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Nitrogen supply to arugula from pig slurry composts in contrasting soils

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ABSTRACT

This study was developed to evaluate nitrogen (N) supply to arugula from composts produced by automated composting of pig slurry (PS). During the composting process, retorted oil shale (ROS) and dicyandiamide (DCD) were added to PS to mitigate gaseous N losses. The study was developed in a greenhouse where four treatments were evaluated, three with compost addition (PS compost, PS compost + ROS, and PS compost + ROS + DCD) and one without compost (control) in two contrasting soils (clayey and sandy-loam). The best result was obtained with the compost without additives (PS compost), which increased the arugula dry matter yield 2.2 times in clayey soil and 6.1 times in sandy-loam soil compared to the control treatment. The presence of ROS in composts reduced arugula dry matter yield in 27% in clayey soil and 35% in sandy-loam, while DCD did not affect arugula dry matter yield. The results of this study show that the addition of ROS to PS during composting reduces N supply to arugula, both in the immediate (first cut) and residual effect (second cut).

Keywords: *Eruca sativa*, automated composting, retorted oil shale, dicyandiamide.

RESUMO

Fornecimento de nitrogênio à rúcula por compostos de dejetos de suínos em solos com características contrastantes

O estudo foi desenvolvido para avaliar o fornecimento de nitrogênio (N) à rúcula através de compostos obtidos por compostagem automatizada de dejetos líquidos de suínos (DLS). Durante a compostagem, xisto retortado (XR) e dicianodiamida (DCD) foram adicionados aos DLS para mitigar as perdas gasosas de N. O estudo foi realizado em casa de vegetação, com quatro tratamentos, sendo três com aplicação dos compostos (composto DLS, composto DLS + XR e composto DLS + XR + DCD) e um sem aplicação de composto (testemunha), em dois solos contrastantes [argiloso (Latossolo) e franco-arenoso (Argissolo)]. O melhor resultado foi obtido com o composto sem aditivos (composto DLS), o qual aumentou a produção de matéria seca da rúcula em 2,2 vezes no Latossolo e 6,1 vezes no Argissolo, comparado ao tratamento testemunha. A presença do XR nos compostos reduziu a produção de rúcula em 27% no Latossolo e em 35% no Argissolo, enquanto a presença de DCD não afetou a produção de matéria seca da rúcula. Os resultados deste estudo indicam que a adição de XR aos DLS durante a compostagem diminui o fornecimento de N à rúcula, tanto no efeito imediato (1º corte) quanto residual (2º corte).

Palavras chave: *Eruca sativa*, compostagem automatizada, xisto retortado, dicianodiamida.

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Intensive pig farming generates a large volume of liquid manure, including mixing of feces, urine, food scraps, and water from the troughs and from the washing of the premises. While pig slurry (PS) contains nutrients to plants, improper use as a fertilizer can result in contamination of soil, air and water resources. Composting of PS is considered an important alternative for manure management, as it produces a stable, sanitized and nutrient-rich organic material (Bernal *et al*., 2017), which facilitates its use as organic fertilizer.

Automated composting consists of frequent PS applications on substrates with high C/N ratio (Oliveira & Higarashi, 2006).The application of PS and turning of the compost piles are done simultaneously with a machine, which provides reduction in labor. Therefore, it is possible to apply a larger volume of PS to substrates compared to traditional composting, where PS is added to the substrate at the beginning of the composting process (Oliveira, 2004). Because PS is added several times during composting, the final compost is likely to be rich in nitrogen, which improves its potential as nutrient source to crops.

There is a lack of researches investigating the agricultural use of composts obtained by automated composting of PS, as this process had been recently introduced in Brazil (Doneda, 2014). Using a dose of 18.4 t ha^{-1} of the compost obtained by this process in lettuce, Cantú (2014) found 1.77 t ha^{-1} leaf dry matter yield in the first crop (immediate effect) and 1.62

t ha^{-1} in the second crop (residual effect) corresponding to an increase of 0.94 and 1.39 t ha^{-1} relative to the control, respectively. These yields are higher than those found by Parizotto & Pandolfo (2009), which ranged from 0.25 to 0.75 t ha^{-1} with increasing doses (0, 10, 20 and 40 t ha^{-1}) of a compost obtained by traditional composting method. According to Cordovil *et al.* (2007), the yield of crops fertilized with composts is associated to compost N mineralization rate. Therefore, it is important to evaluate the N supply potential of the compost obtained with automated composting.

