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ORIGINAL RESEARCH

Vermicompost enrichment using organic wastes: Nitrogen content and mineralization

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Abstract

Purpose This study performed a feasibility assessment of nitrogen enrichment by some organic wastes through vermicomposting as well as its release as a bioavailable form over time.

Methods Soybean and canola wastes as well as the dairy blood powder of industrial slaughterhouse were used as organic wastes to enrich the vermicompost. Composted materials were incubated for nitrogen mineralization kinetic assessment by adjusting moisture content to 50% at 30 ˚C for 80 days. During the incubation, moisture was maintained by weighing. Subsamples were collected after 1, 5, 10, 20, 40, 60, and 80 days of incubation.

Results Among the treatments, those for 25% dairy blood powder contained the highest nitrogen content (4.95 and 3.70% for chicken and cow blood powder, respectively). Nitrogen mineralization through 80 days of incubation ranged from 2.23% (for 50% canola waste treatment) to 2.57% (for 25% blood powder) of the total nitrogen. The mineralization rate ranged from 4.24 and 3.62 mg kg^{-1} day^{-1} for the compost containing 25% chicken and cow blood powder, respectively, to 0.94 and 0.84 mg kg^{-1} day^{-1} in canola and soybean waste, respectively, whereas those for the control treatment equaled 0.81 mg kg^{-1} day^{-1}.

Conclusion Composts containing 25% blood powder were acceptable in terms of quantity and nitrogen release over time, and can serve as a reliable source of available nutrients in the soil.

Keywords Vermicompost, Enrichment, Nitrogen, Mineralization

Introduction

Optimizing the application of organic wastes to improve soil fertility and productivity while minimizing environmental implications is necessary for sustainable agriculture (Masunga et al. 2016). Agricultural, industrial, and municipal organic wastes can be used as recyclable composting materials and promising inputs to protect soil and water resources (Quilty and Cattle 2011). Improving water retention capacity (Williams et al. 1992), soil aggregate stability (Oades 1993) and compactibility (Keller and Dexter 2012), cation exchange capacity (Oorts et al. 2003; Garcia-Gil et al. 2004), and nutrient cycles (Kirkby et al. 2011), and increasing microbial activity, are among the short- and long-term physical, chemical, and biological effects of organic residues. Research on the long-term field application of organic residues shows that these residues increase the yield and availability of nutrients and reduce the need for mineral and chemical fertilizers (Whalen and Chang 2002; Antil et al. 2005). The bioavailability of nutrients in organic residues is influenced by the prevailing conditions of carbon and nitrogen mineralization (Baldock and Nelson 2000). Mineralization of organic nitrogen is a biological process, and the amount and rate of nitrogen release depend on the soil's physical, chemical, and biological properties as well as the chemical composition of the organic matter, such as its carbon-nitrogen ratio (C/N) and the content of cellulose, hemicellulose, lignin, and polyphenols (Mohanty et al. 2011). Knowledge of nitrogen mineralization rates of organic residues entering agricultural lands can play an effective role in the optimized utilization of organic matters, so as to prevent the excessive use of chemical fertilizers and reduce the biological impacts caused by the released nitrogen. Bruun et al. (2006) used labeled nitrogen to study the net rates of nitrogen mineralization from 75

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organic compounds. They reported that the C/N ratio was the most important factor in nitrogen mineralization rate (Bruun et al. 2006). Many equations have been employed to explain the kinetics of soil chemical processes, including the zero-, first-, and second-order kinetic models, the exponential function (the two-constant rate equation), the parabolic diffusion equation, and the Elovich equation. These equations can be employed to obtain rate coefficients, using which the activation energy can be determined to gain information related to the rate-limiting step (Sparks 1989). Kumar et al. (2002) studied the kinetics of nitrogen mineralization in the wastes of sugar beet byproduct-based industries in a 120-day period. They reported that a double exponential function explained the nitrogen release process in the following equation:

