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Manure decomposition in sandy soils fertilized with mineral nitrogen

Decomposição de Esterco em solos arenosos fertilizados com nitrogênio mineral

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ABSTRACT: Potato productivity has declined gradually over the last few years in the micro-region of agreste in Paraiba state due to incorrect soil fertility management, with empirical applications of bovine manure. To aim of supporting the appropriate management of this input, a study was carried out to evaluate the manure mineralization using three methods: CO_2 emission in the field, soil incubation in the laboratory and dry matter loss in plastic net bags. The C-CO_2 emitted on the soil surface was captured with NaOH solution, using chambers placed on the soil surface, in plots without and with the application of 11 Mg ha^{-1} of bovine manure. In the laboratory, soil incubation with manure addition (11 mg ha^{-1}), combined or not with ammonium sulfate (60 kg N ha^{-1}), was performed in hermetically sealed 2000 mL (68fl oz) containers containing NaOH for CO_2 capture, for 180 days. Decomposition bags with manure addition (11 mg ha^{-1}) with and without ammonium sulfate (60 kg N ha^{-1}), buried at 15 cm depth, were followed for 110 days. In the laboratory assay, the decomposition, estimated by the accumulated C-CO_2 emission, was very low, 5 and 3.5% for manure applied alone and with ammonium sulfate, respectively, in 180 days of incubation.

Keywords: Solanum tuberosum; Manure decomposition; Carbon determination methods.

RESUMO: A produtividade da batata vem caindo gradativamente nos últimos anos na microrregião do agreste Paraibano devido ao manejo incorreto da fertilidade do solo, com aplicações empíricas de esterco bovino. Com o objetivo de subsidiar o manejo adequado desse insumo, foi realizado estudo para avaliar a mineralização do esterco por três métodos: emissão de CO_2 em campo, incubação do solo em laboratório e perda de matéria seca em bolsas de rede plástica. O C-CO_2 emitido na superfície do solo foi capturado com solução de NaOH, em câmaras colocadas na superfície do solo, em parcelas sem e com aplicação de 11 mg ha^{-1} de esterco bovino. Em laboratório, a incubação do solo com adição de esterco (11 mg ha^{-1}), combinado ou não com sulfato de amônio (60 kg N ha^{-1}), foi realizada em recipientes hermeticamente fechados de 2.000 mL contendo NaOH para captura de CO_2, por 180 dias. Sacos de decomposição com adição de esterco (11 mg ha^{-1}) com e sem sulfato de amônio (60 kg N ha^{-1}), enterrados a 15 cm de profundidade, foram acompanhados por 110 dias. No ensaio de laboratório, a decomposição, estimada pela emissão acumulada de C-CO_2, foi muito baixa, 5 e 3,5% para esterco aplicado sozinho e com sulfato de amônio, respectivamente, em 180 dias de incubação.

Palavras-chave: Solanum tuberosum; Decomposição de esterco; Métodos de determinação de carbono.

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INTRODUCTION

The production of potatoes (*Solanum tuberosum L.*) in Paraíba state is concentrated in the micro-region of the agreste due to the particular edaphoclimatic conditions favorable to its development. It is grown on soils classified as Psamments (Estados Unidos, 2024) (NEOSSOLO REGOLÍTICO) (Santos *et al*., 2018), with a high proportion of sand, low water retention capacity, cation exchange capacity and natural fertility.

Potato productivity has declined gradually over the last few years, due to incorrect management of soil fertility, with insufficient application of fertilizer to achieve satisfactory yields. This reality is due to the fact that the producers are poorly capitalized, unable to acquire the necessary quantities of fertilizers, and fertilization is almost always limited to the application of bovine manure (Borchartt *et al*., 2011) and occasionally nitrogen fertilizer.
Manure is applied annually, on average 16 mg ha^{-1} (Galvão *et al.*, 2008). Mineral fertilization, when applied, consists of applying N at planting at an average dose of 80kg (176lb) ha^{-1} (Oliveira *et al.*, 2011). There are no studies published for the region that indicate the ideal dose of manure for potato cultivation. A preliminary study in the region, using annual applications of bovine manure for six consecutive years, showed an accumulation of nutrients in the 0- 20cm (0-8in) layer (Silva *et al*., 2007).