Although the use of automated composting has several advantages over traditional composting, as cited above, there are still doubts, especially in regard to the amount of N loss by ammonia (NH_3) volatilization and denitrification during the process. Several strategies have been evaluated to mitigate such losses, especially the use of additives during composting (Barthod *et al.*, 2018), such as: acids (Doneda, 2014), zeolites (Giacomini *et al.*, 2014) and retorted oil shale (Giacomini, 2017). Nitrogen loss by denitrification during composting can be reduced through the use of nitrification inhibitors, as demonstrated by Luo *et al.* (2013) with dicyandiamide (DCD), which inhibits the first step of the nitrification process. Luo *et al.* (2013) and Jiang *et al.* (2016) noted that the DCD addition during the composting process increases the N content in the final compost.

The effects of additives applied to the soil on microorganism's activity are known. Doumer *et al.* (2011) found that application of ROS to soil improved the soil microbial activity and did not reduce microbial biomass and also did not impact the soil enzymatic activity. Regarding DCD, Singh *et al.* (2008) did not observe adverse impact of DCD application on soil respiratory activity or microbial biomass. The same was observed by O'Callaghan *et al.* (2010) who found that DCD application to the soil did not change the diversity of the soil bacterial community. However, DCD could reduce the population size of ammonia-oxidising bacteria (O'Callaghan *et al.*, 2010), the microbes targeted by DCD. According to our knowledge there are no studies evaluating the effect of the presence of these additives in the final compost on a soil microbiota.

There are several studies involving the use of additives to reduce N losses during composting (Barthod *et al.*, 2018; Cáceres *et al.*, 2018), but none have evaluated the effect of additives on the N supply potential of the compost to crops. Moreover, there is still no recommendation for specific application dose of composts produced by automated composting of PS. The use of inadequate doses may result in economic loss and environmental damage. This study aimed to evaluate how the addition of retorted oil shale and dicyandiamide to PS during automated composting affects N supply to arugula in two soils with contrasting characteristics.

MATERIAL AND METHODS

The soils were collected from the surface layer (0-10 cm depth) of two experimental areas that were managed for more than 10 years under a no-till system in the state of Rio Grande do Sul, Southern Brazil. The clayey soil, classified as a Rhodic Hapludox (Soil Survey Staff, 2014), was collected at the experimental area of Fundacep/CCGL, located in Cruz Alta-RS, Brazil (28°33'S, 53°40'W). The sandy-loam soil, classified as Typic Paleudalf (Soil Survey Staff, 2014), was collected at the experimental area of the Soils Department of the Universidade Federal de Santa Maria, located in Santa Maria-RS, Brazil (29°42'S, 53°42'W). The main characteristics of the soils follow: 5.1 pH_{H2O}; 2.4% total C; 0.22% total N; 8.0 mg NH_4^+-N/kg; 19.9 mg NO_3^--N/kg; 13.8 CEC ($cmol_c/dm^3$); 38.7 mg dm^{-3} P-Mehlich-I; 228.0 mg dm^{-3} K; 5.7 $cmol_c$ dm^{-3} Ca; 2.5 $cmol_c$ dm^{-3} Mg; 50.9% clay; 21.5% silt and 27.6% sand for the Rhodic Hapludox (clayey soil); and 4.7 pH_{H2O}; 0.8% total C; 0.08% total N; 9.6 mg NH_4^+-N/kg; 5.8 mg NO_3^--N/kg; 7.6 CEC ($cmol_c/dm^3$); 33.8 mg dm^{-3} P-Mehlich-I; 81.3 mg dm^{-3} K; 1.9 $cmol_c$ dm^{-3} Ca; 0.6 $cmol_c$ dm^{-3} Mg; 10.7% clay; 29.6% silt and 59.8% sand for the Typic Paleudalf (sandy-loam soil). The soils were gently crumbled, sieved at 4 mm and visible organic residues were manually removed.

