 2011; Romano et al. 2015). Soils were incubated for 15 days at 30°C with water content equivalent to field capacity as previously described (Alvarez et al. 2004). Nitrogen mineralized during incubations was calculated as the difference between post and pre-incubation mineral N. Physical properties, mineral N, total N and aerobic N were determined on samples of all sampled depths. Additionally, for surface samples (0–0.2 m), anaerobic incubations (anaerobic N) were also tested as a potential mineralization test. Anaerobic N was defined as the nitrogen mineralized during 1-week incubation under waterlogged conditions and a temperature of 40°C of disturbed soil samples. This variable had been used previously in the Pampas for predicting grain crops response to fertilization (Sainz Rozas et al. 2008; Reussi Calvo et al. 2013). Organic matter from surface samples (0–0.2 m) was fractionated by a method locally developed (Quiroga et al. 1996), which is a modification of the common fractionation of Cambardella and Elliott (1994). Samples of 50 g were dispersed in 150 ml distilled water and shaken 4 h with glass pearls. Suspensions were then sieved by 50 and 100 µm generating three soil fractions: >100, 100–50, and <50 µm. Anaerobic incubations were also performed with the isolated soil fractions as described above for whole soil. Total N and carbon (C) were determined in the soil fractions with an autoanalyzer (LECO Co., Truspec CN, USA). As surface samples were free of carbonates, total C was equivalent to organic C. For all variables, concentrations were transformed into mass data using bulk density for making possible comparison across different soil layers of contrasting bulk density.

Modeling and statistical methods

Nitrogen profile data were modeled using a potential model of the form (Bernoux et al. 1998; Berhongaray et al. 2013):

$$N = A \times d^b \tag{1}$$

where N = nitrogen pool (kg ha^{-1}) at depth d(m), A = cumulative nitrogen to 1 m depth (kg ha^{-1}), b = curvature (slope) of the function.

Lower b values correspond to more stratified nitrogen profiles. When $b = 1$, the nitrogen pool is not stratified and the mass of nitrogen is similar between soil layers. Values of b greater than 1 indicate higher nitrogen pools at deep soil layers than at surface layers. Parameters A and b were fitted by the least square method after transforming the function into a linear model by log transformation (Berhongaray et al. 2013).

Linear and curvilinear regression methods were used for inspecting the relationships between variables testing significance by the F (P = 0.05). Multiple regression methods were also applied testing the polynomial model of grade two, in which lineal and curvilinear effects were included and also interactions between independent variables (Alvarez 2009). A forward stepwise procedure was employed for variable selection and terms were included in the final model only if they were significant (P = 0.05). To avoid overfitting, data were partitioned into 70% for training and 30% for validation and the R parameters were contrasted by the Fisher's Z transformation (Kleinbaum & Kupper 1979). The autocorrelation between variables was prevented using the VIF value, refusing variables with values over 5 (Neter 1990). The performance of multiple regression models was assessed by plotting observed versus estimated data testing ordinates and slopes against cero and one with Irene (Fila et al. 2003). Also ordinates and slopes of simple regressions were tested against 0 and 1. Parameter b was contrasted between different nitrogen pools by a paired t-test. The C/N ratio and the fraction or total N mineralized during anaerobic incubations were also contrasted between different soil physical fractions by means of the t-test.

Results

Sites variability

The variability between sampled fields was very ample (Table 1, Figure 2). The clay and silt content of the fields had a 10-fold range comparing minimum and maximum values, so it was very variable the level of nitrate and ammonium N. Conversely, the organic matter content of the fields showed less variability with a twofold range between extreme values of organic C and total N. In average,

Table 1. Variability of the properties of all sampled fields (0–0.2 m depth; n = 46).

