RESEARCH

NITROGEN MINERALIZATION AND RELEASED NUTRIENTS IN A VOLCANIC SOIL AMENDED WITH POULTRY LITTER

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ABSTRACT

Optimum application rates of poultry litter (PL) spread out on the farmer´s field is a valuable source of available plant nutrients. The aim of this study was to compare the effect of two rates of PL and conventional fertilization (CF) on N mineralization and P, K, Zn, and Cu availability in an Andisol from Southern Chile under controlled conditions. Aerobic incubation was carried out for a 16-wk period. N mineralization rates were higher (61.5%) with the two PL treatments than with conventional fertilizer (23%). CF was associated with high N availability prior to the start of incubation and slight immobilization during the first week, perhaps due to a more rapid conversion of urea into NH_4 which was then temporarily immobilized by the microbial biomass. At the start and end of the incubation period, Olsen-extractable P content was generally higher in CF. Due to the high fixation capacity of the soil studied, extractable P values were slightly increased suggesting that PL mineralization is only associated with a low risk of P contamination in volcanic soil. In PL, K, Zn, and Cu availability were higher than in CF. However, values obtained for Cu and Zn were average in relation to referential values used in agricultural soil. The results indicated that PL could be an alternative to conventional fertilizer under the conditions of the present study.

Key words: aerobic incubation, poultry litter, nitrogen mineralization, nutrient availability, volcanic soil.

INTRODUCTION

The use of organic waste in the amendment of agricultural soils can be beneficial for crops, and at the same time, provide an efficient and cost-effective method for its disposal. Many authors have reported that different types of organic waste can improve physical, chemical, and biological properties of soils (Clark *et al*., 1998; Whalen *et al*., 2000; Cuevas *et al*., 2003; Hansen and Strawn, 2003; Sullivan *et al*., 2003).

Over the last 10 years, poultry production has increased in Chile as a consequence of high red meat prices and a growing population (INE, 2005). This upturn in production has been accompanied by an increase in the generation of poultry litter (PL), a heterogeneous waste consisting of poultry excreta mixed with feathers, waste feed, and bedding materials (Singh *et al*., 2004). The production of broiler chickens in Chile in 2005 was about 500 000 Mg generating an estimated 300 000 Mg of PL (INE, 2005). This manure has traditionally been used as organic amendment for agricultural soils since it contains the macro and micronutrients required by plants, especially N and P (Kavouridou *et al*., 2008). However, when soil is amended with excessive amounts of PL, N from the litter can cause non-point water pollution due to ammonium nitrification when nitrate leaches to the groundwater or contaminates surface water (Sims and Wolf, 1994). Even in situations where PL is applied at normal rates (relationship of N rate with crop needs), nitrate leaching can occur when N is mineralized within a few days of being applied and is not rapidly taken up by a growing crop (Sims and Wolf, 1994). Thus, predicting the amount of plant-available N produced by PL amended soils is necessary for proper plant nutrition and protection of ground and surface water quality.

Another problem associated with long-term PL applications is the increase of P levels exceeding crop requirements (DeLaune *et al*., 2006). The N:P ratio of PL ranges from 0.6 to 1.0 (Evanylo and Mullins, 2000). However, this range of the N:P ratio is higher in crops, for example, 4.2 to 6.7 in corn (*Zea mays* L., Hirzel *et al*., 2007a) and 4.3 to 6.8 in wheat (*Triticum sativum* L., Kelley and Sweeney, 2007). Therefore, PL applications can raise available soil P levels (Sims *et al*., 2000) associated to an increase in soluble P which can contribute to the

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eutrophication of water by runoff and erosion processes.

Soils in Central-South Chile are volcanic in origin. They are characterized by amorphous clay (allophane) minerals and a high capacity of P fixation and organic matter stabilization (Matus *et al*., 2008) which can limit both the supply of P and N. These properties may reduce the adverse effects of excessive P application rates when using organic waste as a fertilizer (Mazzarino *et al*., 1997). Therefore, the application of PL under these conditions can be a sound environmental, economic, and agronomic alternative (Hirzel *et al*., 2007b).