The three compost treatments evaluated in this study were: 1) Pig slurry (PS) compost produced without additives to PS during composting (PS compost); 2) PS compost + retorted oil shale (ROS) produced with ROS addition to PS during composting (PS compost + ROS) and 3) PS compost + ROS + dicyandiamide (DCD) produced with ROS and DCD addition to PS during composting (PS compost + ROS + DCD). PS compost was made by mixing sawdust (70%) and wood shavings (30%) with PS in an automated composting for 245 days.The additives (ROS and DCD) were added 15 times with the PS to the piles, during 133 days of the automated composting to mitigate NH_3, CH_4 and N_2O emissions (Giacomini, 2017). Total organic carbon (TOC) and nitrogen of the composts were determined by dry combustion in Flash EA 1112 Automatic Elemental Analyzer, while inorganic N content was determined according to Tedesco *et al.* (1995). The main characteristics of the composts are shown in Table 1.

This study was conducted during 58 days in a greenhouse (August 20, 2015 to October 17, 2015). The treatments consisted of two contrasting soils (sandy-loam and clayey), three types of composts (PS compost, PS compost + ROS and PS compost + ROS + DCD) and a control treatment for each soil texture (unamended soil), totaling eight treatments. The treatments were arranged as a completely randomized design with four replicates. In each experimental unit, dry clayey and sandy-loam soils (5.5 and 6.5 kg, respectively) were placed in an 8 L pot with 24 and 20.5 cm top and base diameters and 21 cm height. The composts were thoroughly mixed with the soil at 37.2 g/kg of soil for PS compost, 90.2 g/kg of soil for PS compost + ROS and 83.3 g/kg of soil for PS compost + ROS + DCD. These doses were equivalent to an addition of 5.5 g total N/pot (1.0 t total N ha^{-1}) in the clayey soil and 6.5 g total N/pot (1.4 t total N ha^{-1}) in the sandy-loam soil. The compost doses were established according to N requirements of arugula (*Eruca sativa*) according to the technical local recommendation (CQFS-RS/SC, 2004) and assuming a mineralization index of 10% of total compost N (Cantú, 2014).

The arugula was selected due to its high N demand [100-180 kg N ha^{-1} (CQFS-RS/SC, 2004)] and the short vegetative cycle (30-40 days). Two plants were transplanted from tubes to each pot. Plants were grown in a controlled level of soil moisture (80% of field capacity) in a greenhouse. Moisture was controlled by periodically weighing the pots and adding water when needed. The first cut of arugula was made 28 days after transplanting. Leaves were cut 6.0 cm from the soil surface to determine fresh matter and dry matter yields. The second cut was made 58 days after transplanting. At this time, the root production of arugula was also quantified. Leaves and roots were dried in forced air oven at 65°C during 24 h to determine dry matter yield. The dried tissues were ground in a ball mill and total N concentration was determined by dry combustion in CHNS Elemental Analyzer (ThermoFinnigan Flash EA 1112, Milan, Italy).

The accumulation of N by plants was calculated by multiplying leaf and root dry matter yield by N concentration of each constituent. Net N accumulation by arugula was calculated as the difference between the treatments that received N addition via composts and the unfertilized treatment (control). The apparent nitrogen recovery (ANR) with the composts by arugula in the first and second cuts was calculated according to the equation proposed by Craswell & Godwin (1984):

$$ANR = \frac{Nuptake_F - Nuptake_C}{FertilizerNapplied} x\ 100$$

where: ANR is the apparent N recovery (%); N $uptake_F$ (mg/pot) is the amount of N accumulated by the plants supplied with N fertilizer; N $uptake_C$ (mg/pot) is the amount of N absorbed by the plants in the unfertilized control; and Fertilizer N applied (mg/pot) is the N rate applied with the composts.

Fresh and dry matter yields and the amount of N uptaken by arugula were submitted to analysis of variance (ANOVA), considering the soil type, the composts and their interaction. The means between soils were compared by Tukey test at 5% and within each soil by orthogonal contrasts, comparing the influence of the compost (Composts vs. Control), the influence of the additives (Compost without additives vs. Composts with additives) and the influence of DCD (Compost + ROS vs. Compost + ROS + DCD).The differences were considered significant at p≤0.05.

