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DEGRADATION RATE OF LIMED SEWAGE SLUDGE IN AN AGRICULTURAL SOIL

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Abstract

Little is known about the degradation kinetics of sewage sludge, sanitized with $Ca(OH)_2$, in soil. Thus, this work aimed to monitor the degradation of limed sludge, under field conditions, when applied on soil surface or incorporated into the soil. The limed sludge was applied in dystrophic Inceptisol at a dose of 500 kg ha^{-1} yr^{-1} of total nitrogen. The mineralization process in the soil was monitored for 131 days. Samples of organic material were collected for analysis of total and easily oxidizable organic carbon; total, ammonium, nitric and organic nitrogen; volatile solids; and water contents. The undigested secondary sewage sludge generated in wastewater aerobic treatment mineralizes faster when limed and incorporated, compared to being arranged on soil surface. The estimated annual mineralization fraction of the limed sludge was 100% and greater than 95%, when incorporated or arranged on soil surface, respectively. Such values are higher than those established in the Brazilian environmental legislation for undigested sewage sludge disposal on soil.

Key words: organic fertilizer, organic matter, solid wastes

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1. Introduction

The processes of organic matter stabilization in sewage sludge, produced in Wastewater Treatment Plants (WWTP), include aerobic digestion, anaerobic digestion, composting, chemical stability and thermal stability. Composting and liming are cleaning processes (Li et al., 2017; Matos, 2014), whose purpose is to ensure a pathogenicity level that prevents sewage sludge from being harmful to the population or the environment when disposed on the soil. Only after this process, sludge will be ready to be transported and applied to agricultural soil (Godoy, 2013; Liu et al., 2015). If properly sanitized and applied with discretion, sludge can become a soil conditioner, due to its large amount of organic matter and nitrogen concentration. Besides, it enables the recycling of other nutrients. Sludge liming can be performed using quicklime (CaO), hydrated lime ($Ca(OH)_2$) or ash. Hydrated lime, whose transport, storage and application are less dangerous compared to quicklime, may increase pH so that the environment becomes unfavorable to pathogen survival (Matos, 2014). Sewage sludge disposal to soil is an alternative of great potential, but it must be conducted in a way to improve the chemical, physical and biological properties of soils and reduce agricultural production costs. However, the application of excessive doses

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may cause damage to agricultural land. Thus, it is necessary to understand well the dynamics of nutrients and pollutants involved in this system.

Topaç et al. (2008) monitored the mineralization of sludge alkalinized with the addition of ashes, for 360 days, applied on clayey soil, at doses of 100 Mg ha^{-1} of raw sludge (dry matter), with material maintained at 28 °C, and found that, on the first 90 days of incubation, organic nitrogen mineralization was inhibited. After this period, it was favored. Yoshida et al. (2015) found mineralization of about 30% of organic nitrogen in soil mixed with limed sludge and 20% in non-limed sludge, after incubation for 190 days, and assigned the highest values to the improvement of soil pH conditions with the incorporation of limed sludge.

CONAMA Resolution 375/2006 (Brazil, 2006) establishes criteria and procedures for the use of sewage sludge in agriculture. The dose to be applied is based on the nitrogen that can be available and consequently, on the annual sludge mineralization fraction. Established mineralization fractions are 40% for primary and secondary untreated sludge; 30% for digested aerobically sludge; 20% for sludge anaerobically digested; and 10% for composted sludge. However, the determination of organic waste mineralization fraction is complex and affected by many factors that interfere with the dynamics of C and N in the soil, such as soil and climate conditions, waste characteristics and its disposal to the soil (Paula et al., 2013). The form of application to the soil, either incorporated or on the surface, may accomplish completely different results for the amount of N available to plants.The general objective of this work is to monitor the degradation of organic material in limed sewage sludge, under field conditions, and evaluate the effect of the form of disposition (on surface or incorporated) on the coefficients and fractions of sludge mineralization in the soil.