The aim of this study was to determine and compare, under laboratory conditions, N mineralization rate and P, K, Zn, and Cu availability from two PL rates and conventional fertilization (CF) applied to a representative volcanic soil in Southern Chile.

MATERIALS AND METHODS

PL used in the study was collected fresh from a poultry farm in Rancagua, Chile with a 55-d poultry life cycle in a wood shaving litter. The soil used was an uppermost horizon sample (0-20 cm) from a field belonging to the Santa Rosa Research Station of the Instituto de Investigaciones Agropecuarias INIA, Quilamapu Regional Centre (36°36' S; 71°54' W), Chillán, Chile. This soil is classified as a Humic Haploxerands (Stolpe, 2006) and some soil characteristics and poultry litter are shown in Table 1.

PL or CF was mixed with the soil (sieved to 2 mm). Prior to this, PL was oven-dried at 45 ± 2 ºC and ground. The rate of applied PL was the one required to obtain a total of 200 kg N ha^{-1} along with an additional contribution of 130 kg P_2O_5 ha^{-1} and 132 kg K_2O ha^{-1} (low rate PL) derivate of PL chemical characteristics (Table 1), or 400 kg N ha^{-1}, 260 kg P_2O_5 ha^{-1}, and 264 kg K_2O ha^{-1} (high rate PL) estimates from the total content of these nutrients. CF was applied to obtain a total of 400 kg N ha^{-1} (as urea), 260 kg P_2O_5 ha^{-1} (as monocalcium phosphate), and 264 kg K_2O ha^{-1} (as potassium chloride) to obtain the same N, P_2O_5, and K_2O quantities of high rate PL. Samples of the mixed soils (100 g) were placed in 0.25 L plastic jars, moistened to 80% of their water accumulation capacity (equivalent to 0.33 bar), and incubated aerobically at 27 ± 2 ºC in a Köttermann 2771 space heater incubator (model D-3162, Uetze-Hänigsen, Germany) in the dark for 16 wk. The jars were left opened for 1 h and soil moisture was adjusted gravimetrically every week (Laos *et al*., 2000). For each sampling date (0, 1, 2, 4, 8, 12, and 16 wk), five replicates of the control (unamended) and the PL and CF amended soils were randomly selected for inorganic N and extractable P, K, Zn, and Cu analysis.

Table 1. Selected chemical and physical soil properties and poultry litter (PL) (data corrected in dry weight).

Parameter	Soil	PL
Bulk density, Mg m^{-3}	1.2	-
Total porosity, %	54.7	-
Gravimetric water retention at 33 kPa, %	30.0	-
Gravimetric water retention at 15 kPa, %	15.2	-
Dry matter, g kg^{-1}	-	759.2
pH, 1:2.5 (soil-water; PL-water)	6.5	8.1
EC, dS m^{-1}	-	7.4
Organic C, g kg^{-1}	35.5	335.0
TKN, g kg^{-1}	3.7	33.6
N-NO_3, mg kg^{-1}	5.8	7.8
N-NH_4, mg kg^{-1}	9.2	1.7
Total P, g kg^{-1}	-	9.5
Olsen-P, mg kg^{-1}	11.2	-
Total K, g kg^{-1}	-	16.8
NH_4OAc-K, mg kg^{-1}	85.8	-
Total Zn, mg kg^{-1}		190.0
Total Cu, mg kg^{-1}		180.0
DTPA-Zn, mg kg^{-1}	0.4	-
DTPA-Cu, mg kg^{-1}	1.7	-

EC: electrical conductivity; TKN: total Kjeldahl nitrogen; Total: *aqua regia* method (McGrath and Cunliffe, 1985); DTPA: diethylentriaminepentaacetic acid (Lindsay and Novell, 1978).