RESULTS AND DISCUSSION

The differences in characteristics of the two soils influenced arugula yield, which was higher in the clayey soil. Leaf fresh matter yield in the control treatments was 2.2 times higher in the clayey soil than in the sandy-loam soil in the first cut and 8.0 times higher in the second cut (Table 2). This same trend was observed in leaf dry matter yield. The higher yield potential of arugula in the clayey soil is mainly associated to the total soil organic carbon (TOC), which was three times higher than that of the sandy-loam soil. Mineralization of soil organic N increased N availability, which can be observed in the amount of N accumulated in the leaves of the control treatment, which was 3.3 times higher in the clayey soil than in the sandy-loam soil in the first cut and 6.3 times in the second cut (Table 3). The higher nutrient content in the clayey soil than in the sandy-loam soil may also have favored arugula production, as found by Villas Bôas *et al*. (2004), who noted that biomass lettuce yield was directly related to soil TOC content.

The results showed a significant interaction between soils and composts, indicating that arugula responded differently to treatments, depending on soil type. The average leaf fresh and dry

Table 1. Characteristics of pig slurry (PS) composts (dry basis) and doses added to clayey and sandy-loam soils. Santa Maria, UFSM, 2015.

Treatments	DM	Total C	Total N	NH_4^+-N	NO_3^--N	C/N	pH
	(g kg^{-1})						
PS Compost	335.0	378.4	26.9	0.41	0.022	14.1	6.6
PS Compost + ROS	525.0	257.9	11.0	0.15	0.002	23.4	6.4
PS Compost + ROS + DCD	522.0	231.9	12.0	0.17	0.001	19.3	7.8
Clayey soil	**Application dose**						
	(g/pot)			**(mg/pot)**			
PS Compost	204.5	77.4	5.5	83.8	4.5		
PS Compost + ROS	500.0	129.0	5.5	75.0	1.0		
PS Compost + ROS + DCD	458.3	106.3	5.5	77.9	0.5		
Sandy-loam soil							
PS Compost	241.7	91.4	6.5	99.1	5.3		
PS Compost + ROS	590.9	152.4	6.5	88.6	1.2		
PS Compost + ROS + DCD	541.6	125.6	6.5	92.1	0.6		

DM= dry matter; ROS= retorted oil shale; DCD= dicyandiamide.

matter yields in the treatments with the composts application increased by 4.3 and 4.9 times in the first cut in the sandy-loam soil, while these increases were only 2.4 and 2.6 times in the clayey soil, respectively. Although arugula yields increased with addition of composts in both soils (Table 2, contrast A vs. B, C, D), the best response observed in the sandy-loam soil was due to its lower nutrient supply capacity (especially N) as indicated by the low arugula yield in the control treatment. Thus, the results showed greater crop dependence on external nutrient supply in soils with lower organic matter content.

Among the three compost treatments (Table 3, contrast B vs. C, D), the best results in terms of N accumulation and fresh matter yield in both cuts and dry matter yield in the second cut were found in PS compost. One of the hypotheses to justify the average reduction of 30.5% in total dry matter yield of arugula in the two treatments with additives (PS compost + ROS and PS compost + ROS + DCD) in relation to PS compost is the possible effect of ROS on reducing the mineralization of the two composts in soil. In the study of Leão *et al*. (2014), the addition of ROS to the soil reduced C mineralization of soybean crop residues. This suggests that due to its lamellar structure and high specific surface area (Pimentel *et al*., 2006), ROS can favor physical and chemical protection of soil organic matter (SOM) and the adsorption of labile C, hindering its decomposition by soil microbial biomass (Doumer *et al*. 2011), however, more specific studies are necessary to confirm this hypothesis. If confirmed, this would indicate that although ROS reduces compost N availability, its use during composting would increase C retention in soil with the agricultural use of the compost as fertilizer.

The effect of DCD on arugula was found only in fresh matter yield of the second cut in both soils (Table 2, contrast C vs. D), where it increased the average yield by 27.5% (Table 2). Although dry matter yield of the second cut increased with the use of DCD in 33% in the clayey soil and in 42% in the sandy-loam soil, these increases were not significant (p=0.07 and p=0.06, respectively). Table 3 shows that there was also an increasing trend in N availability to arugula in the second cut, where N accumulation increased by 56% in the clayey soil and 62% in the sandy-loam soil. The lower C/N ratio of PS compost + ROS + DCD compared to PS compost + ROS (19.3 vs. 23.4, Table 1) may have facilitated N decomposition and release to the soil of PS compost + ROS + DCD. Probably, the DCD addition during composting has reduced N losses by denitrification, which reduced the C/N ratio of the final compost.

