EVOLUTION OF NUTRIENTS AND SOIL CHEMICAL PROPERTIES OF SEVEN ORGANIC FERTILIZERS IN TWO CONTRASTING SOILS UNDER CONTROLLED CONDITIONS

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ABSTRACT

Organic food production has increased the demand for organic supplies in agriculture. Organic fertilizers are known to have an effect on crop and soil properties, but this effect has been little studied. This research evaluated the effect of seven nitrogen fertilizers allowed for use in organic production and one conventional fertilization treatment adjusted to a similar dose of total nitrogen (N), on chemical properties of two soils of contrasting physicochemical properties (sandy loam Mollisol and silty loam Andisol) incubated under aerobic conditions and controlled 6 times over 112 d. Treatments were: Compost (CO), Fertil (F), Purely Grow (PG), Purely Lysine (PL), Blood meal (BM), Lupine meal (LM), Sodium nitrate (SN), conventional fertilization (CF), and a control without fertilization (CT). The experiment was conducted in a split-plot design for each soil. The results showed that the fertilizers affected soil pH, salinity (electrical conductivity, EC), and the concentrations of phosphorus (P), potassium (K), calcium (Ca), magnesium (Mg) and sulfur (S). In general, the highest values of pH, available P, and exchangeable K, Ca and Mg were obtained using CO in both soils, whereas PL reported the lowest values for most parameters evaluated. The evolution of each parameter over time showed interactions with the fertilization treatment, with a steady decrease in pH and an increase in EC in both soils. Differences in the average values of chemical properties during incubation with respect to their initial values were related to the physicochemical and organic characteristics of each soil.

Key words: Nitrogen, organic fertilizers, soil physical-chemical properties, sulfur, nutrient dynamic, phosphorus, ash volcanic, sandy loam.

INTRODUCTION

Organic production has significantly increased worldwide mainly because of the nutritional quality and safety of organic food, the positive effects on the environment, and economical profits for the farmer (Wang et al., 2008; Karanatsidis and Berova, 2009; Epule et al., 2015). Compared to conventional production, organic farming does not have a large number of tools for controlling pathogens or weeds, while fertilization sources are also limited. In this sense, one of the major concerns in organic farming (for both annual and perennial crops) is nitrogen supply as this is closely related to crop productivity (Miller et al., 2006).

Nitrogen organic fertilizers include: compost, green manures, natural fertilizers, residues from biological processes, fermented in solid-state (Farinas, 2015), bio-organic fertilizers (Chen et al., 2011; Zhao et al., 2011), poultry manure (Hirzel et al., 2010), lupine meal (Li et al., 2009; Li et al., 2015), and blood meal (Ciavatta et al., 1997). These can supply nutrients either through mineralization processes or by releasing them directly into the soil (Tamada, 2004; Hanson, 2006; Bañados et al., 2012; Hirzel et al., 2012; Retamales and Hancock, 2012), resulting in a key point to consider when choosing an organic fertilizer based on the physicochemical properties of the soil.

As these nitrogen sources used as organic fertilizers have different physicochemical characteristics, they can affect soil ecosystems, as well as the chemical, physical, and biological properties of the soil. Therefore it is important to know the impact of organic fertilizers on soil properties in order to determine their potential benefits or adverse effects in organic farming (Pinochet et al., 2000; Cayuela et al., 2009). For example, soil pH can be affected by Al and H concentrations, and also the availability of exchangeable bases, such as Ca, Mg, K, and Na (Castro and Crusciol, 2013; Fageria and Nascente; 2014; Fageria et al., 2014; Moreira et al., 2015). Other soil chemical properties that can be affected by the addition of different nutritional sources are essential nutrients, such as N, P, S and some micronutrients (Hirzel et al., 2007; 2010; Castro and Crusciol, 2013).

The objective of this study was to evaluate the effect of seven organic fertilizers and a conventional source on soil pH, salinity, and the chemical properties of two soils with contrasting characteristics (from the central-south and south of Chile), using fertilization under controlled conditions.

MATERIALS AND METHODS

Soils

Soil samples were collected from two different locations of the central-south and south of Chile, corresponding to "Virquenco", Santa Fe soil series (37°27'35,81'' S; 72°30'02,04'' W) of sandy loam texture (Aquic Haploxeroll); and "Villarrica", Villarrica soil series (39°11'53'' S, 72°15'38'' W) of silty loam texture (Acrudoxic Fulvudand) (CIREN, 1999; 2002; USDA, 2014). Soil samples were collected from 0 to 0.2 m of soil depth, and transported in bags with insulation to the Soil Laboratory of the Chilean Agriculture Research Institute. Soil samples were dried and sieved to 2 mm. The physicochemical properties of the soils are shown in Table 1.