2. Material and methods

The undigested sludge (NDS) was collected from the Arrudas WWTP, administered by the Sanitation Company of Minas Gerais, collected in the secondary decanter of the activated sludge system. The NDS used in the experiment was dewatered on drying bed and subsequently subjected to the liming process, which increased the pH of the material through the addition of hydrated lime ($Ca(OH)_2$). To obtain the liming curve, the sewage sludge was air-dried, prepared and mixed with various doses of hydrated lime, 0, 50, 100, 150, 200 and 250 kg m^{-3}, and then water was added and the mixture remained in reaction for 72 h. The pH of the material was measured in suspension prepared with the solution $CaCl_2$ 0.01 mol L^{-1} (Matos, 2012). To obtain pH = 12, for 72 h, a dose of 113 kg of $Ca(OH)_2$ is obtained for each m^{-3} of NDS. Since NDS presented specific mass equal to 618.5 kg m^{-3}, this dose amounted to 182.7 kg mg^{-1}.

To characterize the receptor soil, total organic carbon concentrations (*TOC*) were quantified, calculated from the concentration of volatile solids; easily oxidisable organic carbon (*OOC*), by oxidation with potassium dichromate in sulfuric medium; total nitrogen (*TN*), by the Kjeldahl modified method; phosphorus, potassium and sodium, extracted by Melich 1 solution and quatification by spectrophotometer method; Ca+Mg, Al^{3+}, extracted by KCl 1 mol L^{-1} solution, the potential acidity (H + Al), extracted by calcium acetate 0.5 mol L and quantified by titrimetric methods; besides the pH index and electrical conductivity, by the potentiometric method, as reported by Matos (2012). The granulometric composition of the soil was also analyzed by the pipette method and the specific soil mass was quantified by the volumetric ring method described in Matos (2012).

In order to characterize NDS and LS, analyses (three replicates) were performed to determine the pH; water content; organic carbon levels, *TN*, amoniacal (NH_4-N) and N nitrate (NO_3-N); total content of *P, K, Ca, Mg, S* and *Na*, quantified in a solution obtained with the nitric perchloric digestion of the samples; total solids (*TS*), total volatile solids (*TVS*) and total fixed solids (*TFS*), by the same methods already mentioned (Matos, 2015). The sludge specific density was calculated as the dry mass contained in a known volume of fresh mass of the material. Table 1 presents the chemical and physical characterization of the soil and sludge used in the experiment. The experiment was conducted in an area of a dystrophic Inceptisol, in the Experimental Area of Urban Waste Treatment of the Department of Agricultural Engineering, Federal University of Viçosa, Viçosa, Minas Gerais. All the analyses were performed at the Laboratory of Soils and Solid Waste, of the same department.

In the experimental area, the soil was dug and removed from the location, forming pits, where plastic pots of 20 cm in height, 30 cm in upper diameter and 20 cm in bottom diameter were introduced, with an approximate volume of 10 L, perforated at the bottom and on the sides to allow contact between the soils contained in the different vases. The soil removed for opening the holes was used to fill the vessels buried in the soil. LS was applied in these vases in two different ways: incorporated, homogeneously mixed to the soil contained in the vases; or superficially disposed on soil surface, without incorporation. Each form of sludge application was carried out in five experimental units (buried vessels). The dose of LS was applied to the soil based on the application of 500 kg ha^{-1} of total N (11.6 Mg ha^{-1} or 81 g de LS per vase).

The field monitoring was done by 131 days (from October 2013 to February 2014), and during this period, samples were collected every two weeks during the first month and once a month in the following months, which provided a total of six sampling dates. The collection from surface material was made to a depth of 3 cm; and from incorporated material, from random spots within the vessels. The concentrations of OOC, TOC, TN, NH4-N and NO_3-N, and water content (Ubu) were quantified according to the methods described by Matos (2015).