Net N mineralized (N_{min}) was calculated as inorganic N (NH_4^+-N + NO_3^--N) for each sampling time minus the quantity determined at time zero. Additionally, the N mineralization rate (which indicates the percentage of organic N mineralized) was calculated using the following Equation [1] (Preusch *et al*., 2002):

$$\% \text{ Nm} = (\text{Nf} - \text{Sf}) - (\text{Ni} - \text{Si})/\text{No} \times 100 \qquad [1]$$

where, Nf: PL or CF amended soil total N (mg NH_4^+-N + NO_3-N kg^{-1} soil) at final sampling time (t = 16 wk); Ni: PL or CF amended soil total N (mg NH_4^+-N + NO_3-N kg^{-1} soil) at initial sampling time (t = 0 wk); Sf: control soil total N (mg NH_4^+-N + NO_3-N kg^{-1} soil) at final sampling time; Si: control soil total N (mg NH_4^+-N + NO_3-N kg^{-1} soil) at initial sampling time; and No: initial organic N (mg kg^{-1}) added to soil.

Nitrogen mineralization potential (No, mg kg^{-1}) and rate constant (k, wk^{-1}) were estimated using the non-linear least squares method. This regression analysis assumed that N mineralization was a first order reaction (Tyson and Cabrera, 1993).

$$Nm_t = \text{No } [1-e^{(-kt)}]$$

where, Nm_t: cumulative organic N mineralized at any specific time (mg kg^{-1}); No: maximum amount of mineralizable organic N (mg kg^{-1}); k: rate constant; and t: incubation time (wk).

Soil inorganic N was extracted with 2 M KCl (ratio 1:5) (Keeney and Nelson, 1982) and calorimetrically analyzed using an autoanalyzer (Skalar, Sanplus, Breda, Netherlands). Results were expressed in terms of oven-dried soil weight. Soil extractable P, K, Cu, and Zn (together) were extracted with 0.5 M $NaHCO_3$ (ratio 1:10) (Olsen-EP), 1 N NH_4Ac (1:20) (NH_4Ac-EK), and 0.005 M diethylenetriaminepentaacetic acid (DTPA) (1:2) (Lindsay and Norvell, 1978) respectively. Soil and PL samples were analyzed following standard procedures at the INIA Laboratory (Methods of Soil Analysis, 1996a; 1996b).

The experimental design was the split-plot design where the treatment was the principal plot and time was the split-plot. Results were examined by ANOVA and the least significant difference (LSD) test ($P = 0.05$) was used for the differences obtained. Potential N mineralization and rate constant were determined using the non-linear Gauss-Newton method (Bonde *et al*., 1988) and calculations were performed using SAS software version 6.2 (SAS Institute, 1989).

RESULTS AND DISCUSSION

Poultry litter chemical properties had an alkaline pH with an electrical conductivity (EC) of 7.4 dS m^{-1} (Table 1). This EC value would not likely cause any salinity problems at applied rates, as occurred in field evaluations of corn crops (Hirzel *et al*., 2007a). Macronutrient concentrations were within the normal range for poultry waste reported by other authors (Rivero and Carracedo, 1999; Ekinci *et al*., 2000; Gascho *et al*., 2001; Sommer and Hutchings,

Table 2. Analysis of variance for the studied parameters.

Parameter		Sources of variability: Treatment (T)	Time	T * Time
Net N mineralized, mg kg^{-1}	DF	3	6	18
	MSE	113 332.6	35 762.5	2060.5
	P > F	< 0.0001	< 0.0001	< 0.0001
Available P, mg kg^{-1}	DF	3	6	18
	MSE	124.99	37.01	4.12
	P > F	< 0.0001	< 0.0001	< 0.0001
Available K, mg kg^{-1}	DF	3	6	18
	MSE	70 220.2	1871.5	340.9
	P > F	< 0.0001	< 0.0001	< 0.0001
Available Zn, mg kg^{-1}	DF	3	6	18
	MSE	0.835	0.075	0.003
	P > F	< 0.0001	< 0.0001	0.0001
Available Cu, mg kg^{-1}	DF	3	6	18
	MSE	1.242	0.129	0.009
	P > F	< 0.0001	< 0.0001	< 0.0001

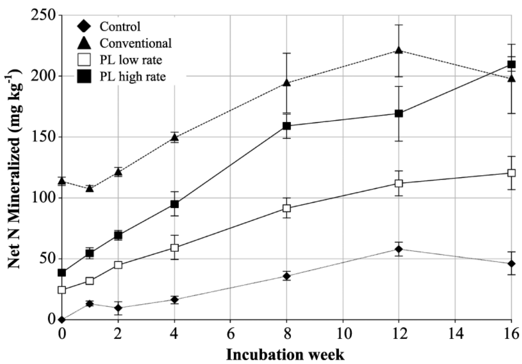
DF: degree of freedom; MSE: mean square error; P > F: probability values.