Parameter	Bulk density (t m^{-3})	Clay (t ha^{-1})	Silt (t ha^{-1})	Sand (t ha^{-1})	Organic C (t ha^{-1})	Total N (t ha^{-1})	C/N	Nitrate N (kg ha^{-1})	Ammonium N (kg ha^{-1})
Maximum	1.53	365	1088	2915	34.5	3.60	11.3	36.3	12.6
Average	1.21	127	667	1634	23.2	2.44	9.5	15.0	6.3
Minimum	1.00	43	91	889	14.1	1.59	6.4	3.5	1.9

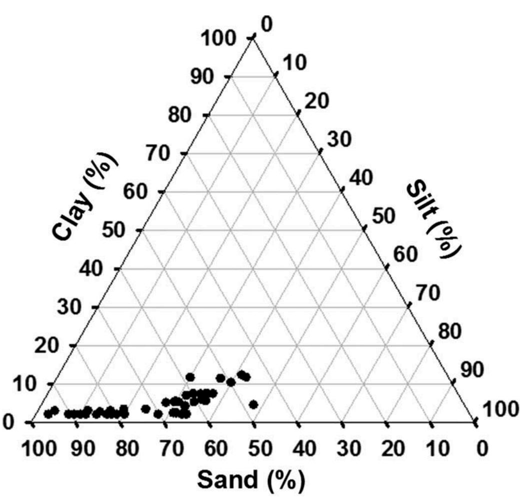

Figure 2. Textural composition of the soils sampled. Values are the average composition to 1 m depth or to the upper limit of the petrocalcic horizon (n = 46).

Table 2. Average values of soil organic matter fractionation and anaerobic incubation mineralization measurements (0–0.2 m).

	Whole soil	Fraction <50 µm	Fraction 50–100 µm	Fraction >100 µm
Organic C (kg ha^{-1})	23,200	18,100	3420	3920
Total N (kg ha^{-1})	2440	1550	355	391
C/N	9.5 a	11.7 b	10.0 a	11.2 b
Anaerobic N (kg ha^{-1})	156	301	276	60
Anaerobic N (% of total N)	6.5 a	23.4 b	32.7 b	22.6 b

Values followed by different letters are different (P = 0.05) for C/N and anaerobic N (% of total N; n = 46).

soil profiles had 70% of sand to 1 m depth without important textural changes in the sampled layers (Figure 2). In 13 of the fields, a petrocalcic horizon was present between 0.6 and 1 m depth. Around 64% of total N was found in the soil fraction <50 µm, the rest partitioned between the 50–100-µm and >100-µm fractions (Table 2). The total N mineralized during the anaerobic incubation was 6.5% when whole soil was incubated but increased ca. fourfold when the isolated soil fractions were incubated (Table 2). During these incubations, only ammonium N was produced. Conversely, during aerobic incubations, only nitrate N was produced, doubling pre-incubation levels, not ammonium N. Aerobic N was in average 25% of anaerobic N. Anaerobic N was not correlated with mineral N, texture or total N, neither it was associated to aerobic N (R^2 = ns). Neither aerobic N nor anaerobic N could be predicted by using the size of any of the fractions isolated (R^2 = ns) but aerobic N correlated with total N (R^2 = 0.21) and mineral N (R^2 = 0.17).

Nitrogen stratification

Total N and mineral N profiles showed a similar stratification pattern (Figure 3), but nitrate N and ammonium N decreased in depth in different ways. The ratio nitrate N/ammonium N changed from 2.4 in the 0–0.2 m layer to 1.5 in the 0.8–1 m layer. In deeper soil, the contribution of ammonium N to the mineral N pool gets greater. Across all sites and depths, nitrate N and ammonium N were not significantly correlated nor was mineral N with soil texture. Only a week correlation was detected between mineral N and total N (R^2 = 0.32). Conversely, mineral N content of the different soil layers was correlated each other. This may allow the estimation of the mineral N content of the whole soil (0–1 m depth) using data from the surface layer (0–0.2 m depth) applying the model: $y = 27 + 1.9x$ (R^2 = 0.64). Much more stratified than nitrogen pools was aerobic N (Figure 2). Around 80% of whole soil mineralization was produced in the upper 0.4 m of the profile. The fraction of total N mineralized during aerobic incubations decrease from 1.5% in upper soil to 0.3% at the bottom of the profile.