$$N_m = N_L[1-\exp(-k_L t)]+kt \quad (1)$$

where K_L and K denote the rate constants of the zero- and first-order equations, respectively, N_L the mineralizable nitrogen, and N_m the mineralized nitrogen at time t. Masunga et al. (2016) used a first-order equation to express nitrogen mineralization from various residues added to the soil:

$$N_{min}(t) = k \times t \times C \quad (2)$$

Due to the insufficient soil organic matter content, especially in arid and semi-arid areas in Iran (Samavat 2007; Jamshidi et al. 2012; Khayamim and Khademi 2015), low nutrient availability, poor soil structure, and low soil water-holding capacity (Raiesi 2006), the utilization of organic residues (mainly in the form of decomposed manure and vermicompost) markedly improves soil condition and crop yield (Golchin 2016). One problem with the utilization of decomposed organic matter is the long time required for the complete decomposition of residues. The use of vermicompost as an organic fertilizer has attracted farmers' interest. Vermicompost results from the concurrent biological activities of earthworm species and soil microorganisms on various animal wastes as well as on agricultural, urban, and industrial wastes (e.g., those of the food, wood, and paper industries), and turns these wastes into stable compounds with minimal environmental impacts (Logsdon 1994; Singh and Sharma 2002; Suthar 2006; Suthar 2007; Tejada et al. 2009). Nevertheless, vermicompost prices are high and its nutrient content is low in Iran, and large quantities of vermicompost are required per unit area of land. Therefore, farmers are losing interest in utilizing vermicompost (Sahraie and Zarafshani 2015). Vermicompost enrichment through the addition of various ingredients, including beneficial microorganisms (Kumar and Singh 2001; Padmavathiamma et al. 2008; Rao et al. 2017), minerals (Adamtey et al. 2009; Ramos et al. 2017), and enriched food material wastes (Song et al. 2014; Das et al. 2016a,b) can improve the nutrient content and quality of the produced composts. However, it seems necessary to know the availability and release processes related to nutrients present in the final product, and also environmental problems. In the present research, various wastes, including soybean and canola straw as well as cattle and chicken dried blood, were added to the raw materials needed for vermicompost production, and was aimed to investigate the degree of nitrogen enrichment and the kinetic release of available nitrogen in the resulting vermicompost.

Materials and Methods

Site description and experimental design

The experiment was conducted in 2018 at the Agricultural Research Field of the Islamic Azad University of Karaj, Iran. The climate is semiarid, with mean annual precipitation and Class A pan evaporation of 247 and 2200 mm, respectively. An experiment using a completely randomized design with 13 treatments and three replications was conducted to determine the feasibility of utilizing agricultural and animal waste in producing vermicompost. For this purpose, soybean and canola straw and cattle and chicken dried blood were used as livestock waste additives to prepare the main substrate for vermicompost production.

Experimental treatments

The dried blood powders of cattle and chicken were obtained from slaughterhouses in Karaj, and soybean and canola residues were provided from farms around the research field. Prior to analysis, samples were dried at 65°C, ground to pass through 0.5 mm sieve (Campbell and Plank 1992). Organic carbon (OC) was measured using the Walkley-Black (wet oxidation) method (Nelson and Sommers 1996), and total nitrogen was measured by employing the Kjeldahl method (Bremner 1996). Results of chemical analysis performed on animal and agricultural waste are presented in Table 1. The control treatment contained 1500 grams of 6-month-old cattle manure (Animal waste is mainly used in vermicompost production in Iran). There were 13 enriched treatments, including 25wt. % (25% waste + 75% cattle manure), 50 wt.% (50% waste + 50% cattle manure), and 75 wt.% (75% waste + 25% cattle manure) in three replications.