Fertilization treatments

The fertilization treatments were: 1) No fertilizer application (CT) as indicator of soil nutrient supply; 2) Compost of plant origin (CO) ($N:P_2O_5:K_2O$; 0.84:0.80:0.45 and C/N ration 11.96), powder formulation; 3) Fertil (F) protein Nitrogen from enzymatic hydrolysis ($N:P_2O_5:K_2O$; 12:0:0 and C/N ratio 7.60), pellet; 4) Purely Grow (PG) plant-based proteins and hydrolyzed fish protein concentrate ($N:P_2O_5:K_2O$;13.1:0.0:4.0 and C/N ratio 6.20), liquid; 5) Purely Lysine (PL) plant-based proteins and hydrolyzed fish protein concentrate ($N:P_2O_5:K_2O$; 15.5:0.0:0.0 and C/N ratio 5.80), pellet; 6) Blood meal (BM) ($N:P_2O_5:K_2O$; 14.5:0.27:0.6 and C/N ratio 3.74), powder; 7) Lupine meal (LM) ($N:P_2O_5:K_2O$;7.93:0.90:1.00 and C/N ratio 5.67), ground grain; 8) Sodium nitrate (SN) ($N:P_2O_5:K_2O$; 15.0:0.0:9.0), granules; and 9) conventional fertilization (CF) with urea, triple superphosphate and potassium sulphate ($N:P_2O_5:K_2O$; 45.0:15.8:29.7), granules. Treatments 2, 3, 4, 5, 6, 7 and 8 are fertilizers allowed for use in organic production; treatments 3, 4, 6 and 8 meet the requirements of the National Organic Program (NOP) (USDA, 2017). The total N rate applied to all the treatments, except CT, was equivalent to 100 mg kg^{-1}.

Soil incubation

Samples of each soil (100 g) were placed into 0.25 L plastic jars, moistened to 80% of their water holding capacity (equivalent to 0.33 bar) and incubated under controlled conditions at 25 ± 2ºC in a refrigerated incubator (Velp Scientifica, model FOC 225E, UsmateVelate, Italy) for 16 wk. The jars were left opened for 1 h, while soil moisture was adjusted gravimetrically two times on a weekly basis (Hirzel et al., 2010). Four replicates of each fertilization treatment were randomly collected at each sampling date (0, 1, 2,

Table 1. Physicochemical properties of Virquenco and Villarrica soils (0-20 cm) prior to the experiment.

Parameter	Soil	
	Virquenco	Villarrica
Clay, %	8.3	23.0
Silt, %	43.2	57.6
Sand, %	48.5	19.4
Water retention at 0.33 bar, %	19.15	83.89
Water retention at 15.00 bar, %	12.09	56.45
Bulk density, g cc^{-1}	1.31	0.56
pH, soil:water 1:5	6.55	5.72
Organic matter, g kg^{-1}	42.2	282.7
Electrical conductivity, dS m^{-1}	0.07	0.13
Available N, mg kg^{-1}	23.4	76.0
Available P, mg kg^{-1}	14.0	11.8
Exchangeable K, cmol$_+$ kg^{-1}	0.42	0.36
Exchangeable Ca, cmol$_+$ kg^{-1}	5.97	10.08
Exchangeable Mg, cmol$_+$ kg^{-1}	1.58	0.85
Exchangeable Na, cmol$_+$ kg^{-1}	0.34	0.08
Exchangeable Al, cmol$_+$ kg^{-1}	0.03	0.09
Available Fe, mg kg^{-1}	50.27	69.15
Available Mn, mg kg^{-1}	2.82	3.89
Available Zn, mg kg^{-1}	0.71	3.78
Available Cu, mg kg^{-1}	1.48	1.08
Available B, mg kg^{-1}	0.30	0.38
Available S, mg kg^{-1}	3.0	16.1

4, 8 and 16 wk) for analysis of pH, EC (electrical conductivity), P, K, Ca, Mg and S.

Soil measurements

Chemical properties were analyzed using the method described by Sadzawka et al. (2006). Soil pH was measured in a 1:2.5 soil/water solution ratio with a pH electrode. Soil organic matter (OM) was determined by the Walkley-Black wet digestion method. Electrical conductivity was evaluated using a conductivity cell (soil:water ratio 1:5). The general characterization considered the measurement of soil available N (NO$_3$-N and NH$_4$-N) that was extracted with 2 mol L^{-1} KCl and determined by colorimetry in a Skalar autoanalyzer (segmented flux spectrophotometer). Available P was determined by 0.5 mol L^{-1} NaHCO$_3$ (Olsen-P) using ascorbic acid-molybdate. Exchangeable Ca, Mg, K, and Na were determined using 1 mol L^{-1} NH$_4$OAc extraction followed by flame spectroscopy, that is, absorption (Ca and Mg) and emission (K and Na). The soil exchangeable Al concentration was determined by 1 mol L^{-1} KCl extraction with absorption spectroscopy. Soil Fe, Mn, Zn, and Cu concentrations were determined in di-ethylene-triamine-penta-acetic acid (DTPA) extract by atomic absorption spectrometry (AAS) (Lindsay and Norvell, 1978). Boron (B) was determined by colorimetry in a solution obtained with hot water. Available S in the soil was extracted with calcium phosphate and determined by turbidimetry. Finally, soil texture was analyzed by the Bouyoucus hydrometer method (Bouyoucos, 1962) and bulk density was determinate by the cylinder method.

Statistical analysis

Each soil was analyzed separately due to their contrasting characteristics (Table 1). The experiment was conducted using a split-plot design. The main plot was the incubation time, while the sub-plot was the fertilization treatment. ANOVA, mean separation test (Tukey), and separation of interactions by contrasts were performed at the 5% significance level, using SAS 8.0 (SAS Institute, Cary, North Carolina, USA). Contrast analyses were used to separate the interactions between incubation time and fertilization treatment.

RESULTS AND DISCUSSION

Soil physicochemical properties

As can be observed in Table 1, clay content was lower in Virquenco soil. Villarrica soil had the highest silt content and the lowest sand content. Both soil series had a slightly acid pH and low salinity (as electrical conductivity, EC). Sulfur and Zn were deficient in Virquenco soil, while Boron was deficient in both soils. The other chemical properties of these soils are not restrictive for most of the crops (Hossain et al., 2015).