The determination of the decomposition rate of organic waste, such as manure, is of great importance for the efficient management of this source, because it makes it possible to estimate its contribution in the supply of nutrients (Canei *et al*., 2018; Zhu *et al*., 2020). The population of organisms has great influence on the processes of transformation, immobilization and recycling of nutrients in the soil, because the soil mesofauna acts by reducing the size of the material recently incorporated, increasing its specific surface, enhancing the action of microorganisms in the process of decomposition/mineralization (Canei *et al*., 2018).

Several parameters have been used to predict the decomposition of plant residues and manure, such as N, C, lignin, hemicellulose and polyphenols contents, besides the C/N and lignin/N ratios (Zhu *et al*., 2020). Depending on the higher or lower number of certain components, the waste degrades more slowly or more quickly, for example, materials rich in sugars, proteins, starches and cellulose are decomposed in less time than those rich in recalcitrant materials such as lignins, molecules of high molecular weight, high stability and resistant to attack by microorganisms (Freitas *et al*., 2019). However, data from laboratory incubation and, or, in-situ mineralization present more real results (Van Kessel; Reeves, 2002), due to the interaction with environmental factors that interfere with mineralization, such as pH, temperature, humidity, and intrinsic characteristics of each soil. The objective of the present work was to estimate the mineralization of manure by three methodologies: C-CO_2 emission in the field, soil incubation in the laboratory and loss of dry matter in plastic bags.

2 MATERIAL AND METHODS

The field experiment was conducted in a potato-growing area belonging to small farmers in the municipality of Esperança, PB (0º7 01' 22" S, 35º 51' 36" e 631 m (2070ft) altitude). The climate of the region, according to the Köppen classification is BSh, hot and humid tropical, with an average annual temperature of 22.5°C (73 °F), annual rainfall 753.8 mm (25 fl oz), indicating a water deficiency during most of the year (INMET, 2020).

In a soils classified as Psamments (Estados Unidos, 2024) (NEOSSOLO REGOLÍTICO) (Santos *et al*., 2018) with sandy loam texture, trials with pockets of decomposition and CO_2 emission in the field were developed in plots with application of mineral N (Ammonium Sulfate) and manure (Bovine) in potato production, before mineral and organic fertilization, the analysis of soil chemical attributes was performed as recommended by Teixeira *et al*. (2017) (Table 1).

Table 1. Chemical attributes of a Regosol in experimental area.

Depth	pH (1:25)	C	P	K^+	Ca^{++}	Mg^{++}	Al^{+++}
cm	H_2O	g kg^{-1}	------mg kg^{-1}------		-------------cmol$_c$ kg^{-1}-------------		
0-20	7.1	10.3	114	164	2.8	1.0	0.00

P e K^+ (Melich-1), Ca^{++} and Mg^{++} (KCl 1 mol L^{-1}) e C (Walkley-Black)

The digestion of manure, for chemical characterization was performed through the action of sulfuric acid (H_2SO_4) and hydrogen peroxide (H_2O_2), to determine and quantify the contents of Nitrogen (N) Phosphorus (P), Potassium (K^+), Calcium (Ca^{++}) and Magnesium (Mg^{++}) according to Carmo et al. (2000), ash and lignin, 14% (Van Soest, 1963) (Table 2).

Table 2. Chemical analysis of bovine manure, from the municipality of Esperança-PB.

N	P avai.*	K^+	Ca^{++}	Mg^{++}	Gray	Lignin
		g kg^{-1}			%	
8.7	3.1	12.0	12.0	5.3	82	14

*P available

The mineralization study using plastic bags was performed on plots that received 11mg ha^{-1}, equivalent to 100 kg ha^{-1} of N, of manure in the absence of mineral N and with the same dose of manure combined with 60 kg (132lb) ha^{-1} of N. Mineralization was estimated by measuring the dry matter loss of the material on different collection dates placed in polyethylene bags.