Table 1. Chemical and physical characteristics of soil (air dried fine-textured soil) and undigested non-limed (NDS) and limed sludge (LS). Means of three replicates

Soil			***Sewage sludge***			
Variables	***Unit***	***Values***	***Variables***	***Unit***	***Non-limed (NDS)***	***Limed (LS)***
pH	-	5.5	*pH*	-	7.6±0,0	12.4±0.0
OOC	(dag kg^{-1})*	0.88	*OOC****	g kg^{-1}	31.5±5,5	186.6±35.7
TOC	(dag kg^{-1})	1.06	$TOC_{(v.s.)}$***	g kg^{-1}	324.7±31,2	348.0±23.4
O.M.	(dag kg^{-1})	1.82	TN^{***}	g kg^{-1}	49.2±0,6	38.9±1.9
TN	(g kg^{-1})	1.03	NO_3-*N****	mg kg^{-1}	82.8±29,0	78.6±0.4
EC	(µS cm^{-1})	107.08	NH_4-*N****	g kg^{-1}	30.0±7,9	12.8±2.4
K^+	(mg dm^{-3})	57.2	*C/N****	-	6.6	7.1
Na^+	(mg dm^{-3})	< 0.01	*Na****	g kg^{-1}	21.1±0,7	13.9±0.7
Ca+Mg	(cmol$_c$ dm^{-3})	2.86	*K****	g kg^{-1}	1.9±0,1	4.2±0.5
P_{disp}	(mg dm^3)	52.58	*P****	g kg^{-1}	11.5±0,3	17.5±1.2
Al^{3+}	(cmol$_c$ dm^{-3})	0.07	*TS****	g L^{-1}	44.0±5,1	980.1±5.0
H+Al	(cmol$_c$ dm^{-3})	7.41	*TFS***	g kg^{-1}	440.2±53,7	400.1±40.3
Clay	(dag kg^{-1})	43.0	*TVS***	g kg^{-1}	559.8±53,7	599.9±40.3
Silt	(dag kg^{-1})	12.0	U_{bu}***	dag kg^{-1}	96.0±0,5	12.2±0.5
Sand	(dag kg^{-1})	45.0	*ρ****	kg dm^{-3}	0.90	0.90
ρ	(g cm^{-3})	1.07				

Note: OOC - easily oxidizable organic carbon; $TOC_{(v.s.)}$ *- total organic carbon, obtained with dry material, similar to TVS/1.724; O.M. - content of organic matter; TN - total nitrogen; EC - electrical conductivity; C/N = TOC/TN ratio; K - potassium; Na - sodium; Ca+Mg - calcium + exchangeable magnesium;* P_{disp} *- available phosphorus; TS - Total solids; TFS - Total fixed solids; TVS - total volatile solids;* U_{bu} *- water content on wet basis; ρ - specific mass.*

** is the same as %, ** in relation to dry matter; *** in relation to fresh matter*

Organic nitrogen (*ON*) was calculated from the difference between *TN* and the sum of NH_4-*N* and NO_3-*N*. Soil temperature was monitored by measurements using a thermocouple digital thermometer, at the depth of 10 cm, in the treatment soil where the residue was incorporated, and through IR thermometer in the treatments without incorporation of the residue.

The simple exponential model of first-order chemical kinetics, proposed by Stanford and Smith (1972) was adopted to describe the mineralization of *TOC* (Eq. 1), *OOC* (Eq. 2) and *ON* (Eq. 3) in the soil.