Virquenco soil

Incubation time (T) had an effect on all the parameters evaluated ($p < 0.01$) (pH, EC, P, K, Ca, Mg, and S) (Table 2), while fertilization treatment (F) affected ($p < 0.01$) pH, EC, P, K, Ca, and S (Table 2). These parameters also showed T∗F interaction ($p < 0.01$ and $p < 0.05$) (Table 2). Changes over time for pH, EC, available P, exchangeable K, exchangeable Ca, exchangeable Mg and available S are presented in Figs.1a, 2a, 3a, 4a, 5a, 6a and 7a, respectively. The effect of each fertilization treatment, as observed in the average value recorded for each parameter during the incubation time, is presented in Table 3.

The highest pH value was obtained in CO ($p < 0.05$) (Table 3), which might be an effect of the complexation of exchangeable Al in the OM of the compost (Damatto Júnior et al., 2006). A decrease in soil pH was observed in all the treatments with respect to CO (Table 3), while CT was higher than the other treatments, except BM. There were no differences between F, PG, LM, CF and BM ($p > 0.05$), which were all higher

Table 2. Significance levels for the parameters evaluated in the experiment.

Parameter	Virquenco soil			Villarrica soil		
	Incubation time (T)	Treatment (F)	Interaction T∗F	Incubation time (T)	Treatment (F)	Interaction T∗F
pH	**	**	**	**	**	**
EC	**	**	**	**	**	**
P	**	**	**	**	**	**
K	**	**	*	**	**	**
Ca	**	**	**	**	ns	*
Mg	**	ns	**	**	**	**
S	**	**	**	**	**	**

Significances: * $p < 0.05$; ** $p < 0.01$; ns: non-significant results.

Table 3. Contrast analysis between fertilization treatments for each soil as the average value of all the evaluation period.

Virquenco soil	CT	CO	F	PG	PL	BM	LM	SN	CF
pH, soil:water 1:2.5	6.35b	6.47a	6.25c	6.24cd	6.08e	6.30bc	6.27c	6.18d	6.24cd
EC, dS m⁻¹	0.11g	0.11g	0.16e	0.20c	0.24b	0.16e	0.14f	0.26a	0.18d
Available P, mg kg⁻¹	14.1c	20.2a	13.9cd	13.8cd	13.5d	13.8cd	13.9cd	13.7cd	15.8b
Exchangeable K, mg kg⁻¹	168d	239a	167d	195c	165d	167d	176d	215b	214b
Exchangeable Ca, cmol₊ kg⁻¹	6.4ab	6.8a	6.5ab	6.6ab	6.1b	6.0b	6.0b	6.0b	6.3ab
Exchangeable Mg, cmol₊ kg⁻¹	1.85a	1.96a	1.77a	1.80a	1.70a	1.67a	1.66a	1.72a	1.83a
Available S, mg kg⁻¹	1.70b	1.98b	3.53b	1.75b	1.48b	1.67b	1.81b	1.70b	24.3a
Villarrica soil	CT	CO	F	PG	PL	BM	LM	SN	CF
pH, soil:water 1:2.5	5.59a	5.55ab	5.50c	5.47cd	5.43d	5.50bc	5.49c	5.50bc	5.51bc
EC, dS m⁻¹	0.27e	0.29de	0.33bc	0.40a	0.39a	0.34bc	0.32cd	0.40a	0.36b
Available P, mg kg⁻¹	11.9bc	11.9bc	11.7cd	11.5d	11.7cd	11.8bcd	11.7cd	12.0b	12.4a
Exchangeable K, mg kg⁻¹	129de	141cd	129de	153bc	126e	135de	134de	177a	164b
Exchangeable Ca, cmol₊ kg⁻¹	10.5a	10.6a	10.7a	10.5a	10.8a	11.0a	10.5a	10.7a	11.0a
Exchangeable Mg, cmol₊ kg⁻¹	0.87cde	0.98a	0.88cde	0.85de	0.87cde	0.88cd	0.83e	0.90bc	0.93ab
Available S, mg kg⁻¹	26.4ab	25.2abc	24.4abcd	21.7de	19.9e	23.6bcd	22.9cd	24.3abcd	26.6a

Different letters in the same row indicate significant differences between treatments according to Tukey's test ($p < 0.05$). Abbreviations: CT: Control without fertilization; CO: Compost; F: Fertil; PG: Purely Grow; PL: Purely Lysine; LM: Lupine Meal; BM: Blood Meal; SN: Sodium Nitrate; CF: Conventional Fertilization.

than PL (p < 0.05). The lowest pH value obtained with the use of PL could be associated with a higher ammonia release; ammonia is nitrified afterwards, reducing soil pH, as well as the stimulant effect of N over the mineralization of organic matter, and therefore, organic acid production (Fageria and Nascente, 2014). Values obtained (Fig. 1a) showed a decrease in soil pH during the incubation time except in BM, PL and CO, which showed an increase at 7 d incubation. All these changes could be related to chemical reaction processes involved in mineralization and nutrient release (Kirchmann et al., 2007; Hirzel et al., 2010; Fageria and Nascente, 2014). These results differ from those reported by Bulluck et al. (2002), who found that soil pH increased with organic amendments due to Al complexation and an increase in basic cations in the soil solution. Al content in Virquenco soil was very low (Table 1).