The plastic mesh litter bags were made with the dimensions of 15 x 20 cm (6 x 8in), with two distinct meshes, a 1 mm (0.04in) mesh on top and a 0.6 mm (0.02in) mesh on the bottom, to minimize the loss of manure to the soil, by decreasing the size of the particles as the decomposition advances.

In each bag, 20 g (0.7oz) of dry manure of known composition and grain size between 2 (0.08in) and 4.76 mm (0.2in), representative of the manure used by producers, was placed. A total of 21 bags were placed in each plot, placed horizontally in the soil at a depth of 15 cm (6in). Three bags were randomly removed after 1, 2, 3, 5, 7, 11 and 14 weeks of placement.

The remaining material in the bags was separated from the mineral fraction with the help of a brush and later dried in a forced circulation oven at 65 ºC (149 °F). After this procedure, the material was weighed and then ground and analyzed for ash content (Teixeira *et al.,* 2017). The ash content was used to correct for soil contamination of the manure contained in the bags (Potthoff; Loftfield, 1998). The dry matter loss from the bags was transformed into manure OM loss using the remaining dry matter data and the ash content of the samples.

In situ CO_2 emission was based on the method of capturing CO_2 emitted on the soil surface with NaOH solution. The emission was measured in plots without manure and mineral N addition, contrasted with the emission from plots with 11 mg ha^{-1} manure addition and no N mineral. For this purpose, 2.8 dm^{-3} chambers consisting of a circular plastic container with a radius of 11 cm (4in) and a height of 12 cm (5in) were used. The containers remained inverted for 24:00 h on the soil surface on each sampling date, with the edges inserted into the soil and affixed by metal pins through holes in the edges. Two containers with 20mL (0.7 fl oz) of 0.1 M NaOH were placed inside each chamber to capture the emitted CO_2.

Four cameras per plot were installed, and measurements were taken until the potato was harvested 74 days after planting, twice a week for the first 30 days and once a week from the second month on.

After the 24-hour period had elapsed, the NaOH was transferred to a sealed container and then taken to the laboratory for quantification of the carbonate, which was quantified by potentiometric titration with 0.05 M HCl (Sampaio; Salcedo, 1982).

To evaluate CO_2 emission in vitro, the soil was incubated in hermetically sealed 2000 mL (68 fl oz) containers with a NaOH trap to capture CO_2. The soil used for incubation was collected from the area where the experiment was conducted with manure decomposition and mineralization using plastic bags and CO_2 emission in the field. Samples from the 0-20 cm (0-8 in) layer were used, collected before the implementation of the field experiment.

The treatments were as follows: control (soil without manure); manure in three granulometries (smaller than 0.53 mm (0.021in); 0.53-2 mm (0.021-0.8in) and 2-4 mm (0.08-0.2in) at a dose of 11mg ha^{-1} of manure (85% dry matter) in a factorial arrangement with two doses of mineral N (0 and 60kg (132lb) ha^{-1}), with four repetitions.

The manure and nitrogen fertilizer were mixed to 100 g (4 oz) of air-dried soil in small plastic cups, which were then incubated inside 2000 mL (68 fl oz) screw-capped bottles; the amount of manure (dry matter) and mineral N were calculated by considering the density of the soil in the plastic cup.

The soil was moistened with a volume of water equivalent to 40% of the pore volume. After placing inside the flasks, the beaker containing soil, a container with 20 mL (0.7 fl oz) of 1mol L^{-1} NaOH and another with water were placed to keep the air humidity stable, and the flasks were immediately closed hermetically.

The flasks were opened, 3, 7, 15, 30, 60, 90, 120, 150 and 180 days after the start of incubation, to exchange the NaOH and quantify CO_2 by potentiometric titration of the C sequestered by NaOH (Sampaio; Salcedo, 1982).

The results were submitted to analysis of variance in orthogonal contrasts between the different treatments for the variable C-CO_2 emission, using the SAS statistical program (SAS, 1990).