$$TOC_{(min)} = TOC_{(0)}(1-e^{-Kc(T)t}) \tag{1}$$

$$OOC_{(min)} = OOC_{(0)}(1-e^{-Kc(eo)t}) \tag{2}$$

$$ON_{(min)} = ON_0(1-e^{-Kn\,t}) \tag{3}$$

where: $TOC_{(min)}$– concentration of degraded organic carbon at determined time *t* (mg kg^{-1}); $TOC_{(0)}$ - initial concentration of mineralizable organic carbon in the soil (mg kg^{-1}); $K_{c(T)}$ -mineralization coefficient of the *TOC* (day^{-1}); $K_{c(eo)}$ - mineralization coefficient of the *OOC* (day^{-1}); *t* - time elapsed after incubation of the soil with the organic material (days); $OOC_{(min)}$ - concentration of degraded mineralizable organic carbon at determined time *t* (mg kg^{-1}); $OOC_{o(0)}$ - initial concentration of mineralizable organic carbon in the soil (mg kg^{-1}); $ON_{(min)}$ - concentration of mineralized organic nitrogen at determined time *t* (mg kg^{-1}); ON_0 - concentration of potentially mineralizable organic nitrogen in the soil (mg kg^{-1}); and K_n - mineralization coefficient of the ON_0 (day^{-1}). The mineralization potential and mineralization coefficients were obtained after the adjustment of mathematical models, by non-linear regression, using the *Sigma Plot* 12.0 software system. The mineralization fraction of organic *C* and *N* was calculated using both methods (Paula et al., 2013), as described below:

Method 1

Organic *C* and *N* mineralization fraction observed in the field ($MF_{(ob)}$), calculated by means of Eqs. 4-6, which use the carbon and nitrogen concentration values quantified at the beginning and end of the process.

$$MFTOC_{(ob)} = (TOC_{(i)} - TOC_{(f)})100/TOC_{(i)} \tag{4}$$

$$MFOOC_{(ob)} = (OOC_{(i)} - OOC_{(f)})100/OOC_{(i)} \tag{5}$$

$$MFON_{(ob)} = (ON_{(i)} - ON_{(f)})100/ON_{(i)} \tag{6}$$

where: $MFTOC_{(ob)}$ - mineralization fraction considering the $TOC_{(i)}$ of the sludge as a reference (%); $TOC_{(i)}$ - total organic carbon of the sludge immediately after application to the soil (dag kg^{-1} or %); $TOC_{(f)}$.- total organic carbon of the sludge at 131 days after application to the soil (dag kg^{-1}); $MFOOC_{(ob)}$ - mineralization fraction considering the $OOC_{(i)}$ of the sludge as a reference (%); $OOC_{(i)}$ - easily oxidizable organic carbon of the sludge immediately after application to the soil (dag kg^{-1}); $OOC_{(f)}$ - easily oxidizable organic fraction of the sludge at 131 days after application to the soil (dag kg^{-1}); $MFON_{(ob)}$ - mineralization fraction considering the $ON_{(i)}$ of the residue as a reference (%); $ON_{(i)}$ - organic nitrogen of the sludge immediately after application to the soil (dag kg^{-1}); $ON_{(f)}$ - organic nitrogen of the soil at 131 days after application to the soil (dag kg^{-1}).

Method 2

Mineralization Fraction of C and organic N ($MF_{(aj)}$), adjusted, calculated by means of Eqs. (7)-(9), according to the values of carbon and nitrogen concentrations calculated from the adjusted exponential equations, considering the potentially mineralizable $TOC_{(min)}$, $OOC_{(min)}$ and $ON_{(min)}$ of the sludge samples as a reference.