The highest EC value (Table 3) was recorded in SN (p < 0.05), which can be explained by its Na content. The second highest EC value was obtained in PL (p < 0.05), which could be associated with

its ammonia concentration. Differences were also observed between the other treatments, while the lowest value was obtained in CT and CO. The lack of fertilization in CT and the slow rate of nutrient release described for CO can account for this situation (Cooperband et al., 2002). In general, the EC was low in all the treatments, which is considered as having no effects in agriculture. However, these results are not consistent with those reported by Jiménez-Becker et al. (2010), who described an increase in EC when compost of manure was used, compared to compost of plant origin and a control without compost. Regarding EC (Fig. 2a), all treatments had an increase during the incubation time, associated with organic matter mineralization and release of nutrients (Kirchmann et al., 2007; Hirzel et al., 2010; Fageria and Nascente, 2014). All treatments showed interaction between incubation time and fertilization treatment (Table 2); this could be related to different rates of N release and other nutrients (Li et al., 2015; Muñoz-Vega et al., 2016).

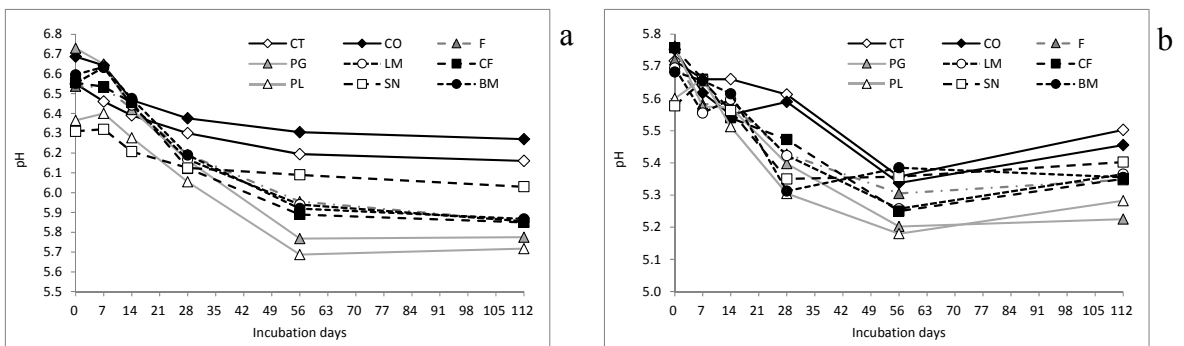The highest available P concentration was observed in CO (p < 0.05) (Table 3), with

Fig. 1. Evolution of soil pH during the incubation time. a) Virquenco soil; b) Villarrica soil.
Abbreviations: CT: Control without fertilization; CO: Compost; F: Fertil; PG: Purely Grow; PL: Purely Lysine; LM: Lupine Meal; BM: Blood Meal; SN: Sodium Nitrate; CF: Conventional Fertilization.
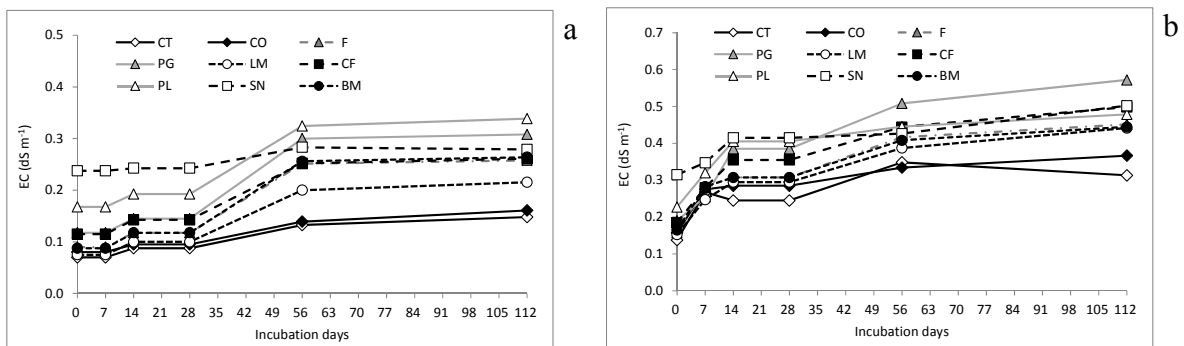

Fig. 2. Evolution of soil electrical conductivity (EC) during the incubation time. a) Virquenco soil; b) Villarrica soil.
Abbreviations: CT: Control without fertilization; CO: Compost; F: Fertil; PG: Purely Grow; PL: Purely Lysine; LM: Lupine Meal; BM: Blood Meal; SN: Sodium Nitrate; CF: Conventional Fertilization.

differences between the other treatments. On the other hand, the lowest value was obtained in PL, BM, SN, LM, PG, F and PL (p < 0.05). All treatments had an average P concentration similar to that recorded at the beginning of the experiment (Table 1), except CO since this treatment showed an increase of 6 mg kg^{-1} with respect to the initial concentration. This increase in P concentration could be related to reactions of anionic exchange with organic compounds derived from compost mineralization (Eghball, 2002; Eghball et al., 2004). The evolution of P concentration (Fig. 3a) showed an increase until the 28-d in all treatments, followed by a decrease. In general, all treatments had small changes during the incubation time, with differences between times shown by the interactions between incubation time and fertilization treatment (Table 2). For treatments with high organic fraction, such as CO, LM and BM, these results do not agree with those of Herencia et al. (2007) and Silva et al. (2016), who proposed that the use of organic amendments increases P solubility, which could respond to an effect of organization of P associated with biological activity and formation of complex of organic compounds.