2001; Brink *et al*., 2002; Rees and Castle, 2002; Johnson *et al*. 2004; Singh *et al*., 2004; Sistani *et al*., 2004), whereas total Cu and Zn concentrations were more than two or even three times lower than those indicated by the above-mentioned authors, probably due to the dietary and sanitary treatments used for the chicken broilers.

Table 2 shows the ANOVA results for net N mineralized, available P, K, Zn, and Cu. There was a positive effect of incubation time for all the nutrients analyzed, thus generating interaction with each treatment evaluated. Moreover, the curves obtained presented similar behavior between treatments.

Figure 1 shows the net N mineralized in PL and CF amended soils. Initial mineralization of N from PL occurred earlier than for CF. Soil amended at both PL rates showed a constant increase in inorganic N over the 16-wk experimental period. In contrast, treatment with CF was associated with a slight immobilization of N during the first week and probable loss by NH_3 volatilization and with a trend towards net N mineralized over the following weeks. One possible explanation for this difference is that a significant proportion of organic N in PL is in the form of uric acid which is converted into urea (Sims and Wolf, 1993which is then converted into NH_4, NH_3, and NO_3. A slow conversion of uric acid into urea could lead to a small but steady increase in NH_4 (Figure 1).

The rapid release of N in the CF treatment could lead to NO_3 leaching if the fertilizer is applied to the soil when there is no crop demand. Since the application of PL did not result in a rapid accumulation of inorganic N, also indicated for chicken poultry manure by Ruiz Díaz *et al*. (2008), it poses a lower risk of NO_3 leaching than CF and a higher N uptake by the crop, as indicated by Hirzel *et al*. (2007a) for corn field experiments. Net N mineralized recorded in the CF treatment during the 4th to 16th weeks was similar to that obtained in soil amended with the low rate PL treatment. Net N mineralized was higher with the high rate PL treatment over the entire incubation period as a consequence of the higher proportion of organic N at the start of the experiment with respect to the CF treatment. Conventional fertilization was associated with high N availability as NH_4 prior to the start of incubation.



Vertical bars are standard errors.

Figure 1. Net N mineralized (NH_4^+-N + NO_3^--N) over the incubation period for the control, conventional fertilizer (CF), and low and high rate poultry litter (PL) treatments.

Net N mineralization rate, calculated as the percentage of added total N, was higher in the two PL treatments (61 and 62% for the high and low rates, respectively) compared to the CF treatment (23%), and the values obtained were similar to those indicated by Ruiz Díaz *et al*. (2008). This low rate obtained in the CF treatment is attributed to the fact that an important fraction of ureic N was hydrolyzed over a short time period before the start of the incubation period. With regards to PL treatments, both high and low rates produced similar percentages and the low rate supplied much less inorganic N than the high rate due to its lower total N content per pot. Percentage organic N mineralized from PL was relatively high, thus indicating that it probably contained organic N that was relatively easy to decompose (material applied was uncomposted PL). Similar results were reported by Preusch *et al*. (2002) who found N mineralization rates for fresh PL ranging from 42 to 64%, while Tyson and Cabrera (1993) indicated lower rates for incubations of uncomposted broiler litter in a loamy sand and in a fine sandy loam (25 and 37%).

The predominant form of inorganic N was NH_4-N when incubation started (t = 0). Nitrification gradually increased and NO_3-N was the predominant form at the end of incubation (t = 16) (Table 3). Similar results were reported by Laos *et al*. (2000) when working with different types of organic amendment. CF showed a marked initial inorganic N content, supporting the earlier explanation of N immobilization observed in this treatment during the first week.