The potential function did a very good job for modeling total N, mineral N and aerobic N in soils without petrocalcic horizon (Figure 4). The model could be significantly fitted to nearly all profiles with

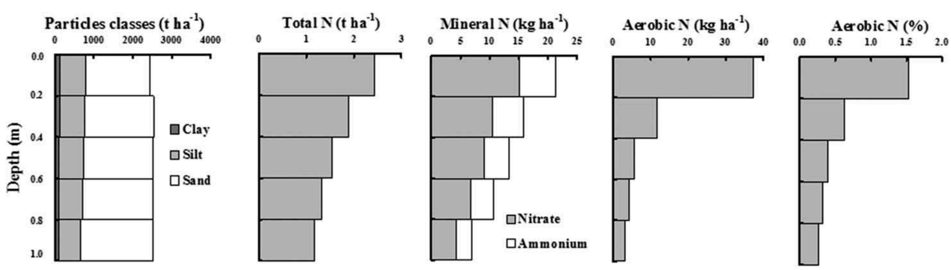

Figure 3. Average particle classes composition and nitrogen pools of all the soil profiles (n = 46) as a function of depth. Aerobic N (%) represents the percentage of total N mineralized during aerobic incubations. For the upper soil layers (0–20, 20–40 and 40–60 cm), values are the average of 46 fields (soils without petrocalcic horizon). For deep soil layers, values are the average of fields without petrocalcic horizon (60–80 cm, n = 41 and 80–100 cm, n = 33).

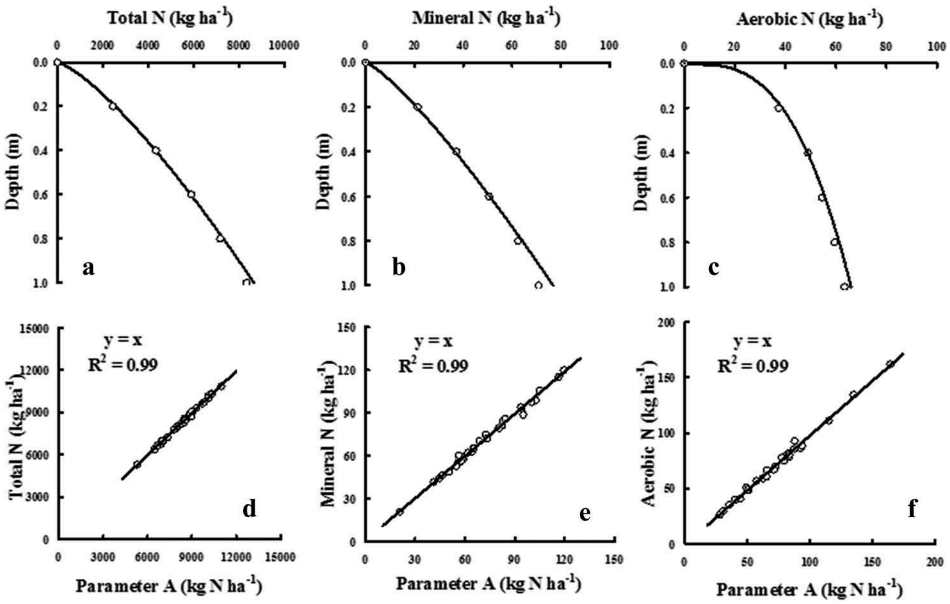

Figure 4. Performance of the potential model for fitting cumulative profiles of total N (a), mineral N (b) and aerobic N (c). Values of each variable are the averages of the cumulative stocks of nitrogen of the 33 fields without petrocalcic horizon. Regressions of observed cumulative values of total N (d), mineral N (e) and aerobic N (f) to 1 m depth against the parameter *A* of the potential model fitted to each variable. In all cases, fits corresponded to fields without petrocalcic horizon (n = 33).

Table 3. Performance of the potential model for fitting to nitrogen profile data of fields without petrocalcic horizon (n = 33).