Table 1 Chemical analysis of used cow manure and organic wastes

Organic waste	C/N	Organic carbon (%)	Total nitrogen (%)	Moisture (%)
Manure	22.66	27.20	1.20	35
Canola waste	48.31	42.51	0.88	19
Soybean waste	41.35	54.59	1.32	21
Cow blood powder	2.77	39.47	14.23	24
Chicken blood powder	2.68	43.10	16.05	20

Vermicomposting procedure

The wastes as well as cattle were mixed thoroughly, sieved in 1 cm mesh in order to find uniform particle size and to remove undesirable materials, so that the vermicomposting process could be performed properly. Composts were produced in 2.5L polyethylene lidded containers with several openings and 2 cm of gravel at the bottom for drainage. Relative humidity was raised to 75%, and the temperature during the vermicomposting process was kept at 25˚C as well as substrate moisture at 40 wt.% by frequent weighing. At the beginning of the process, 250 mature red worms belonging to species *Eisenia foetida* were added to each container. This large number of red worms was used to accelerate the composting process. Temperature and moisture were continuously controlled during the period the red worms were active. After 10 days, the substrate situation was examined to ensure that the composting process was completed (as indicated by the change in container content and by the attempt the red worms made to leave the container). The substrates were sieved, and the red worms were removed.

Nitrogen release experiment

For carrying out the kinetic release experiment samples for each treatment were kept in an incubator at 30 ˚C and constant 50% moisture content, and subsamples were taken from them 1, 5, 10, 20, 40, 60, and 80 days after incubation to measure their soluble nitrogen contents. For each nitrogen measurement, 5 g of the samples together with 20 ml of 0.05M calcium chloride was put on a shaker for 30 minutes. The suspension was passed through the Whatman filter paper and kept to measure nitrate and ammonium nitrogen. A spectrophotometer was used to measure the concentrations of nitrate and ammonium nitrogen (Motsara and Roy 2008).

Statistical analysis

The data were subjected to analysis of variance and Duncan test of means by use of SAS program as a completely randomized design. Many kinetic models were used and fitted to the information to study the rate of nitrogen mineralization (Table 2). Finally, the best-fit kinetic model was selected, and nitrogen release coefficients were determined using the equation $SE = \sqrt{\frac{(q-q')^2}{(N-2)}}$ in which q and q′ denote the measured and estimated quantities, respectively, and N represents the number of samples.

Table 2 Kinetic models used in this study

Model	Equation	Parameters
Zero-order	$q_t=q_0-k_0t$	K_0, Zero-order rate constant($mgkg^{-1}h^{-1}$)
First-order	$lnq_t=lnq_1-k_1t$	K_1, First- order rate constant(h^{-1})
Second-order	$1/q_t=1/q_2-k_2t$	K_2, Second-order rate constant [$(mgkg^{-1})^{-1}$]
Third-order	$1/q_t^2 =1/q_3^2-k_3t$	K_3, Third-order rate constant[$(mgkg^{-1})^{-2}h^{-2}$]
Parabolic	$q_t=q_0+k_pt^{0.5}$	Kp, diffusion rate constant
Exponential	$q_t=at^{b}$	a, magnitude constant($mg\ kg^{-1}(h^{-1})^b$), and b rate constant
Simple Elovich	$q_t=1/\beta_s ln(\alpha_s\beta_s)+1/\beta_s lnt$	αs, initial constant ($mg\ kg^{-1}\ h^{-1}$)and βs, rate constant [$(mg\ kg^{-1})^{-1}$]

Results and Discussion

Due to the higher protein content of animal tissues compared to plant tissues, their presence in the compost produced from animal wastes leads to higher nitrogen enrichment levels in the treatments containing dried blood (Table 3). Vermicompost nitrogen content was improved when wastes having higher nitrogen content were incorporated. During the vermicompost production process, treatments containing 50 and 75% dried blood were omitted due to the stench and loss of earthworms. The treatments containing 25% chicken or cattle dried blood had the highest average nitrogen contents (4.95 and 3.70%, respectively). A comparison of soybean and canola wastes indicated that treatments containing canola wastes had higher nitrogen content percentages than those containing soybean wastes. These differences were statistically significant when the wastes constituted 50 and 75 wt% of the composts (Table 3).