3 RESULTS AND DISCUSSION

The loss of organic matter from the manure was more pronounced in the plots that received nitrogen during all 110 days of the trial, reaching 51 and 41% of the original carbon mass with and without nitrogen, respectively (Figure 1), corresponding to dry matter losses of 25.5 and 19%. Silva *et al*. (2007) performed a goat manure decomposition test under similar conditions, in the same soils and climate, and obtained dry matter losses of 60% after 82 days. This value, much higher in dry matter loss, probably occurred because they used goat manure, which had four times more N than the bovine manure used in this trial, since the N content is a determinant in the rate of decomposition of organic waste (Zhu *et al*., 2020).

The low nitrogen content and high lignin, less than 20g.kg^{-1} and 150 g.kg^{-1}, respectively (Mafongoya *et al.,* 1998) in the manure used may have been delaying factors in the decomposition of the manure without N, considering that the higher the C/N ratio the lower the speed of material decomposition (Zhu *et al*., 2020). Under some conditions, the (lignin + polyphenols)/N ratio has been considered more suitable than the C/N ratio to predict the decomposition rate of organic plant residues (Braga *et al*., 2016).

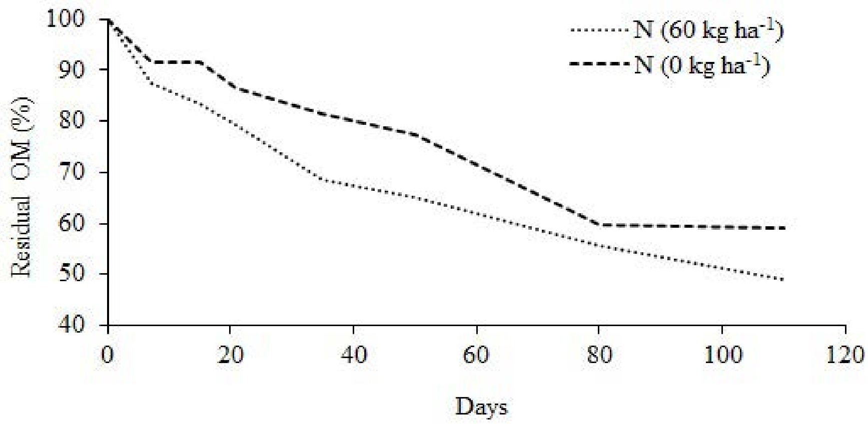

Figure 1. Percentage of organic matter added via manure remaining in litter bags over 110 days with and without N-mineral application.

Manure applied alone can lead to a deficiency of nutrients to plants, especially N. Menezes and Salcedo (2007) observed net immobilization of N during the first 56 days of the incubation trial, with soil and manure with a composition similar to that of this study. When the application is made together with a more labile source of nitrogen, either green manure (Costa Júnior *et al*., 2018; Zuffo *et al*., 2020) or mineral fertilizer, the possibility of synchrony between the availability of nutrients in the soil and the demand of crops increases.

The curves of CO_2 emission in the soil with and without manure addition (Figure 2) presented quite synchrony between each other in the oscillations throughout the studied period, and in the plots with manure application the fluxes were consistently higher. As mentioned earlier, it is believed that the high content of lignin and the low content of N in the manure used were responsible for the small difference in CO_2 emission in the field, when comparing the amounts of C from manure mineralized in the plots with and without manure application.

Twenty days after the incorporation of manure in the soil, the C-CO_2 flux was significantly correlated ($R= 0.79$, $p<0.01$) with the accumulated precipitation in the 5 days prior to the measurement (Figure 2 A and B). The greater availability of water favored the intensification of microbial activity and, consequently, greater emission of C. The decomposition of any organic waste depends, besides the chemical composition, on soil conditions, especially moisture and temperature (Canei *et al*., 2018; Sharma *et al*., 2017). This fact can be confirmed by the low emission of CO_2 at 57 days, this measurement was performed after a few days without precipitation and, since this is a soil with high sand content (82%), which maintains moisture for short periods, it may have influenced the activity of microorganisms due to lack of water.