Table 3. Initial and final NO_3-N and NH_4-N contents in the soil for the control, conventional fertilizer (CF), low rate of poultry litter (low rate PL), and high rate of poultry litter (high rate PL) treatments.

Treatments	NO_3-N t = 0	NH_4-N t = 0	NO_3-N t = 16	NH_4-N t = 16
	mg kg^{-1}			
Soil	5.20	13.01	59.90	3.64
Soil + low rate PL	5.83	35.82	133.9	3.93
Soil + high rate PL	5.32	50.63	201.7	2.89
Soil + CF	4.85	126.03	210.4	4.62

t=0 incubation started; t=16 end of incubation.

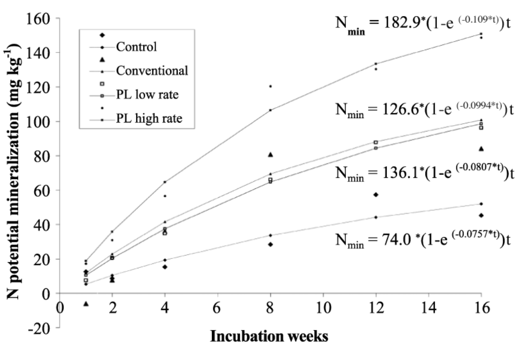
Net N mineralization in CF strongly increased until the 12th week of incubation (Figure 1) and then decreased over time, except for PL treatments. A similar effect was reported by Whalen *et al*. (2000) and Hartz *et al*. (2000). For that matter, the use of CF presented a higher N availability in relation to the PL treatments during the first 12t wk of incubation, fact which would limit its subsequent availability increase. In contrast, PL presented minor initial availability of N pools (Sims and Wolf, 1994) which contribute to increase N availability at the end of the evaluated incubation period.

Table 4 and Figure 2 show N mineralization potentials obtained by fitting the one-pool model to cumulative N mineralized over time. Values indicate that most mineralizable N in both PL and CF had been released by the 16th week. As expected, N mineralization potential was higher for high rate PL, but mineralization rate constants were similarly low for all treatments, suggesting a relatively slow release of N over time compared with results obtained by Ruiz Díaz *et al*. (2008).

Table 4. Nitrogen mineralization potential (No) in the soil and rate of mineralization (*k*) per week, calculated by nonlinear regression assuming first order kinetics for the control, conventional fertilization (CF), low rate of poultry litter (low rate PL), and high rate of poultry litter (high rate PL) treatments.

Treatments	No	*k*
	mg N kg^{-1}	
CF	126.6 (32.8)	0.0994 (0.0470)
Low rate PL	136.1 (18.7)	0.0807 (0.0183)
High rate PL	182.9 (20.8)	0.1090 (0.0239)
Soil	74.0 (22.9)	0.0757 (0.0375)

Value in parenthesis standard error.

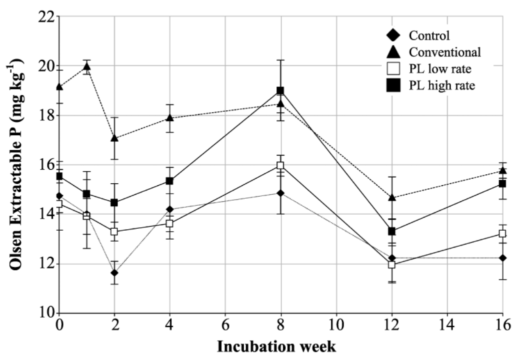


t = time in weeks.

Figure 2. Potential N mineralization, (N_{min}) calculated by nonlinear regression assuming first order kinetics for the control, conventional fertilizer (CF), and low and high rate poultry litter (PL) treatments.