The highest K concentration was observed in CO (p < 0.05) (Table 3), followed by SN and CF (p < 0.05), with no differences between CF and PG (p > 0.05). The lowest K concentrations were obtained in treatments CT, F, LM, PL and BM, with no differences between them (p > 0.05). The higher K concentration in treatments CO, SN and CF could be explained by their K/N ratio 0.54, 0.60, and 0.66, respectively. Increases in K concentration using compost have been previously described by other authors (Jiménez-Becker et al., 2010; Bustamante et al., 2011). Regarding the initial K concentration of the soils (Table 1), it was observed that the CO, PG, SN and CF resulted in an increase in K concentration (Table 3), with some changes during the incubation time (Fig. 4a) as confirmed by the interaction between incubation time and fertilization treatment (Table 2). This increase in K concentration could respond to reactions of desorption from the clay fraction.
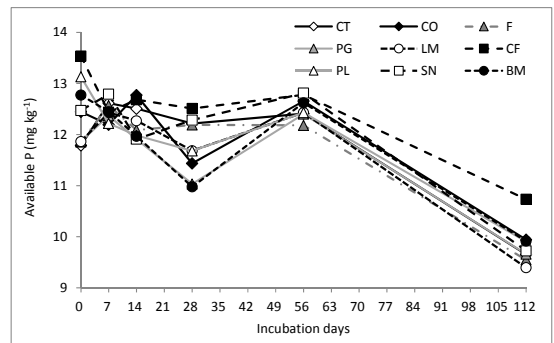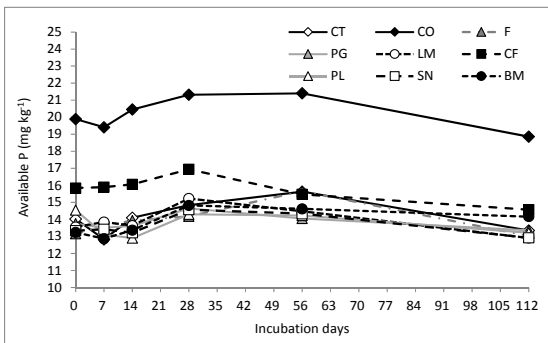

Fig. 3. Evolution of soil available phosphorous (P) during the incubation time. a) Virquenco soil; b) Villarrica soil.
Abbreviations: CT: Control without fertilization; CO: Compost; F: Fertil; PG: Purely Grow; PL: Purely Lysine; LM: Lupine Meal; BM: Blood Meal; SN: Sodium Nitrate; CF: Conventional Fertilization.
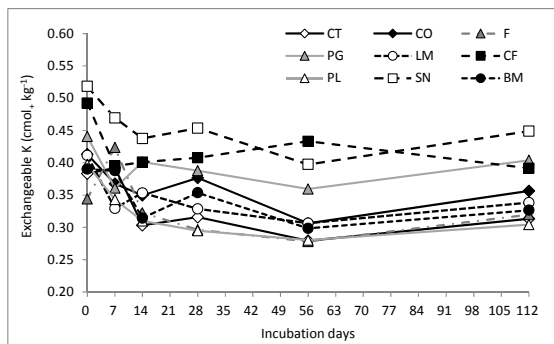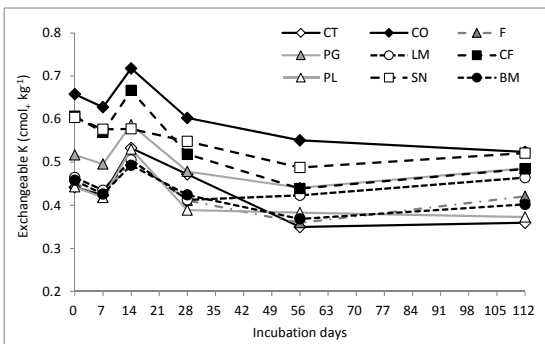

Fig. 4. Evolution of soil exchangeable potassium (K) during the incubation time. a) Virquenco soil; b) Villarrica soil.
Abbreviations: CT: Control without fertilization; CO: Compost; F: Fertil; PG: Purely Grow; PL: Purely Lysine; LM: Lupine Meal; BM: Blood Meal; SN: Sodium Nitrate; CF: Conventional Fertilization.

Ca concentration showed small differences between treatments (Table 3 and Fig. 5a). Few changes were observed during the incubation time (Fig. 5a) as shown in the interaction analysis (Table 2). The highest average Ca concentration was obtained with CO, which was different from values of PL, BM, LM and SN (p < 0.05), with no differences between these treatments (p > 0.05). Ca concentrations during the incubation time (Fig. 5a) increased at 7-day with the use of LM, PG, CF and PL, but it showed a sharp decrease in LM between 56 and 112 d. These changes over the time have been reported by Hirzel et al. (2016) for short incubation times with different calcium fertilizers in two soils of loam and clay loam texture.

No differences were found between treatments (p > 0.05) for Mg (Table 3). In general, values were slightly higher than the initial concentrations (Table 1). Regarding the evolution of Mg concentration, some changes were observed (Fig. 6a) as demonstrated by the interaction between incubation time and fertilization treatment (Table 2). The biggest changes were observed during

the first 28 d incubation (Fig. 6a). Variations in the concentrations of either exchangeable or available Mg during short incubation periods with different soils and fertilization treatments have been previously reported by Hirzel et al. (2016), and they have been associated with variations in the soil pH as an effect of a higher desorption of cations under a reduction of soil pH during the incubation period (Havlin et al., 1999; Fageria and Nascente, 2014).