(Conclusão)

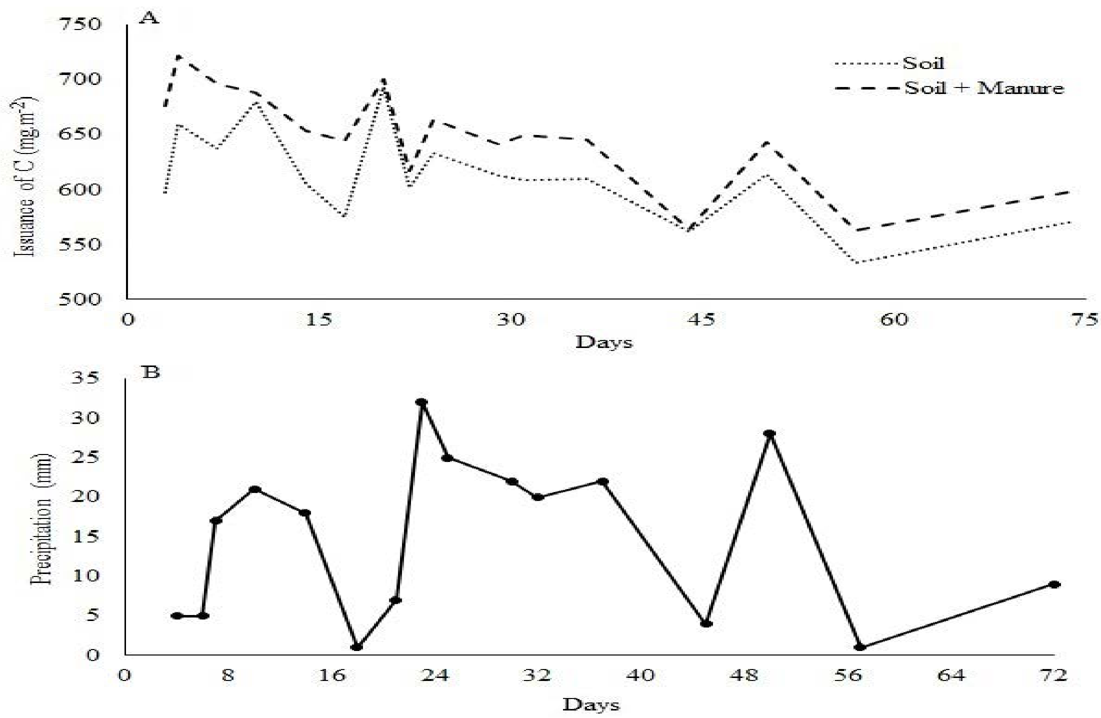

Figure 2. A: amount of C-CO_2 emitted on the surface of a Regosol in plots with and without manure application, over 74 days of field test. B: accumulated rainfall 5 days before the measurement of C-CO_2 emission.

Comparing the C of manure lost estimated with decomposition bags in plots with manure but no N (41% at 110 days, Figure 1) with the data estimated with direct emission in the field (<3%) (Figure 3), there is a very large difference. This is probably due to the fact that in the bags there were losses of the manure fractions that decreased to a diameter smaller than 0.6 mm (0.02in), and that passed through the mesh. This material is computed as mineralized. By measuring the CO_2 emission in the soil, only the C tha mg has actually been mineralized is considered.