During the first 4 wk, Olsen-P content of CF treated soil was higher than that of either of the two PL treated soil (Figure 3). Values were similar for high rate PL and CF after week 8. The highest values were detected in week 8 in both PL treatments, while the highest value was obtained during the first week in the CF treatment. With the exception of the 8th and 16th weeks, more Olsen-P was extracted from the CF treatment, which is possibly due to the relatively strong solubility of the form of P in the fertilizer. Rich in total P, PL released less P. Different forms of organic P include non-labile phospholipids, inositols, and orthophosphate diesters which are more resistant to degradation (Dao, 2004; Verma *et al*., 2005; Silveira *et al*., 2006). This could explain the low extractable P values obtained. However, none of the values obtained in any treatment were high, suggesting a strong fixation and/or adsorbance capacity of volcanic soil. Similar results were reported by Oehl *et al*. (2004) working with organic and inorganic P sources incubated in different soils. At the end of the current incubation, extractable P in CF, low rate PL, and high rate PL treatments were higher than the control with 3.52, 0.95, and 2.98 mg kg^{-1}, respectively. Similar results were reported by Hirzel and Walter (2008) for soil incubations in field conditions with poultry litter and conventional fertilization. These results support high P fixation capacity of the soil under study. In relation to CF, P fertilizer value of PL for the same P rate was 84.7% at the end of the incubation period.

NH_4Ac-EK showed relatively stable behavior over the incubation period (Figure 4); values obtained for all treatments were similar and increasing in all cases. The highest value was obtained with the high rate PL. This suggests that PL had a somewhat higher K availability



Vertical bars are standard errors.

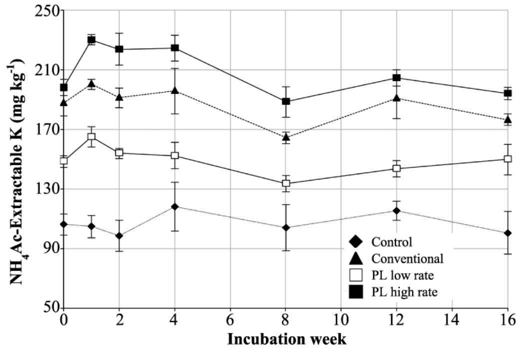
Figure 3. Soil Olsen-extractable P (Olsen-EP) over the incubation period for the control, conventional fertilizer (CF), and low and high rate poultry litter (PL) treatments.

than CF when both were applied at the same rate (Brady and Weil, 1996). At the end of incubation, NH_4Ac-EK content was higher than in the control with 93.5, 76.0, and 49.3 mg kg^{-1} in the high rate PL, CF, and low rate PL treatments, respectively. Added K was retained in the soil in all treatments. This retention was high at mid-incubation which could be due to less available K as a result of soluble K fixation by micaceous clay minerals characteristic of volcanic ash soils (Joussein *et al*., 2004).

DTPA-EZn and ECu values obtained in both PL treatments were higher than those obtained in the CF treatment (Figures 5 and 6). These increases in available soil Zn and Cu represent the typical expected response. Similar results have been reported by other authors for both incubation and field experiments in which different organic amendments were applied to different types of soil (Jackson *et al*., 2003; Pascual *et al*., 2004; Sullivan *et al*., 2006; Walter *et al*., 2006a; 2006b). In general, all treatments showed similar behavior during the first 2 wk of incubation. DTPA-EZn and ECu contents fell, probably due to their fixation in organic and/or inorganic soil compounds. Releases of these elements were observed during week 8 followed by another decrease in their values, and, a slight increase later. Concentration of Zn and Cu in the CF treatment was lower than in the control, probably due to the higher release of organic compounds generated by the higher biological activity stimulation in CF, which presents Cu and Zn fixation or stabilization capacity (Glendinning, 2000), or due to precipitation reactions associated to hydroxides generated by urea hydrolysis (Basta and Tabatabai, 1992) or cationic exchange reactions (Silva, 2004) generated by K application in CF. Nevertheless, values obtained over the incubation period were low as a consequence of the low concentration of these elements in applied PL (Table 1). Maximum values obtained were 0.72 and 1.32 mg kg^{-1} for Zn and Cu, respectively, much lower than the values obtained by Jackson *et al*. (2003), values corresponding to a medium level of availability for agricultural crops according to Havlin *et al*. (1999).