Table 3 Organic carbon, nitrogen and C/N ration in different vermicompost treatments after 10 days of composting

Vermicompost treatment	Organic carbon (%)	Total nitrogen (%)	C/N	Moisture (%)
Control(100%manure)	21.20(±0.71)	0.98(±0.06) G	21.63	37
25% canola waste+75% manure	23.01(±0.45)	1.34(±0.06) F	17.17	30
25% soybean waste+75% manure	26.12(±0.68)	1.21(±0.03)F	21.59	32
50% canola waste+50% manure	25.12(±0.72)	1.81(±0.06)D	13.89	27
50% soybean waste+50% manure	28.67(±0.66)	1.52(±0.1) E	18.86	30
75% canola waste+25% manure	28.11(±0.81)	2.20(±0.08) C	12.77	26
75% soybean waste+25% manure	34.55(±0.41)	1.65(±0.03) DE	20.94	27
25% chicken blood powder +75% manure	23.34(±0.64)	4.95(±0.16) A	4.71	41
25% Cow blood powder +75% manure	23.98(±0.76)	3.7(±0.06) B	6.48	39

Nitrogen Release Process from the Compost

The quantities of released mineralized nitrogen in various treatments varied depending on the total nitrogen content. During the 80-day incubation period, the percentages of nitrogen mineralization fluctuated from 2.23% in the treatment containing 50% canola residues to 2.57% in the treatment with 25% dried blood from the total nitrogen content (Fig. 1). As illustrated in Fig. 1, the nitrogen mineralization rate was slow at the beginning, but considerably increased when approaching the end of the composting period.

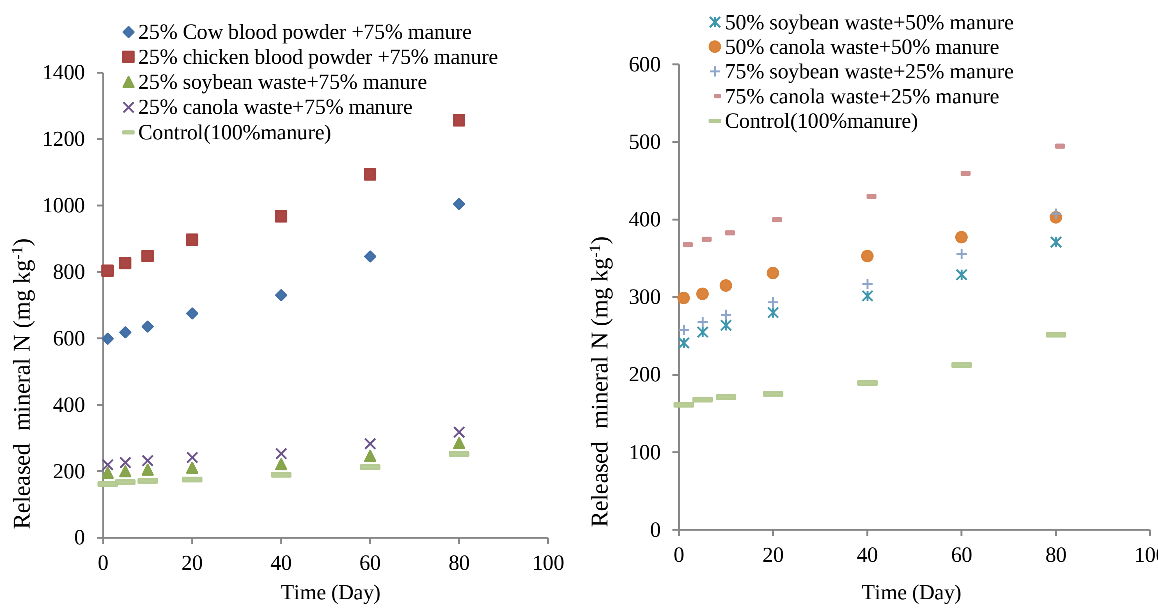

Fig. 1 Inorganic nitrogen release pattern in different vermicompost treatments through 80-day incubation