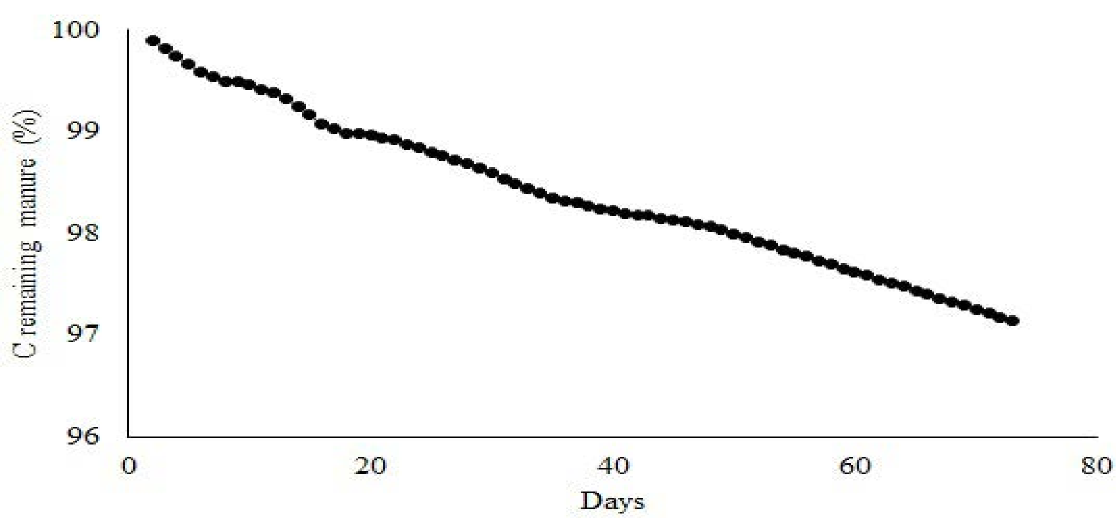

Figure 3. percentage of mineralized manure C, estimated by C-CO_2 emission in the field, in a Regosol with manure application, over 75 days of field trial.

The emission of C-CO_2 in the soil with manure addition was 33% higher than in the control soil (Table 3), being statistically significant (Table 4). The contribution of C via manure increases the supply of energy to soil microorganisms, leading to greater emission of CO_2 via respiration, however, the low content of N in this material can cause immobilization of soil N by microorganisms (Lazicki *et al*., 2020). Under similar conditions, net immobilization of soil N was observed with the addition of manure for 56 days (Menezes; Salcedo, 2007).

The addition of N-mineral to the soil also increased the amount of C-CO_2 emitted by 18%, accumulated over 180 days, compared to untreated soil (Table 4). The supply of readily available N, combined with disturbance, to the soil promotes the increase in decomposition rate (Guimaraes *et al*. 2017), and may lead to the reduction in soil C-stock.

Regarding the granulometry, the highest accumulated emission of C-CO_2 occurred in the coarsest manure fraction, 2-4 mm (0.08-0.2in), (Table 3). The larger granulometry of the material could limit its contact with microorganisms and present lower emission of C (Alexander, 1977), but the analysis of the ash content in the different granulometric fractions of the manure showed that in the coarser fraction the content of OM was much higher. The manure before being separated into different particle sizes had 82% ash. After separation by particle size, the ash contents were as follows 85, 78 and 72% for the fractions smaller than 0.53 mm (0.021in), 0.53-2 mm (0.021-0.08in) and 2-4 mm (0.08-0.2in), respectively.

The manure was collected in direct contact with the soil and, consequently, mineral contamination may be high. This situation seems to be frequent in the manures of the region, as determined by Galvão *et al. (*2008). The higher concentration of ash in the finest particle size is probably due to the fact that the soil particles are also within this particle size range.

Table 3. Emission of C-CO_2 in a Regosol fertilized with combination of ammonium sulfate and manure with three granulometries in 180 days of laboratory test

Treatments	**C-CO_2**
	mg kg soil^{-1}
Control	4.6
N	5.4
EG1	5.8
EG2	6.1
EG3	6.6
EG1N	5.3
EG2N	5.3
EG3N	6.4

Control: (no fertilization); N: (ammonium sulfate, 60 kg (132lb) N ha^{-1}); E: (manure, 11 mg ha^{-1}); EG1: (particle size <0.53 mm (0.021in)); EG2: (particle size between 0.53-2 mm (0.021-0.08in)) and EG3: (particle size between 2-4 mm (0.08-0.2in)).