Nitrogen accumulation by arugula increased in treatments with compost addition (Table 3, contrast A vs. B, C, D) in both cuts and in both soils. The increase was greater in the treatment

Table 2. Fresh and dry matter yields of arugula after the application of pig slurry (PS) composts with and without the addition of retorted oil shale (ROS) and dicyandiamide (DCD) in clayey and sandy-loam soils. Santa Maria, UFSM, 2015.

Treatments	Fresh matter (g/pot)			Dry matter (g/pot)			
	1st cut	2nd cut	Total	1st cut	2nd cut		Total
	Leaves	Leaves		Leaves	Leaves	Roots	
Clayey soil							
Control (A)	16.42 a	20.89 a	37.31 a	1.21 a	1.40 a	0.38 a	2.99 a
PS Compost (B)	44.17 a	36.40 a	80.57 a	3.38 a	2.74 a	0.60 a	6.72 a
PS Compost + ROS (C)	37.97 a	15.10 a	53.08 a	3.09 a	1.08 a	0.56 a	4.73 a
PS Compost+ ROS + DCD (D)	36.58 a	19.24 a	55.82 a	3.11 a	1.44 a	0.47 a	5.02 a
Contrasts				(*p value*)			
A vs. B, C, D	<0.01	0.04	<0.01	<0.01	0.03	<0.01	<0.01
B vs. C, D	<0.01	<0.01	<0.01	0.14	<0.01	<0.01	<0.01
C vs. D	0.19	0.01	0.07	0.94	0.07	0.01	0.26
Sandy-loam soil							
Control (A)	7.59 b	2.60 b	10.19 b	0.48 b	0.28 b	0.06 b	0.82 b
PS Compost (B)	43.48 a	23.40 b	66.88 b	2.98 a	1.79 b	0.26 b	5.03 b
PS Compost + ROS (C)	26.43 b	11.83 b	38.26 b	1.99 b	0.91 a	0.20 b	3.10 b
PS Compost+ ROS + DCD (D)	27.76 b	15.15 b	42.91 b	2.11 b	1.29 a	0.18 b	3.58 b
Contrasts				(*p value*)			
A vs. B, C, D	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
B vs. C, D	<0.01	<0.01	<0.01	<0.01	<0.01	0.02	<0.01
C vs. D	0.21	0.03	<0.01	0.57	0.06	0.66	0.07

The letters in the columns compare same treatment between soils, according to Tukey test ($p \leq 0.05$).

Table 3. Accumulation and apparent nitrogen recovery (ANR) by arugula after the application of pig slurry (PS) composts, with and without the addition of retorted oil shale (ROS), and dicyandiamide (DCD) to clayey and sandy-loam soils. Santa Maria, UFSM, 2015.

Treatments	N accumulation (mg/pot)				ANR	
	1st cut	2nd cut		Total	1st cut	2nd cut[1]
	Leaves	Leaves	Roots			
Clayey soil					(%)	
Control (A)	74.2 a	79.5 a	9.6 a	163.3 a	-	-
PS Compost (B)	197.3 a	103.6 a	14.3 a	315.2 a	2.2 a	0.5 a
PS Compost + ROS (C)	151.7 a	25.1 a	12.3 a	189.1 a	1.4 a	-0.9 b
PS Compost + ROS + DCD (D)	158.3 a	39.3 a	10.1 a	207.7 a	1.5 a	-0.7 b
Contrasts			*(p value)*			
A vs. B, C, D	<0.01	<0.01	<0.01	<0.01	-	-
B vs. C, D	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
C vs. D	0.60	0.08	0.02	0.21	0.51	0.12
Sandy-loam soil		(mg N/pot)			(%)	
Control (A)	22.2 b	12.6 b	1.2 b	36.0 b	-	-
PS Compost (B)	172.2 a	58.7 b	7.1 b	238.0 b	2.3 a	0.8 a
PS Compost + ROS (C)	87.5 b	24.1 a	3.9 b	115.5 b	1.0 b	0.2 a
PS Compost + ROS + DCD (D)	89.5 b	39.0 a	4.2 b	132.7 b	1.0 b	0.5 a
Contrasts			*(p value)*			
A vs. B, C, D	<0.01	<0.01	<0.01	<0.01	-	-
B vs. C, D	<0.01	<0.01	<0.01	<0.01	<0.01	<0.01
C vs. D	0.87	0.07	0.72	0.24	0.88	0.09