Kinetic equations were employed for treatments containing 25% of various residue types to better compare mineralization rates and introduce the model that best described nitrogen release (Fig. 2). It was inferred from the coefficients of determination and standard errors of the fitted models that these coefficients increased, while the standard errors decreased, from zero-order to second-order equations, so that we managed to introduce the first-order equation (R^2= 0.99, SE=0.02) and the second-order equation (R^2=0.99, SE=0.001) as the best models for describing the release of mineralized nitrogen. The parabolic diffusion equation (R^2=0.91, SE=22.2), the two-constant rate equation (R^2=0.76, SE=0.06), and a simplified form of the Elovich equation were the kinetic equations with a lower accuracy in estimating the nitrogen mineralization rate (Table 4). Paustian et al. (1997) stated that the first-order kinetic model was suitable for the mineralization of organic residues. A gradual release of N from compost has been shown to follow first order kinetics (Gale et al. 2006; McGinnis et al. 2010). McGinnis et al. (2010) reported 9.5% of initial N content released by vermicomposted dairy manure (40%) amended to pine bark during 16-week incubation. Using the model proposed by Campbell et al. (1991), Raiesi and Kabiri (2017) also studied the nitrogen mineralization rate in a calcareous loam soil under various tillage systems. Moreover, Soodaei Mashaei et al. (2007) reported the first-order kinetic model as the best model expressing nitrogen mineralization in a soil treated with compost, vermicompost, and manure.

Based on the results of the zero-degree equation, the highest nitrogen release rates were recorded in treatments containing 25% cattle and chicken manure (4.81 and 5.43 mg $kg^{-1}day^{-1}$, respectively), whereas the lowest belonged to the control and the treatment with 25% soybean residues, with the average of 1.036 and 1.029 mg nitrogen $kg^{-1}day^{-1}$, respectively (Table 5). Results of fitting the first-order model showed that the treatment containing 25% chicken manure had the highest constant rate (0.006 $mgday^{-1}$), whereas the treatment with 50% canola residues had the lowest constant rate (0.003 mg day^{-1}). Nevertheless, the highest nitrogen mineralization rates in the first-order kinetic model belonged to the treatments containing 25% cattle and chicken manure residues (3.62 and 4.24 mg $kg^{-1}day^{-1}$) and the lowest to the control treatment and the treatment with 25% soybean stems (0.81 and 0.83 mg nitrogen/kg/day, respectively). Therefore, nitrogen mineralization rates were 0.78 and 0.68% in the treatments with cattle and chicken dried blood, and 0.66 and 0.55% in the control treatment and in the treatment containing 25% soybean stems during the 80-day incubation period, respectively. Considering the total nitrogen content in the treatments with 25% cattle and chicken dried blood, these materials can be regarded as considerable sources for satisfying plant nutrition requirements. Geisseler et al. (2019) studied 30 farms in Northern California to enter the total soil nitrogen content into fertilizer requirement calculations, and reported that the nitrogen mineralization rate under the incubation temperature of 25 ˚C varied from 0.7 to 3.5%. By studying nitrogen release from olive and rural waste composts, Cabrera et al. (2005) considered the first-order equation as the best model expressing this process, and reported the constant mineralization rates to be 0.0029 and 0.00092 mg day^{-1}, respectively.