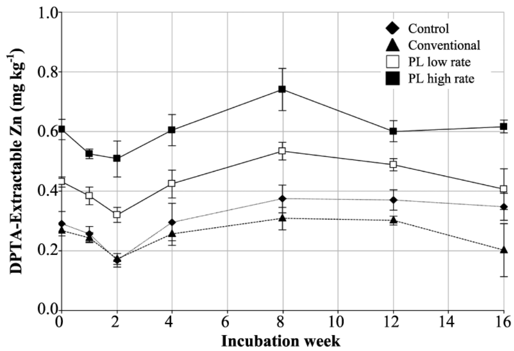
CONCLUSIONS

This study showed that PL rates applied to a Chilean volcanic soil provided a source of available N, P, and K quantitatively similar to CF in incubation experiments and initial N availability was higher with CF. N mineralization rate was also higher with PL. On the other hand, Zn and Cu concentrations generated during incubation were higher with the use of PL use than CF.



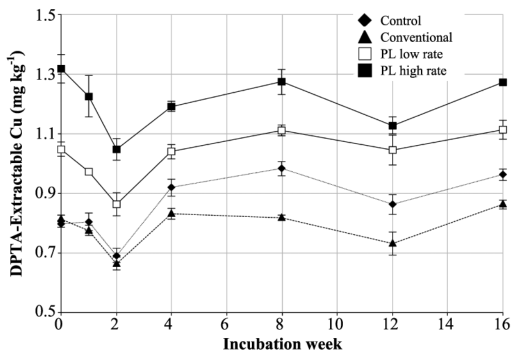
Vertical bars are standard errors.

Figure 4. Soil NH_4Ac-extractable K (NH_4Ac-EK) over the incubation period for the control, conventional fertilizer (CF), and low and high rate poultry litter (PL) treatments.



Vertical bars are standard errors.

Figure 5. Soil diethylenetriaminepentaacetic acid extractable Zn (DTPA-EZn) over the incubation period for the control, conventional fertilizer (CF), and low and high rate poultry litter (PL) treatments.



Vertical bars are standard errors.

Figure 6. Soil diethylenetriaminepentaacetic acid extractable Cu (DTPA-ECu) over the incubation period for the control, conventional fertilizer (CF), and low and high rate poultry litter (PL) treatments.

RESUMEN

Mineralización de nitrógeno y liberación de nutrientes en un suelo volcánico enmendado con cama de broiler. En sistemas agrícolas que utilizan dosis correctas de insumos, la cama de broiler (CB) puede constituir una fuente económica de nutrientes para las plantas. El objetivo de este trabajo fue estudiar el efecto de CB en dos dosis y fertilización convencional (FC) sobre la mineralización de N y la disponibilidad de P, K, Zn y Cu en un suelo volcánico de la zona centro-sur de Chile en condiciones controladas. Una incubación aeróbica fue realizada durante un período de 16 semanas. Las tasas de mineralización de N fueron mayores con los tratamientos de CB utilizados (61,5%) respecto al uso de FC (23%). La FC fue asociada con una alta disponibilidad de N previa al inicio de incubación y leve inmovilización durante la primera semana, debido a una rápida conversión de urea en NH_4, el cual fue temporalmente inmovilizado por la biomasa microbiana. Entre inicio y término del período de incubación la concentración de P extractable Olsen fue generalmente mayor con la FC. Debido a la alta capacidad de fijación del suelo, los valores de P extractable fueron levemente incrementados, lo cual sugiere que la mineralización de CB es asociada con un bajo riesgo de contaminación en suelos volcánicos. En la CB la disponibilidad de K, Zn y Cu fue mayor que la FC, sin embargo, los valores para Cu y Zn fueron medios en relación a la referencia usada en suelos agrícolas. Para las condiciones de este estudio, los resultados sugieren que la CB sería una alternativa a los fertilizantes convencionales.

Palabras clave: incubación aeróbica, cama de broiler, mineralización de nitrógeno, disponibilidad de nutrientes, suelo volcánico.

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