CF had the highest concentration of S (p < 0.05), with no differences between the other treatments (p > 0.05) (Table 3). The higher S concentration in CF was previously discussed and explained by the S concentration in the potassium sulfate used as fertilizer. In addition, the absence of differences between the other treatments might be explained by the low or no S content of each fertilization treatment. The average S value in all treatments, except CF and F, was slightly lower than the initial concentration (Table 1). Regarding the evolution of S concentration, all treatments, except CF, showed small changes
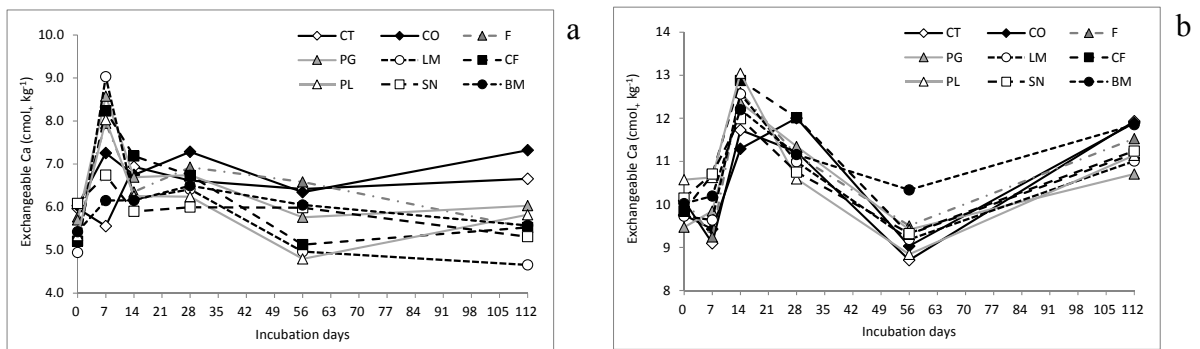

Fig. 5. Evolution of soil exchangeable calcium (Ca) during the incubation time. a) Virquenco soil; b) Villarrica soil.
Abbreviations: CT: Control without fertilization; CO: Compost; F: Fertil; PG: Purely Grow; PL: Purely Lysine; LM: Lupine Meal; BM: Blood Meal; SN: Sodium Nitrate; CF: Conventional Fertilization.
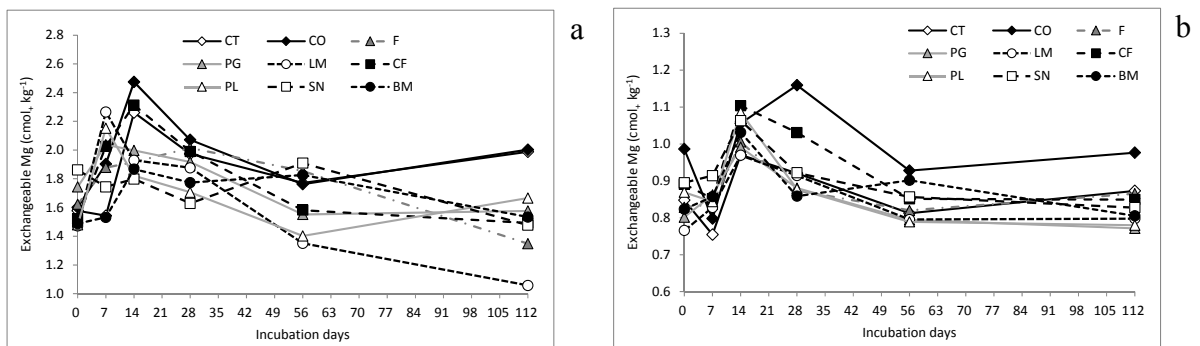

Fig. 6. Evolution of the soil exchangeable magnesium (Mg) during the incubation time. a) Virquenco soil; b) Villarrica soil.
Abbreviations: CT: Control without fertilization; CO: Compost; F: Fertil; PG: Purely Grow; PL: Purely Lysine; LM: Lupine Meal; BM: Blood Meal; SN: Sodium Nitrate; CF: Conventional Fertilization.

during the incubation time, while CF had a strong decrease from 0 to 7 d, followed by an increase until the 28-d (Fig. 7a). Most of the treatments recorded a decrease until the 56-d (Fig. 7a), and this situation along with the changes observed during all the incubation time are demonstrated by the interaction between incubation time and fertilization treatment (Table 2).

Villarrica soil

Incubation time (T) had an effect ($p < 0.01$) on all parameters evaluated (pH, EC, P, K, Ca, Mg, and S) (Table 2). Fertilization treatment (F) affected ($p < 0.01$) most of the parameters in Villarrica soil (pH, EC, P, K, Mg, and S) (Table 2). These parameters were also affected by the T*F interaction ($p < 0.01$ and $p < 0.05$) (Table 2). The evolution over the time for pH, EC, available P, exchangeable K, exchangeable Ca, exchangeable Mg and available S are presented in Figs. 1b, 2b, 3b, 4b, 5b, 6b, and 7b, respectively. The effect of each fertilization treatment, as observed in the average value recorded for each parameter during the incubation time, is presented the Table 3.