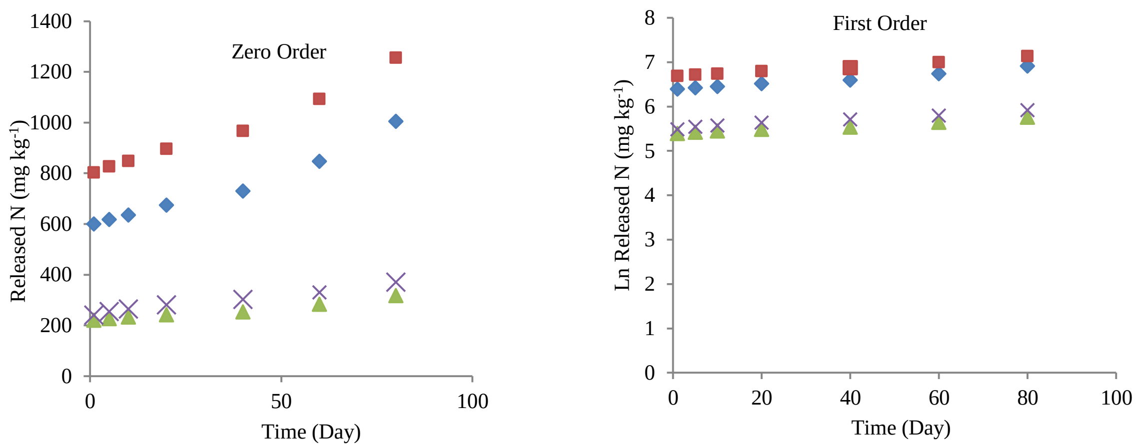

Fig. 2 Fitted kinetic models on 25% organic waste enrichment treatments

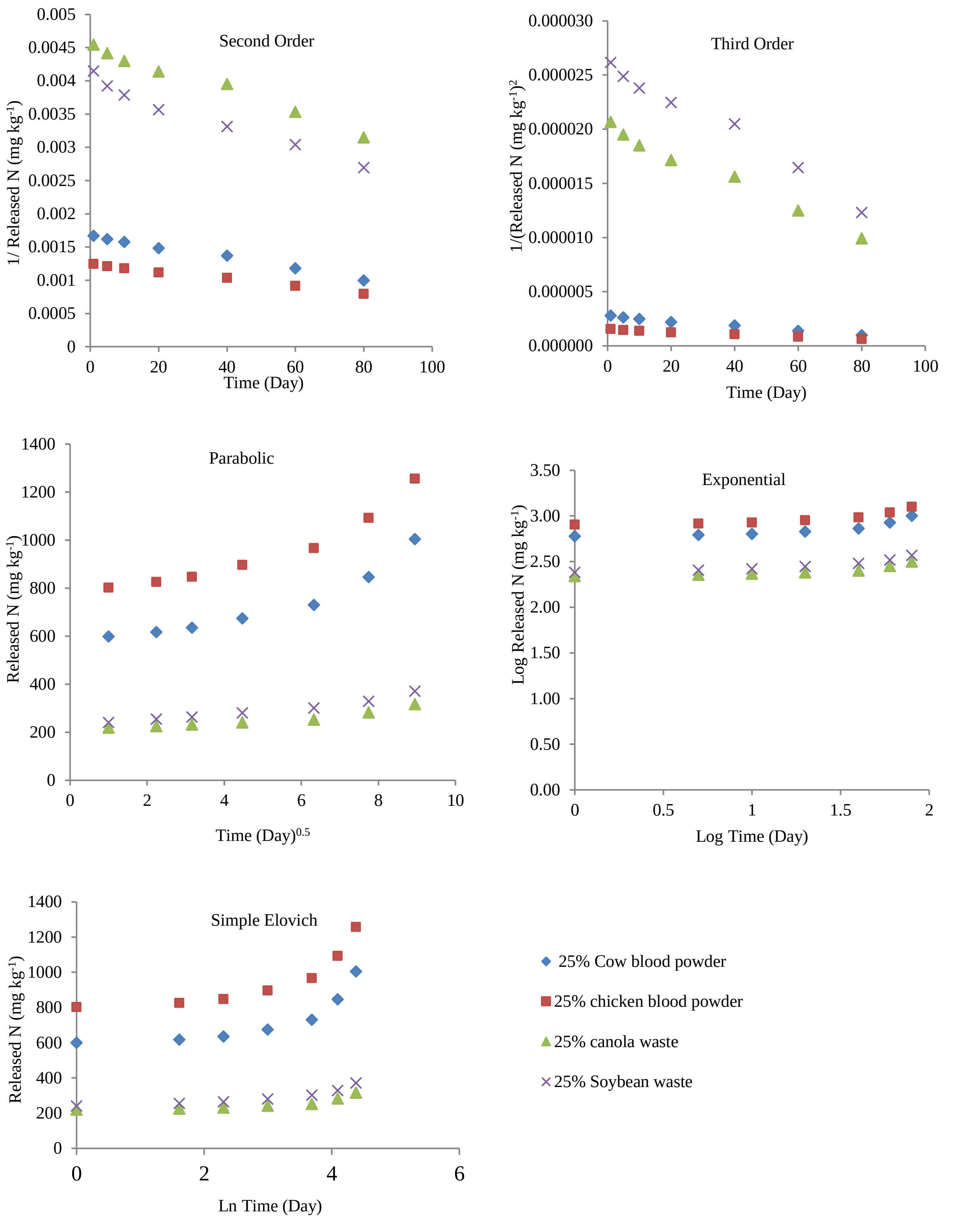

Fig. 2 Continued.

Table 4 Determination coefficient and standard error of kinetic models of nitrogen release of vermicompost treatments through 80 days incubation

Treatment	Zero order	First order	Second order	Parabolic	Exponential	Simple Elovich
	Determination coefficient(SE)					
Control (manure100%)	0.95(8.13)	0.97(0.03)	0.98(0.001)	0.85(13.8)	0.69(0.04)	0.64(21.20)
Canola waste25% + manure 75%	0.97(6.49)	0.98(0.02)	0.99(0.001)	0.89(12.57)	0.74(0.03)	0.70(21.23)
Soybean waste25%+ manure75%	0.95(8.26)	0.96(0.03)	0.98(0.001)	0.85(13.81)	0.68(0.04)	0.64(21.14)
Canola waste50%+ manure 50%	0.99(2.82)	0.99(0.01)	0.98(0.001)	0.97(6.94)	0.83(0.22)	0.81(18.81)
Soybean waste50% + manure 50 %	0.99(5.68)	0.99(0.02)	0.97(0.001)	0.95(10.84)	0.84(0.03)	0.79(22.84)
Canola 75% waste+ manure 25%	0.99(1.27)	0.99(0.01)	0.99(0.001)	0.96(10.95)	0.80(0.02)	0.77(25.10)
Soybean waste75% + manure 25%	0.98(7.34)	0.99(0.02)	0.99(0.001)	0.96(16.82)	0.78(0.04)	0.73(30.93)