The N input from the fertilizer along with the manure decreased the emission of C-CO_2 contributed by the manure (Table 4), being an indication that C is being incorporated into the soil, since to fix C in the soil there needs to be N availability.

Table 4. Orthogonal contrasts among different treatments for C-CO_2 emission in Regosol with combined addition of manure and mineral N

Contrasts	C-CO_2 mg kg soil^{-1}
Control X N1	-0.55**
Control x E2	-1.2**
N X N + E	-0.22ns
E x E + N	-0.44**
EG1N +EG2N x EG3N3	0.15ns
EG1 +EG2 x EG3	0.35 *

N1: (60 kg (132lb) N ha^{-1}); E2: (11 mg ha^{-1}); EG1: (grain size <0.53 mm (0.021in)); EG2: (grain size between 0.53-2 mm (0.021-0.08in)) and EG3: (grain size between 2-4 mm (0.08-02in)); ns: not significant; ** significant at 1%; * significant at 5%.

The decomposition of manure, estimated by the accumulated C-CO_2 emitted, was very low, 5 and 3.5% for manure applied alone and with ammonium sulfate, No significant statistical differences, respectively (Figure 4).

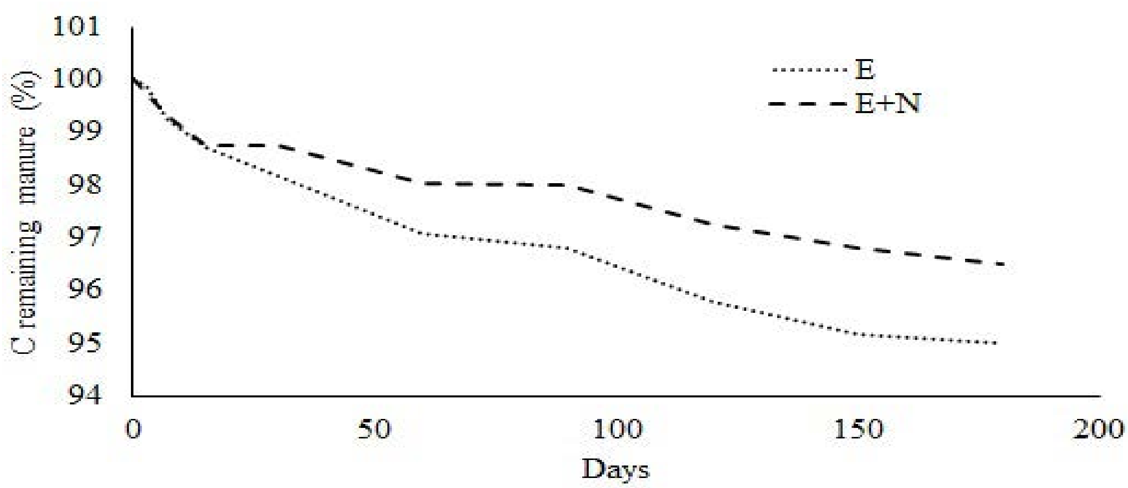

Figure 4. percentage of mineralized manure C, estimated by laboratory C-CO_2 emission, in a Regosol with manure and ammonium sulfate application over 180 days.

The slow mineralization of the manure may have been associated with the coarse particle size of the material used, which hinders contact between the soil-residue and decomposing organisms. Menezes and Salcedo (2007), evaluating the effects of fertilization with gliricidia and manure, finely ground, in a laboratory incubation trial, did not observe delay in the beginning of decomposition, evaluated by the net mineralization of N. From the third week, the decomposition of the manure applied together with N-mineral showed a tendency of more intense mineralization than the manure applied alone. In addition, the low nitrogen content and the high lignin content of the manure contribute to the delay in decomposition of manure without N (Fox *et al*., 1990).

4 CONCLUSIONS

The application of manure combined with mineral N showed higher C-CO_2 emission.

The CO_2 emission measured in the field was closely related to precipitation, showing that the environmental conditions combined with the chemical characteristics of the manure led to slow decomposition.

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