	Cases with adjust significant (%)	R^2	Average parameter *A* (kg N ha^{-1})	Parameter *b*			Cases with *b* > 1
				−95%	Average	+95%	
Total N	100	0.98–0.99	8350	0.71	0.74 a	0.77	0
Mineral N	100	0.97–0.99	72.3	0.66	0.73 a	0.80	2
Aerobic N	88	0.95–0.99	73.4	0.28	0.33 b	0.39	0

Parameter *A* represents cumulative values to 1 m depth and parameter *b* the curvature of the model. For the *b* parameter, confidence intervals of 95% are showed. When *b* > 1, subsurface layers had greater stocks than the upper ones. Different letters indicate the significance of the potential model was tested at $P < 0.05$.

high R^2 (Table 3). In two fields, the *b* parameter had values greater than 1 indicating more mineral N content in deeper soil layers that at surface. The model was very useful to estimate the cumulative mass of nitrogen to 1 m depth (parameter *A*) and the curvature of the function was not different for total N and mineral N. Aerobic N had a lower *b* because of its greater stratification. Using data of aerobic N for the 0–0.2 m layer and the average parameter *b* for estimating mineralization at the whole soil profile of fields with no depth restriction, a good performance was achieved (Figure 5a). A better estimation of whole profile mineralization could be attained when using surface mineralization as predicting variable and a simple regression model (Figure 5b). This latter option could be applied to all fields. By applying this methodology, the overall profile mineralization potential can be estimated, sampling and incubating only samples from the upper soil layer.

Development of a pedotransfer function

Multiple regression methods allowed developing a model for predicting aerobic N using total N and depth as predictors (Figure 6, Equation. 2). The model was fitted using all samples (n = 212) across fields (n = 46) and depth layers (n = 3–5) and had good generalization ability as no significant difference was detected between the R^2 of the training and validation data sets. The

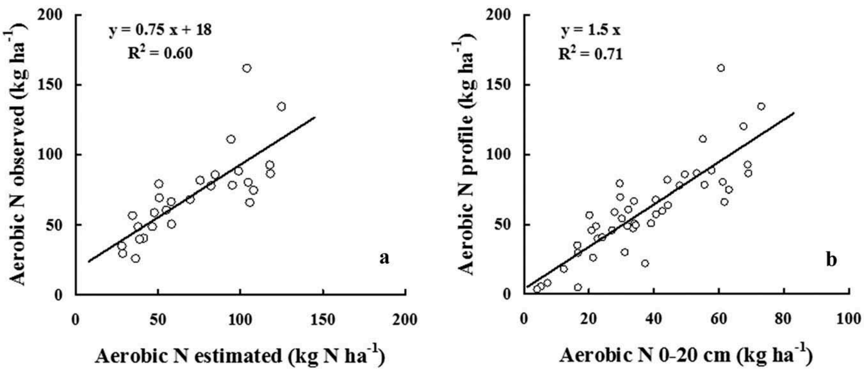

Figure 5. a: Relationship between aerobic N to 1 m depth observed and estimated using the potential model with the average *b* parameter (0.33). Only fields without petrocalcic horizon were included in the regression (n = 33). b: Relationship between aerobic N in the whole profile and aerobic N in the 0–20-cm soil layer. All fields (with and without petrocalcic horizon) were included (n = 46).

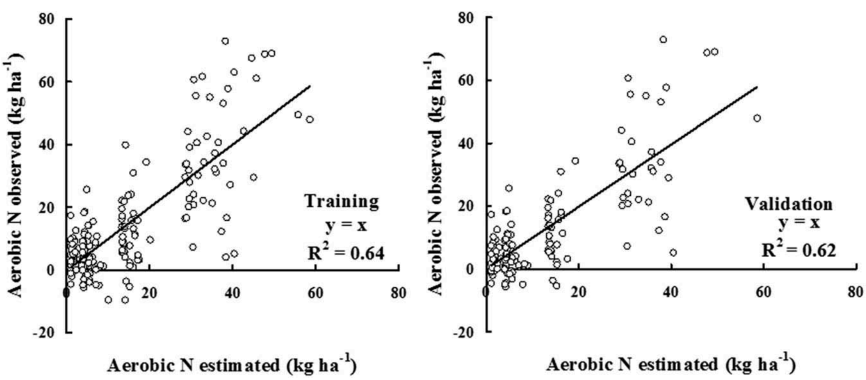

Figure 6. Performance of a multiple regression model for estimating aerobic N across all fields and depths. Estimated values were calculated with Equation (2).