Chicken blood25% + manure 75%	0.98(25.72)	0.99(0.02)	0.99(0.001)	0.90(57.09)	0.74(0.40)	0.70(100.0)
Cow blood 25% + manure 75%	0.97(29.43)	0.99(0.02)	0.99(0.001)	0.88(57.03)	0.72(0.05)	0.66(93.74)

Other researchers studied nitrogen mineralization from various plant residues. Ebid et al. (2007) reported nitrogen mineralization rates for composted kitchen garbage, tea leaves, and coffee wastes to be 0.255, 0.199, and 0.101 mg day^{-1}, respectively. Stewart et al. (1998) observed that the nitrogen mineralization rate for mushroom compost was 0.0629 mg day^{-1}. In addition, Frankenberger and Abdul Majid (1985) reported small k values in the compost of the residues of four legume species (alfalfa, clover, peas, and soybean), equal to 0.013, 0.026, 0.0064, and 0.029 mg day^{-1}, respectively. Also, Bruun et al. (2006) investigated nitrogen and carbon mineralization in 75 types of organic matter using the ^{15}N isotope dilution techniques, and noticed that, for all types of organic matter, the C/N ratio was the most important factor in nitrogen mineralization (R^2=0.90). They also reported that the nitrogen mineralization rate was 0.09 mg/g carbon/day.