$$MFTOC_{(aj)} = (TOC_{(min)} / TOC_{(0)})100 \tag{7}$$

$$MFOOC_{(aj)} = (OOC_{(min)} / OOC_{(0)})100 \tag{8}$$

$$MFON_{(aj)} = (ON_{(min)} / ON_{0})100 \tag{9}$$

where: $MFTOC_{(aj)}$ - mineralization fraction calculated based on the adjusted exponential equations, considering the potentially oxidizable TOC of the sludge as a reference (%); $TOC_{(min)}$ - accumulated concentration of TOC of the mineralized sludge during the 131 experimental days (dag kg^{-1}); $TOC_{(0)}$ - potentially mineralizable TOC of the sludge (dag kg^{-1}); $MFOOC_{(aj)}$ - mineralization fraction calculated from the adjusted exponential equations, considering potentially mineralizable OOC of the sludge as a reference (%); $OOC_{(min)}$ - accumulated concentration of OOC of the mineralized sludge after 131 experimental days (dag kg^{-1}); $OOC_{(0)}$ - potentially mineralizable OOC of the sludge (dag kg^{-1}); $MFON_{(aj)}$ - mineralization fraction calculated from the adjusted exponential equations, considering the potentially mineralizable ON of the sludge as a reference (%); $ON_{(min)}$ - accumulated concentration of ON of the mineralized sludge after 131 experimental days (mg kg^{-1}); ON_0 - potentially mineralizable ON of the sludge (mg kg^{-1}).

For calculation of the mineralization fractions and adjusts of the experimental equations, the concentrations of *OOC*, *TOC* and *ON* measured in the field were adopted, after subtracting the concentrations of *OOC*, *TOC* and *ON* of the control soil, except in the situation where the residue was applied superficially. This is because the sample in the case of incorporated application contained both soil and waste.

3. Results and discussions

The water content and temperature on the soil surface to vary, respectively, from 1.1 to 38.1 dag kg^{-1} and from 24.2 to 42.2 ºC in the monitoring period of this experiment. On the other hand, at the average depth of the residue incorporation layer, the water content and temperature ranged from 15.2 to 22.1 dag kg^{-1} and 21.0 to 36.5ºC, respectively. For short periods of time, the value of 40 °C was slightly exceeded and the water content became too low (1.1 dag kg^{-1}), but, in general, the environmental conditions favored the degradation of the organic material disposed to the soil, since, according to Costa and Sangakkara (2006), under soil temperatures between 5 °C and 35 °C, degradation is accelerated, if the temperature does not exceed 40 °C.

Fig. 1 shows the curves of cumulative mineralization concentration, of *TOC*, *OOC* and *NO* of LS, respectively, according to the time of monitoring. It is observed that the first-order kinetics simple exponential model, proposed by Stanford and Smith (1972), adjusted well to the data obtained in the two treatments for a minimum significance level of 5% for the coefficients. The analysis of the adjusted equations demonstrates that the LS arranged on soil surface showed mineralization coefficients of *TOC, OOC* and *ON* 1.3; 1.2 and 2.3 times smaller than the coefficients obtained when it was incorporated. Besides the reduced contact with the soil and its micro/meso biota, which speeds the degradation of organic material (Pereira et al., 2015), the high pH of the material, resulting from the liming process, which was maintained because the material was not mixed to the soil, inhibited the growth of the afore mentioned organisms and thereby the degradation of LS.

Table 2 shows the parameters of the equations adjusted for $TOC_{(min)}$, $OOC_{(min)}$) and $ON_{(min)}$, for each form of disposition of LS to the soil and the estimated values of mineralization fractions of *TOC*, *OOC* and *ON*, calculated by the Method 1 (Eqs. 5-7) and Method 2 (Eqs. 7-9). Torri et al. (2003) studied the dynamics of the *OOC* of the sewage sludge incorporated into soils typical of the Argentine pampa and obtained $K_{c(eo)}$ rates from 0.030 to 0.035 day^{-1} in more acidic soils and 0.07 day^{-1} in the soil with pH close to neutrality. The results presented in this work ($K_{c(eo)}$ = 0,036 day^{-1}), obtained with the incorporation of sewage sludge in acidic soil (pH = 5.5), are very close to those found by the mentioned authors, for soils with similar acidity levels. This may indicate that the liming of sewage sludge did not provide any significant change in the degradation of the material, when incorporated into the soil.