The highest pH value was obtained in the CT treatment ($p < 0.05$), which was similar to CO ($p > 0.05$) (Table 3). The lowest pH values were obtained in PL and PG ($p < 0.05$) (Table 3). No differences were observed between CO, BM, SN and CF ($p > 0.05$). Similarly, no differences were found between F, PG, BM, LM, SN and CF ($p > 0.05$). In general, all the treatments generated a pH from slightly acid to moderately acid (Table 3). The higher pH value obtained in CT may be explained by the no addition of fertilizer (nitrogen mainly), or due to nitrogen fertilization inducing a mineralization process that resulted in acidification of the soil in the other treatments (Kirchmann et al., 2007; Hirzel et al., 2010; Fageria and Nascente, 2014). The effect of CO on soil pH was previously discussed and associated

with the complexation of exchangeable Al in the organic matter of the compost (Damatto Júnior et al., 2006). The lowest value of pH obtained with the use of PL and PG could be related to a higher N release (Mondini et al., 2008; Muñoz-Vega et al., 2016), which also generates a higher concentration of ammonia that is nitrified afterwards, reducing soil pH. Regarding pH evolution (Fig. 1b), all treatments showed a decrease in soil pH over time. The interaction between incubation time and fertilization treatment (Table 2) is observed in the different magnitudes of the decrease in pH during the incubation time between treatments (Fig. 1b). As for Virquenco soil, these results differ from those reported by Bulluck et al. (2002) for the use of organic amendments and their effect on increasing soil pH.

The highest EC values were registered in PG, PL and SN treatments ($p < 0.05$) (Table 3). The lowest EC value was obtained in CT ($p < 0.05$), associated with the absence of fertilization, which was similar to the value obtained with CO, associated with its slow rate of N release (Eghball, 2002; Muñoz-Vega et al., 2016) and its buffer capacity on the ions present in the soil (Yang et al., 2012). The effect of SN on EC can be associated with its Na content, while that of PG and PL could be explained by their ammonia content and their high rate of N release (Muñoz-Vega et al., 2016). Regarding EC evolution (Fig. 2b), all treatments showed an increase during the incubation time, associated with OM mineralization and release of nutrients (Kirchmann et al., 2007; Hirzel et al., 2010; Fageria and Nascente, 2014). There were differences in the magnitude of these increases in each treatment during the incubation time. These were detected in the interaction analysis (Table 2) and could be associated with the different rates of N release and other nutrients (Li et al., 2015; Muñoz-Vega et al., 2016).
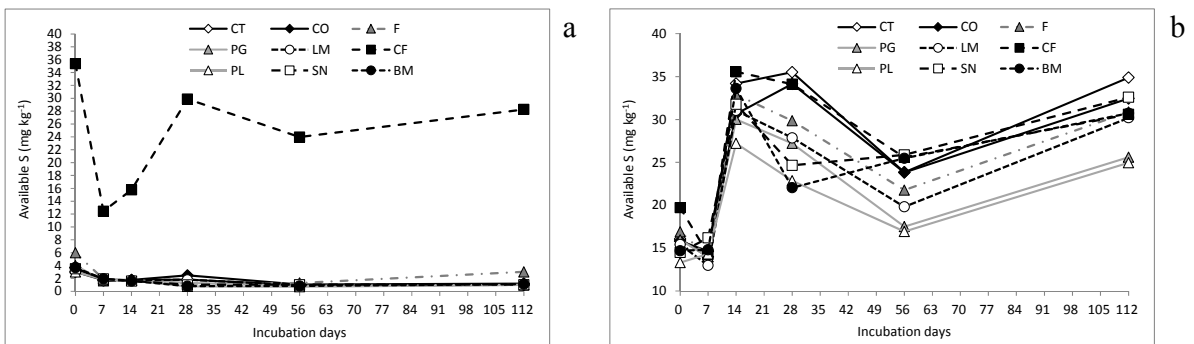
Fig. 7. Evolution of soil available sulfur (S) during the incubation time. a) Virquenco soil; b) Villarrica soil.

Abbreviations: CT: Control without fertilization; CO: Compost; F:Fertil; PG: Purely Grow; PL: Purely Lysine; LM: Lupine Meal; BM: Blood Meal; SN: Sodium Nitrate; CF: Conventional Fertilization.

The highest available P concentration was observed in CF (p < 0.05) (Table 3), with differences between the other treatments. The lowest value was obtained in PG (p < 0.05), which was similar to F, PL, BM and LM (p > 0.05). The results obtained showed that all the treatments presented a low P content (Table 3). For CO, BM, and CF treatments, organic acid concentration probably increased during the incubation time due to mineralization processes, which reduced the adsorption of P in the soil, increasing its availability (Laboski and Lamb, 2003; Herencia et al., 2007; Fageria and Nascente, 2014).The average P concentration in all treatments was similar to the initial values (Table 1), except for CF; this could be associated with the high P rate used as fertilization (P/N ratio = 0.35) and the speed of P release of the fertilizer used (triple superphosphate). These results do not agree with those of Herencia et al. (2007) and Silva et al. (2016), who proposed that the use of organic amendments increases P solubility. In terms of the evolution of P concentration (Fig. 3b), variable effects can be observed. An increase in available P was observed from day 0 to 7 in LM, CT and SN, but this decreased in CF and PG during the same period. No clear trend was observed between days 7 and 56 as some treatments showed either a decrease or an increase in P concentration. Finally, a strong decrease was observed from day 56 of incubation in all the treatments (Fig. 3b). These increases, decreases and differences in magnitude between treatments during the incubation time were detected with the interaction analysis (Table 2), and could be linked to the different rates of N release and other nutrients (Li et al., 2015; Muñoz-Vega et al., 2016), as well as the buffer effect of a soil with high OM content and high Al content as in Villarrica soil (Havlin et al., 1999; Barreal et al., 2001) (Table 1). Regarding Virquenco soil, Villarrica had lower P availability (p < 0.05), which was associated with its allophanic and imogolite clay content (Barreal et al., 2001; Matus et al., 2008; Hirzel et al., 2010).