Table 5 Coefficient of kinetic models of nitrogen release of vermicompost treatments through 80 days incubation

Treatment	Zero order		First order			Second order		Parabolic		Exponential		Simple Elovich	
	q_0	k_0	q_1	k_1	$q_1 k_1$	q_2	k_2	q_3	k_p	a	b	α	β
Control (manure100%)	158	1.036	157.85	0.005	0.789	161.9	0.00002	141.4	10.05	146.4	0.084	0.044	0.061
Canola waste25% + manure 75%	218	1.147	216.4	0.004	0.866	221.3	0.00002	198.8	11.28	206.1	0.073	0.026	0.053
Soybean waste25%+ manure75%	191	1.029	190.6	0.004	0.762	195.1	0.00002	175.2	9.98	182.5	0.071	0.020	0.061
Canola waste50%+ manure 50%	300	1.294	296.6	0.003	0.900	302.9	0.00001	276.9	13.12	282.6	0.066	0.019	0.044
Soybean waste50% + manure 50 %	245	1.509	243.4	0.005	1.217	249.1	0.00002	218.2	15.2	226.2	0.090	0.077	0.038
Canola 75% waste+ manure 25%	367	1.583	362.2	0.004	1.449	370.3	0.000008	338.9	15.9	347.0	0.064	0.021	0.037
Soybean waste75% + manure 25%	256	1.779	255.5	0.005	1.277	261.9	0.00002	225.8	17.6	237.9	0.094	0.102	0.034
Chicken blood25% + manure 75%	788	5.43	782.9	0.005	3.914	806.6	0.000005	697.3	53.4	736.9	0.091	0.167	0.011
Cow blood 25% + manure 75%	581	4.81	581.5	0.006	3.489	600.6	0.000008	502.7	46.9	542.3	0.103	0.215	0.013

The initial compost mineralization rate ($q_1 \times k_1$) at the t=0 time was employed as the nitrogen availability index (Serna and Pomares 1992; Bruun et al. 2006). Its values for the composts containing 25% chicken and cattle dried blood were 3.91 and 3.49, for treatments with 25% canola and soybean residues 0.87 and 0.76, and for the control treatment 0.79 mg $kg^{-1}day^{-1}$, respectively. Griffin and Laine (1983) found a desirable relationship between this index, yield, and nitrogen uptake. Ebid et al. (2007) reported the $q \times k$ values for tea leaves, coffee waste, and kitchen garbage composts (1.90, 1.25, and 5.71 mg $kg^{-1}day^{-1}$, respectively). Furthermore, Frankenberger and Abdul Majid (1985) observed that the values of this index in alfalfa, lentil, soybean, and clover composts were 1.51, 1.27, 4.58, and 4.65 mg $kg^{-1}day^{-1}$, respectively.

Conclusion

Nitrogen availability is a factor limiting the use of vermicompost as a bio-fertilizer in agriculture. The utilization of wastes and by-products to enrich composts improves their quality and promises reduced impacts and environmental hazards that result from keeping wastes in the environment. In this research, the enrichment of animal wastes used in producing vermicompost was examined through adding dried blood wastes from slaughterhouses as well as soybean and canola crop residues, and the process and degree of nitrogen release were evaluated. Results suggested that the treatments containing 25% chicken and cattle dried blood increased the nitrogen content of the produced fertilizer to acceptable levels (4.95 and 3.7%, respectively). Moreover, the results of studying the release of the existing nitrogen (4.24 and 3.62 mg $kg^{-1}day^{-1}$) indicated the suitable supporting potential of this element in the blood-enriched compost. It is recommended that more accurate studies be conducted in the future to address the health aspects and the interaction effects of soil organisms and input compounds.

Compliance with ethical standards

Conflict of interest The authors declare that there are no conflicts of interest associated with this study.

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