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Full Length Research Paper

Kinetic of pigs' manures decomposition and nutrient release pattern in ferralitic soil of Benin (West Africa)

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Our study aims to assess the kinetic of the decomposition and nutrient mineralization process of organic manures from pigs' dejection. A litter bag study was carried out during 12 weeks following decomposition and nutrient release process in ferralitic soil in southern Benin (West Africa). 200 g of pigs' manures from four groups of pigs fed with four diets were considered as treatments: T1 (recommended diet composition, consisted of 15% *Azolla pinnata* + 55% provender + 5% coconut copra + 5% oil palm + 5% soybean bran + 10% rice bran + 5% kitchen waste), T2 (partially improved diet with *Azolla pinnata*, consisted of 30% *Azolla pinnata* + 65% rice bran + 5% oil palm), T3 (improved diet with *Azolla pinnata*, consisted of 47.5% *Azolla pinnata* + 47.5% rice bran + 5% oil palm), and T4 (improved diet with cereal bran, consisted of 15% *Azolla pinnata* + 40% rice bran + 40% wheat bran + 5% oil palm). Animals of six months age were fed during three months. A randomized complete block design with three replicates was set up for litter bag study. One component exponential decomposition model $y = y_0e^{-kt}$ was found for all treatments. Nutrient mineralization was slow in the soil. Less than 50% of the pigs' manures were decomposed after 12 weeks. In addition, manure from treatment T1 was richer in K, Ca and Mg than manures from treatment T3. High quantity (42.65%) of N was released in treatment T3. Pigs fed with diet enriched with Azolla produce manure which has released high N proportion in the soil. This is an opportunity to sustain food crop production.

Key words: Pigs' diet composition, *Azolla pinnata*, soil fertility, organic manure, decomposition rate.

INTRODUCTION

Soil and water pollution due to intensification of livestock breeding is one of the concerns in agricultural sector (Follett and Delgado, 2002; Bokossa et al., 2014a). This is attributed to an increase quantity of nitrate released

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from the decomposition and mineralization of the organic manures produced (Pilar et al., 2005) which are used to improve soil fertility. Better management of these sources of nutrient especially during plant growth could avoid such situation and improve productivity in the depleted soils (Kaleem et al., 2007; Inckel et al., 2007; Bernal et al., 2009). It is recognized that, most of the tropical soil especially the ferralitic soils are poor in organic matter which is relevant to sustain soil fertility (Merckx et al., 2001). Nutrient deficiency problem in the sub-Saharan Africa's soil is well known and sufficiently documented. Also, N release from organic waste mineralization in agriculture has been successfully studied (Vasconcelos et al., 1999; Cordovil et al., 2007; Amadji et al., 2009). Nevertheless as mentioned (Merckx, 2002), emphasis must be put in the quality of these organic inputs to enhance crop production.

In Benin (West Africa), the organic manure widely used in agricultural sector to enhance crop production is poultry manure due to its high quality (Amadji et al., 2009). Furthermore, pigs' manure is also an opportunity for soil fertility replenishment as pigs breeding is an important activity in Benin agricultural sector (Accodji et al., 2009) leading to an important quantity of dejection produced. Development of strategies to recycle nutrient from these organic wastes is a challenge as most of the agricultural soils in southern Benin are depleted (Saïdou et al., 2003). Furthermore, study of Bokossa et al. (2014b) revealed that when pigs are nourished with diet of high nutritious ingredient such as *Azolla filiculoides*, the chemical quality of the manures produced are improved.

Nutrients released from organic waste mineralization have been of interest (Vasconcelos et al., 1999; Vagstad et al., 2001; Evers, 2002; Cordovil et al., 2007; Amadji et al., 2009). But no information is available on the amount of nutrients recycled in short term in the soil when the manures are from pigs nourished with diet enriched with *Azolla*, although such information is essential to quantify maximum rates of decomposition and mineralization. Therefore, knowledge on the kinetic of the decomposition and nutrient release pattern of this organic manure is of importance. In fact, knowing the kinetic of the mineralization process, one could overlap the amount of nutrient released and plant nutrient requirement. It will also be used as a tool to integrate current knowledge to quantify the amount of organic manure to be applied during fertilization or to predict organic matter dynamics in the soil to enhance crop production.

The principle of first-order kinetics (Henin and Dupuis, 1945) has been widely adopted in modeling organic matter mineralization. There are nowadays several literatures on litter decomposition. Many studies have been carried out under laboratory conditions (Palm and Sanchez, 1991; Tian et al., 1992; Lupwayi and Haque, 1998) or under field conditions but with plant residues (Handayanto et al., 1994; Mwiinga et al., 1994; Oglesby and Fownes, 1992; Wieder et al., 2009; Liu et al., 2009). However, in Benin there is no study on the decomposition of pigs' manures in the soil.

The present study aims to: (i) assess the decomposition pattern of different types of pigs' manure in a ferralitic soil, (ii) determine the kinetics of mineralization of different types of pigs' manure in a ferralitic soil and finally, (iii) assess the amount of N, P, K, Ca and Mg released regarding the types of pigs' manure.