Thus, mineralization fractions of *OOC, TOC* (for surface disposal only) and *ON* (only for the incorporated form) of LS were superior to 90%, which suggests that Methods 1 and 2 obtained similar results. As regards the assessment method, the mineralization fraction estimates ($MFON_{(aj)}$) are considered more reliable, since the Method 1 is more strongly influenced by specific concentrations ($ON_{(i)}$ and $ON_{(f)}$), which are, in the case of nitrogen, more prone to instability.

Pereira et al. (2015) found values of mineralization fractions of *OOC* and *ON*, for peach palm residue, of 93.5 and 95.3%, when it was incorporated into the soil; and 59.8 and 62.7%, when disposed on soil surface, respectively, for 102 days of monitoring. The author credited the higher values obtained by the mineralization fractions of residue shredded and incorporated into the soil to increased contact with the soil, which provided greater degradation when compared with that obtained in waste disposed on the soil surface. Paula et al. (2013) found, however, higher values of *MFOOC* and *MFON* for the anaerobic sludge disposed on the surface, compared to sludge incorporated into the soil and attributed these results to lower dilution of the nitrogen present in the sludge when disposed on the surface, which facilitated the degradation of the residues.

Using the adjusted equations, the mineralization fractions of *TOC, OOC* and *ON* for 40, 131 and 365 days degradation were estimated, and the results are shown in Table 3. The annual mineralization fraction was estimated to be the variable used to determine the dose of sludge to be applied to the soil, a request of Brazilian legislation. Hattori and Mukai (1986) obtained *TOC* mineralization fractions from 20 to 44%, while those of *ON* ranged from 15 to 28% during the incubation of sewage sludge incorporated into the soil, for a period of 8 weeks. Matos et al. (2018) estimated values for mineralization fractions of the anaerobically digested sludge, based on the difference between the initial and final contents of *TOC*, *OOC* and *ON* in samples of the material collected, of 99.5 and 100%, respectively, when incorporated with the soil or applied to the soil surface.