model can be used when only total N data of the soil layer are available for estimating mineralization of that layer and the corresponding depth. It showed that aerobic N increased with greater total N content and decreased with depth.

$$\text{Aerobic N} = 55 - 106\ \text{depth} + 75\ \text{depth}^2 - 22\ \text{total N} + 7.0\ \text{total N}^2 \qquad (2)$$

where aerobic N = kg ha^{-1}, depth = m (at the middle of the soil layer), total N = t ha^{-1}.

Discussion

Performance of incubation and fractionation methods

Anaerobic incubations and physical fractionation of organic matter gave poor results in these soils. Anaerobic and aerobic mineralization were not correlated nor was the former associated to soil properties. Physical fractionation of organic matter, separating soil fractions by their density, allowed identifying the source of nitrogen (Alvarez et al. 1998) and carbon (Alvarez et al. 1993) for mineralization in fine textured soils of the Pampas. The size fractionation tested here failed to isolate the easily mineralizable fraction in sandy soils despite fractions of greater size are expected to be more labile (Cambardella & Elliott 1994). Anaerobic N was in average fourfold greater than aerobic N in Pampean surface soils. Commonly, anaerobic N is greater than aerobic N (Barrios et al. 1996; Curtin & McCallum 2004; Kader et al. 2013) because under anaerobic conditions, conversion efficiency is greater (Gale & Gilmour 1988). This makes its determination easier reducing experimental error but as this variable was not associated to any soil property, including total N, we discarded it and chose the aerobic method for evaluating potential mineralization. Usually, mineralization of nitrogen during anaerobic incubations is correlated to the total N pool (Wang et al. 2001; Curtin & McCallum 2004) or its labile fractions (Barrios et al. 1996) in most soils. However, in tropical soils, Kader et al. (2013) did not found significant association between anaerobic N and soil nitrogen pools as in our case.

Nitrogen stratification

The stratification pattern of mineral N allows its estimation to 1 m depth when only data from the 0–0.2-m layer are available. The average tendency in our sandy soils was a decrease of 23% of the mineral N stock as layer depth increased 0.2 m. If only nitrate N was taken into account, the decrease in depth was very similar. This stratification pattern is much different from the one reported for loam and clayed soils of the Pampas, mainly Argiudolls (Phaeozem), in which nitrate N decreases 45% by 0.2 m depth layer (Alvarez et al. 2001). The coarse texture of our soils determined more lixiviation of mineral N to deeper layers or more mineralization in depth. As a practical consequence, if estimations methods for mineral N or nitrate N would be applied using nitrogen at surface as predictor, equations must be separately adjusted to different textural classes.

Aerobic N as a fraction of total N decreased with depth so it had a much more stratification pattern than total N. This occurred despite there were no textural changes along the soil profile and protecting effect of fine particles may be discarded. The multiple regression model fitted also showed a depth effect on mineralization, which was independent of the total N content of the soil layer. Because nitrogen mineralization is correlated to total N, usually, it decreases with depth (Groot & Houda 1995; Iversen et al. 2011). In some soils, it has been observed that the fraction of total N mineralized decreases with depth too, but not always (Weier & Macrae 1993; Persson & Wién 1995). This phenomenon has been also reported for coarse textured soils (Cassman & Munns 1980; Dodd et al. 2000). Soil organic matter stability increases with depth because labile forms are less abundant. For example, nitrogen mineralization at surface layers may be higher because more nitrogen is allocated in easy mineralizable forms of organic matter as the microbial biomass (Murphy et al. 1998). It has also been reported more mineralization at surface soil because the upper soil layer contents more residues that release nitrogen during decomposition (Schmied et al. 2003). Despite that, all these processes lead to the aerobic N decrease in depth observed in the sandy Pampean soils, nitrogen mineralization in the 0.2–1-m layer accounted for an important fraction of the overall soil mineralization.