For K, the highest concentration was observed in SN (p < 0.05) (Table 3), followed by CF and PG, with no differences between them (p > 0.05). The lowest K concentrations were obtained in PL, BM, LM and F, without differences between these treatments and with CT. The highest K concentration obtained in SN is associated with its K/N ratio (0.6). Moreover, a higher K concentration in the CF treatment can be associated with its high K/N ratio (0.66). K concentration also showed a trend to decrease between the initial and final incubation time points. The changes in the evolution of K concentration of each treatment during the incubation time was detected in the interaction analysis (Table 2) and could be

associated with the different rates of N release and other nutrients (Li et al., 2015; Muñoz-Vega et al., 2016), as well as the cation exchange in the secondary minerals of the ash volcanic soils, such as Villarrica soil (Havlin et al., 1999; Hirzel et al., 2010).

Ca concentration had no differences between treatments (p > 0.05) (Table 3), which could be associated with the buffer capacity (Yang et al., 2012) and reactions of the cation exchange in the secondary minerals of this soil (Havlin et al., 1999; Hirzel et al., 2010). Compared to the initial Ca concentration of the soil (Table 1), values either remained similar or slightly increased during the incubation time (Table 3), and also recorded a lot of changes in the evolution of each treatment during the incubation time (Fig. 5b). These changes were detected in the interaction analysis (Table 2); they are related to reactions of cation exchange in the secondary minerals of the ash volcanic soils (Havlin et al., 1999; Hirzel et al., 2010), and also to changes in soil pH as an effect of a higher desorption of cations under a reduction of soil pH during the incubation period (Table 3, Figs. 1b, 4b, 5b, and 6b) (Fageria and Nascente, 2014; Havlin et al., 1999). Changes in the evolution of Ca concentration were also described by Hirzel et al. (2016) in soil incubated for a short period of time.

For Mg concentration, the highest value was obtained in CO (p < 0.05), which was similar to CF (p > 0.05) (Table 3). The lowest Mg concentration was obtained in LM (p < 0.05), which was similar to PL, PG, F and CT (p > 0.05). This higher Mg concentration in CO can be explained by the composition of CO with a 0.38% of Mg (data not shown). The average value of Mg concentration was similar to the initial one (Tables 1 and 3), except for CO, CF and SN treatments, which were higher than the initial value. Regarding the evolution of the Mg concentration of each treatment during the incubation time (Fig. 6b), several changes were observed as detected by the interaction analysis between both variation sources (Table 2). These changes in the cation concentration during the incubation time have been previously discussed for K and Ca (Havlin et al., 1999; Hirzel et al., 2010; Fageria and Nascente, 2014).

The highest S concentration was observed in CF (p < 0.05) (Table 3), which was similar to CT, CO, F and SN (p > 0.05). The lowest S concentration was obtained in PL (p < 0.05), which was similar to PG (p > 0.05). The higher S concentration in CF can be explained by the 18% of S in the potassium sulfate used as fertilizer (data not shown). Regarding the initial S concentration (Table 1), there was an increase in the S concentration for all treatments

(Table 3), considering the average value during the incubation time, which could be explained by the mineralization process of the soil organic matter (Havlin et al., 1999). The evolution of S concentration during the incubation time (Fig. 7b) for each fertilization treatment showed many changes as observed in the interaction analysis (Table 2). In this sense, either a decrease or an increase in S concentration should have occurred from the 0-d until the final incubation time period, but this did not occur (Fig. 7b). This trend in the evolution of S concentration over the incubation period in Villarrica soil (Fig. 7b) was different from that observed for Virquenco soil (Fig. 7a). This can be explained by the biological activity in a soil with high OM content, like Villarrica (Table 1), which immobilizes this element (Wu et al., 1993), and also by processes of adsorption of sulfates in the soil anionic exchange capacity (Barreal et al., 2001). The increase in available S after immobilization observed in Villarrica soil (Fig. 7b) between 7 and 14, and 56 and 112 days, may be a response of the biological activity, since S mineralization is driven by the search for energy, which releases S as a by-product (Blum et al., 2013).

CONCLUSIONS

The results in this study, which was conducted under controlled conditions, indicate that the use of organic fertilizers had different effects on soil pH, salinity and concentrations of P, K, Ca, Mg, and S in two soils (sandy loam Mollisol and silty loam Andisol). None of the organic fertilizers registered the highest values for all parameters evaluated. However, the use of CO had the highest values of pH, available P, and exchangeable K, Ca, and Mg. On the other hand, the PL treatment showed, in general, the lowest values for most of the parameters evaluated. For both soils, the evolution over time for each parameter had different trends that interacted with the fertilization treatment, and in general resulted in a steady decrease in pH and an increase in salinity. Finally, the two soils showed differences for the chemical parameters evaluated over time, which were mainly associated with the initial properties of each soil.

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