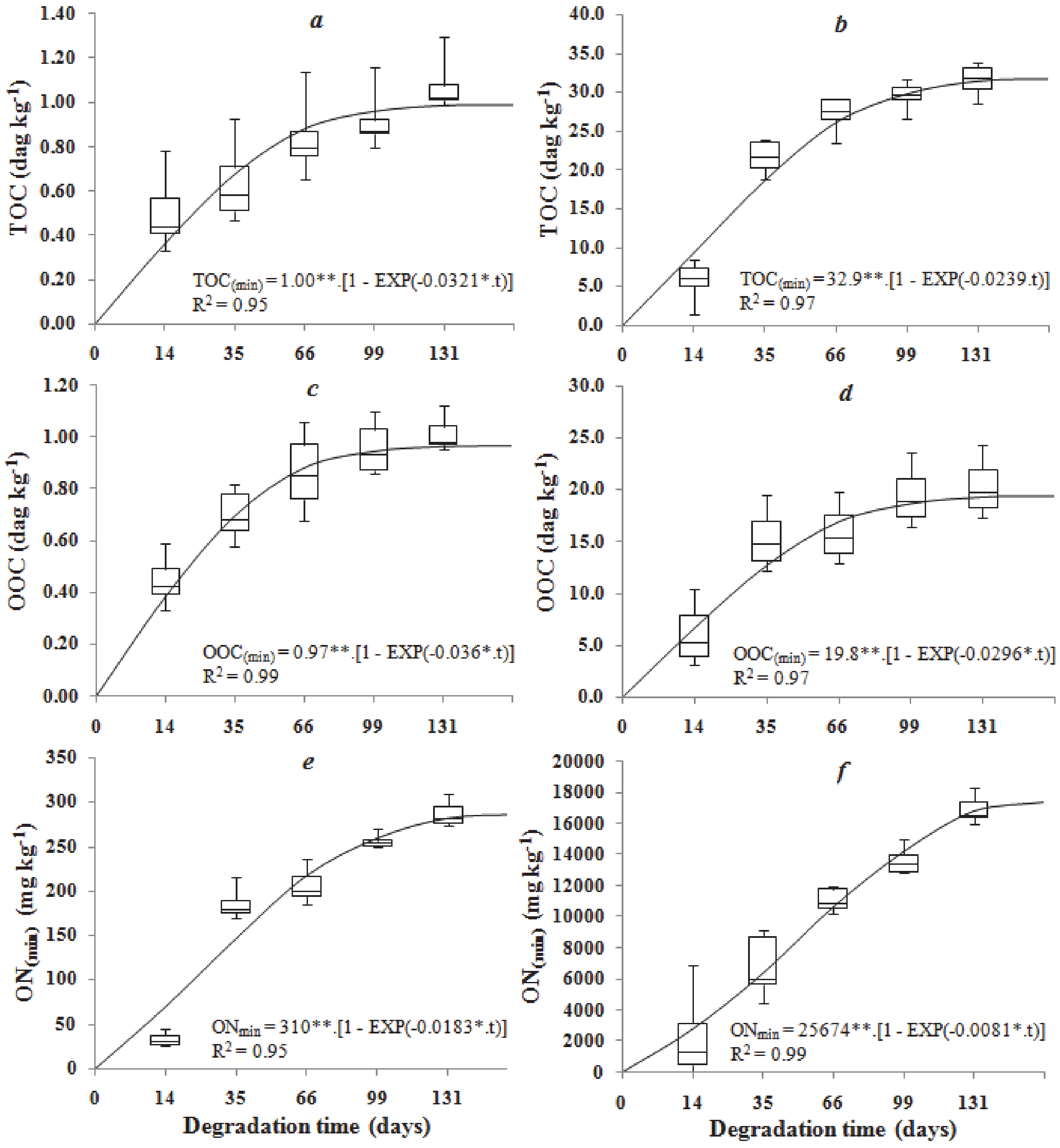

Fig. 1. Cumulative concentration of total mineralized organic carbon (*a* and *b*), easily oxidizable mineralized organic carbon (*c* and *d*) and mineralized organic nitrogen (*e* and *f*) of limed sludge (LS), respectively, incorporated into the soil (*a*, *c* and *e*) or on soil surface (*b*, *d* and *f*) and adjusted equations, for 131 days of monitoring
(**,* significant at 1% and 5%, respectively dag kg^{-1} is the same as %)

Table 2. Parameters of the first order kinetics equations of the total (*TOC*) and easily oxidizable organic carbon (*OOC*) and organic nitrogen (*ON*), its equation adjustment parameters ($TOC_{(0)}$, $OOC_{(0)}$, ON_0), mineralization coefficients ($K_{c(T)}$, $K_{c(eo)}$ and K_n) and adjusted mineralized fractions ($MFOC_{(aj)}$, $MFOOC_{(aj)}$ and $MFON_{(aj)}$) and observed ($MFTOC_{(ob)}$, $MFOOC_{(ob)}$ and $MFON_{(ob)}$), in the soil where the undigested and limed sewage sludge was incorporated or applied on soil surface and monitored for 131 days

TOC	**Form of application**	$TOC_{(0)}$	$K_{c(T)}$	R^2	$TOC_{(min)}$	$MFTOC_{(aj)}$	$MFTOC_{(ob)}$
		(dag kg^{-1})	**(day^{-1})**	**-**	**(dag kg^{-1})**	**(%)**	**(%)**
	Incorporated	1.00	0.0321	0.95	0.99	98.5	85.7
	On surface	32.9	0.0239	0.97	31.4	95.6	97.3
OOC	**Form of application**	$OOC_{(0)}$	$K_{c(eo)}$	R^2	$OOC_{(min)}$	$MFOOC_{(aj)}$	$MFOOC_{(ob)}$
		(dag kg^{-1})	**(day^{-1})**	**-**	**(dag kg^{-1})**	**(%)**	**(%)**
	Incorporated	0.97	0.0360	0.99	0.96	99.1	93.0
	On surface	19.8	0.0296	0.97	19.3	97.9	98.1
ON	**Form of application**	ON_0	K_n	R^2	$ON_{(min)}$	$MFON_{(aj)}$	$MFON_{(ob)}$
		(mg kg^{-1})	**(day^{-1})**	**-**	**(mg kg^{-1})**	**(%)**	**(%)**
	Incorporated	310	0.0183	0.95	282	90.9	65.9
	On surface	25674	0.0081	0.99	16789	65.4	88.0