The potential model fitted very well to total N, mineral N and aerobic N profiles and could be a useful tool for estimation of these variables in depth. This model has been previously used in the Pampas for modeling organic carbon stocks in the profile, both for coarse and clayed soils, with good results (Berhongaray et al. 2013). The curvature reported for carbon (b = 0.56) was different than the value we adjusted for total N (b = 0.76). Carbon seems to be more stratified than nitrogen in coarse soils. This would impact on the C/N ratio of these soils leading to a strong decrease in depth, but this needs future confirmation. The estimation of whole profile aerobic N by this model had a good performance but could be improved by a simple regression method which would be preferred because of its simplicity and better fit. Using the average slope of the regression between aerobic N in the 0–0.2 m layer and the whole profile mineralization, a much simple estimation method can be applied. As the regression had ordinate equal to zero, nitrogen mineralization to 1 m depth can be estimated affecting surface mineralization (0–0.2 m) by a factor of 1.5. This factor must not be extrapolated to different soils than those studied here.

Estimation of mineralization without laboratory incubations

The pedotransfer function fitted that allows nitrogen mineralization estimation using as predictors total N and depth, saves the need of laboratory incubations for mineralization assessing. Similar methods can be adapted to other sandy soils. Many models were developed previously relating soil variables to mineralization of surface soil. Predictors commonly included in models were total N (Liu et al. 2010; Colman & Schimel 2013), texture (Manguiat et al. 1996; Smit & Velthof 2010) and the labile fractions of organic matter (Hassink 1995; Li et al. 2008). These predictors, usually combined, allowed mineralization estimations. In clayed soils, mineralization decreased in depth as a consequence of organic matter stabilization and textural protection. In the coarse Pampean soils of this study, because of the uniform texture composition along the profile, using only total N and depth as predictor, a good estimation of mineralization could be performed. Depth could subrogate other variables that are commonly used for assessing organic matter resistance to degradation as are labile fractions (Hassink 1995; Li et al. 2008).

If nitrogen mineralization would be determined in sandy Pampean soils as an index of potential mineralization and possible response to nitrogen, as in other cropping areas of the World (Mulvaney et al. 2001), sampling the 0–0.2-m layer is adequate as mineralization along all soil layers is correlated. Likewise, when fertilizer rates are calculated by the mass balance approach and predicting models of field mineralization require results of mineralization in laboratory test (Alvarez et al. 2004), surface results would be as effective as whole profile evaluations because of the abovementioned correlation. This laboratory test can be replaced by estimations using pedotransfer functions though with lower adjustment.

Conclusions

In the sandy soils of the Semiarid Pampa, aerobic incubation allowed a better characterization of nitrogen mineralization potential than the anaerobic method and could be used for modeling it. Particulate organic matter fraction was not correlated to mineralization. Subsurface and deep soil (0.2–1 m depth) accounted for 40% of the overall mineralization. Because nitrogen mineralization at different soil layers was correlated, deep mineralization can be estimated using surface data by simple regression models. A pedotransfer function was also adjusted for nitrogen mineralization estimation at different soil depths that uses as predictors the total nitrogen content of the soil layer and its depth. Models developed for estimating the soil nitrogen supply capacity during crop growing seasons at the field, which uses surface mineralization as predictors, would not be substantially improved by including deep mineralization data.

Disclosure statement

No potential conflict of interest was reported by the authors.

Funding

This work was supported by the Fondo para la Investigación Científica y Tecnológica: [Grant Number: PID-BID 37164 – 49]; Universidad de Buenos Aires: [Projects 20020100617 and 20020130100484BA]; Consejo Nacional de Investigaciones Científicas y Técnicas: [Grant Number PIP 112-200801-02608].

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