[1]Leaves + roots. Letters in the columns compare same treatments between soils, Tukey test ($p \leq 0.05$).

without additives (PS compost) than in those with the addition of ROS and DCD (Table 3, contrast B vs. C, D). The net N accumulation by arugula in the first cut was 123.1 mg/pot in PS compost and 80.8 mg/pot in the average of the treatments with additives in the clayey soil and 150.0 and 66.3 mg/pot in the sandy-loam soil, respectively. The amounts of mineral N added were 88.3 mg/pot in PS compost and 77.2 mg/pot in the average of treatments with additives in the clayey soil and 104.4 and 96.7 mg/pot in the sandy-loam soil, respectively (Table 1). These results show that most of the N accumulated by arugula in the first cut was already in the mineral form in the composts when they were added to soil. In the second cut, only arugula of PS compost accumulated more N (24.1 mg/pot) than in the control treatment in the clayey soil. In the sandy-loam soil, N accumulation by arugula of PS compost surpassed the control treatment in 46.1 mg/pot as well as the average of the two treatments with additives in 27.2 mg/pot. It is likely that the decomposition and nitrogen release of the composts added to the sandy-loam soil were favored, increasing N availability to arugula in the second cut. In an incubation study by Nendel *et al*. (2004), N mineralization of organic composts was higher in soils with lower clay content. This occurred because the lower physical protection of sand compared to clay facilitated the access of the soil microorganisms to the composts.

Nitrogen accumulation by arugula of the control treatment in the clayey soil in the second cut was close to that found in the first cut. On the other hand, N accumulation in treatments with compost addition was lower in the second cut than in the first one. In the treatments with ROS and ROS + DCD, N accumulation was even lower than in the control treatment. In the sandy-loam soil, N accumulation decreased in all treatments in the second cut. These results show the small residual effect of compost N, in addition to the possibility of microbial immobilization of soil N when composts with ROS and ROS + DCD were added to the clayey soil. Giacomini (2017) found that the addition of ROS to PS reduced the decomposition rate of the mixture of PS with substrate during composting. According to Pimentel *et al*. (2006), ROS composition (mainly of minerals, quartz, feldspads, micas, in addition to pyrite and carbonates), promotes chemically and physically protection of organic carbon, reducing its availability to heterotrophic microorganisms. According to Cambardella *et al*. (2003), organic substrates that partially decompose due to sub-optimal conditions during the composting process can be degraded after compost incorporation into the soil. Therefore, it is likely that the decomposition of the composts with ROS continued after application to soil, favoring microbial immobilization of N and reducing availability to arugula in the second cut.

The apparent nitrogen recovery (ANR) by arugula with PS compost did not exceed 2.2% in the clayey soil and 2.3% in the sandy-loam soil in the first cut. In the second cut, only 0.5% of the N applied in this treatment was recovered by arugula in the clayey soil and 0.8% in the sandy-loam soil. In the study of Yang *et al*. (2004), the ANR by ryegrass with pig slurry compost application (795 kg total N/ha) was 3.3% after 20 weeks of cultivation. In two successive crops of lettuce, Cantú (2014) found 12.7% ANR of the applied N (500 kg N ha^{-1}) to soil via pig slurry compost which was produced through automated composting. These results show that in spite of the addition of high amounts of N through 15 applications of PS in 245 days of composting (Giacomini, 2017), the organic N of the compost was slowly mineralized after addition to soil. This confirms the results of studies that found a high proportion of organic carbon and nitrogen of composts being recalcitrant and resistant to microbial degradation (Cordovil *et al*., 2005; Ribeiro *et al*., 2010; Masunga *et al*., 2016). This aspect is not different in the compost of PS obtained through automated composting process.

The results of this study show that the exclusive use of the compost was able to sustain arugula yield only in the first cut, even at high doses. In crops where more than one cut is normally done, as is the case of arugula, nitrogen fertilization after the first cut is necessary, since the organic N mineralization of the compost is low. The use of ROS and ROS + DCD to reduce N losses during composting reduced the efficiency of the composts in supplying N to arugula.

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