Table 3. Mineralization fractions of *TOC*, *OOC* and *ON* of the undigested and limed sewage sludge incorporated and on soil surface, calculated using the equations adjusted for different periods of degradation time

TOC	**Form of application**	**40 days**		**131 days**		**365 days**	
		$TOC_{(min)}$	$MFTOC_{(aj)}^{(2)}$	$TOC_{T(min)}$	$MFTOC_{(aj)}^{(2)}$	$TOC_{(min)}$	$MFTOC_{(aj)}$
		(dag kg^{-1})	**(%)**	**(dag kg^{-1})**	**(%)**	**(dag kg^{-1})**	**(%)**
	Incorporated	0.73	72.3	0.99	98,5	1.00	100.0
	On surface	20.2	61.6	31.4	95.6	32.9	100.0
OOC	**Form of application**	**40 days**		**131 days**		**365 days**	
		$OOC_{(min)}$	$MFOOC_{(aj)}^{(2)}$	$OOC_{(min)}$	$MFOOC_{(aj)}^{(2)}$	$OOC_{(min)}$	$MFOOC_{(aj)}$
		(dag kg^{-1})	**(%)**	**(dag kg^{-1})**	**(%)**	**(dag kg^{-1})**	**(%)**
	Incorporated	0.74	76.3	0.96	99.1	0.97	100.0
	On surface	13.7	69.4	19.4	97.9	19.8	100.0
ON	**Form of application**	**40 days**		**131 days**		**365 days**	
		$ON_{(min)}$	$MFON_{(aj)}^{(2)}$	$ON_{(min)}$	$MFON_{(aj)}$	$ON_{(min)}$	$MFON_{(aj)}$
		(dag kg^{-1})	**(%)**	**(dag kg^{-1})**	**(%)**	**(dag kg^{-1})**	**(%)**
	Incorporated	161	51.9	282	90.9	309	99.9
	On surface	7105	27.7	16789	65.4	24338	94.8

Andrade et al. (2005) found mineralization fraction between 7 and 22% of sewage sludge, quantified under laboratory conditions, without specification of degradation time. Moretti et al. (2013) analyzed the mineralization of a compound produced from digested sewage sludge mixture with tree pruning, incorporated into the soil and incubated for 147 days in laboratory conditions and obtained adjusted $MFON_{(aj)}$ of 11.7%. In this case, the low mineralization rates obtained are due to the likely higher carbon:nitrogen ratio (C:N ratio) and the stability of the material under laboratory conditions.

In the estimates, in this study, of LS mineralization fractions in 365 days, the values achieved surpassed 94.8%, regardless of the reference used (*TOC*, *OOC* and *ON*) and the form of disposal of the organic residue to the soil. The higher mineralization fractions estimated, besides Pereira et al. (2015), are due to several factors provided by the field conditions: higher volume of soil in contact with the residues; the fact that it is an open system, which allows the free flow of solutes and soil meso-organisms (insects, arthropods); and soil and weather conditions, such as rainfall and incident solar radiation.

4. Conclusions

The mineralization coefficients and mineralization fractions of total and easily oxidizable organic carbon and organic nitrogen showed that the secondary undigested sewage sludge, generated in the limed sewage aerobic treatment, mineralizes more quickly when incorporated into the soil than when disposed on soil surface.

Undigested sewage sludge, even when limed, regardless of its disposal to the soil, showed mineralization fraction higher than 95% in the studied soil.

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