MATERIALS AND METHODS

Experimental site

The experiment was carried out on the site of the Laboratory of Research on Wetlands (LRW), Department of Zoology, Faculty of Science and Technique, University of Abomey-Calavi, Benin (West Africa). It is located at Abomey-Calavi between 6° 24' 53.3'' N; 2° 20' 18.8'' E and 6° 24' 53.4'' N; 2° 20' 18.5'' E and 9 masl. The area is characterized by sub-equatorial climate with two rainy seasons (March to end of July and mid-September to November) and two dry seasons (August to mid-September and December to March). The area is dominated by ferralitic soil presenting the following characteristics: pH (water) (6.49 ± 0.04), total-N (0.08 ± 0.00 %), P-Bray 1 (15.00 ± 0.02 mg/kg) and exchangeable K^+ (0.12 ± 0.01 cmol/kg), Ca^{2+} (2.33 ± 0.05 cmol/kg) and Mg^{2+} (0.73 ± 0.03 cmol/kg). *Azolla pinnata* an aquatic fern used to enrich pigs' diet was produced during three months (April to end of June, 2014) in a pond set up at the experimental site.

Pigs feeding and manure collection

Pigs feeding and manures collection according to the types of diet served to the animal were carried out on the experimental site following the same procedure as in our previous study (Bokossa et al., 2014a). The manures were daily collected and mixed according to the diet served. They were collected during the feeding experiment from April to June, 2014 and air dried at ambient temperature. About 50 kg of dejection were collected per type of diet. The diets were made based on results from experiments carried out by Accodji et al. (2009). The diets consisted of recommended diet composition (T1): 15% *A. pinnata* + 55% provender + 5% coconut copra + 5% oil palm + 5% soybean bran + 10% rice bran + 5% kitchen waste; partially improved diet with *A. pinnata* (T2): 30% *A. pinnata* + 65% rice bran + 5% oil palm; improved diet with *A. pinnata* (T3) : 47.5% *A. pinnata* + 47.5% rice bran + 5% oil palm; and improved diet with cereal bran (T4): 15% *A. pinnata* + 40% rice bran + 40% wheat bran + 5% oil palm. Four white landrace pigs of six months old per type of diet were considered leading to 16 animals used in total. Table 1 presents the chemical composition of the different types of manure studied.

Experimental design and decomposition process

A completely randomized block design with three replications was set up. The treatments consisted of different types of dry manure collected from the feeding experiment. Manure bag decomposition used in this experiment was made of nylon mosquito wire with a mesh size of 1 mm due to the powder condition after drying of the manures. The nylon was set up in the soil (0 to 15 cm depth where biological activities are intense) and also adapted from litter-bag techniques (Hartemink and O'sullivan, 2001). For each treatment, 12 manure nylon bags were filled with 200 g oven dried (at 65°C)

Table 1. Chemical characteristics of pigs' manures (composite sample) regarding the composition of the diets used to feed the animal.

Treatments	Nutrient content (g kg^{-1}) in the pigs' manures					
	C	N	P	K	Ca	Mg
T1	261.87	15.35	5.40	7.25	6.15	5.85
T2	294.45	14.42	4.78	4.65	5.81	4.99
T3	375.86	17.02	6.12	4.89	4.58	4.52
T4	267.24	14.12	4.92	5.11	5.72	5.69

T1 = Pigs nourished with recommended diet composition; T2 = Pigs nourished with diet partially improved with *Azolla pinnata*; T3 = Pigs nourished with diet improved with *Azolla pinnata*; T4 = Pigs nourished with diet improved with cereal bran.

manure material. Manure nylon bags were randomly placed in the soil (6 lots in total) which were sampled each fortnight that is on 15, 30, 45, 60, 75 and 90 days of decomposition, with one manure nylon bag randomly selected from each lot and transported to the laboratory for the analysis. During each sampling period, three manure nylon bags per treatment were collected. Furthermore, non-decomposed manures in each nylon bag were carefully put in crucible aluminum after removing the nylon bag and oven dried at 65°C for 72 h to determine manure mass remaining at the Laboratory of Wetland Research. The samples were then weighted to determine the weight lost. Samples were ground (mesh; 1 mm) and sent to the Laboratory of Soil Science Water and Environment of Benin National Agricultural Research Institute (LSSEE/INRAB) at Agonkanmey (Benin) for nutrient analysis.

Manure analyses

Manure analyses were carried out on the non-decomposed pigs' manures. Methods used for the analyses of the non-decomposed manures were that described by NF EN 14082 norm used at the LSSEE/INRAB's laboratory. The analyses were performed on: organic carbon (dry ashing in a muffle furnace at 550°C for 24 h then, organic matter was determined by the difference between the treated sample and the mass of ash obtained which was assigned an empirical coefficient of 2). The ash obtained was used for the determination of Ca, Mg, K and P content. It was gathered in 6 N of HCl involving a period of heating at 125°C then the residue was dissolved in 1 N of HNO_3. Ca, Mg and K were determined by atomic absorption spectrophotometry and P was measured colorimetrically by ammonium molybdate with ascorbic acid at a wavelength of 660 nm.

Data analysis

Several models (linear, parametric and exponential) were tested using EXCEL software. We also consulted studies performed by Wieder et al. (2009) and Liu et al. (2009) on litter decomposition at different times during the year. It was finally found that the single component negative exponential decay model provided good fit for the different types of pigs' manure decomposition pattern in the soil over the complete time of observation. The statistical analyses were performed using SAS 9.2 package. Analysis of variance was run on the decomposition data, nutrient released in the soil considering periods of decomposition and treatments (types of manure) as main factors, standard errors of the difference in means were calculated. Student Newman-Keuls test was performed to compare differences in means among treatments. All significance levels were set at $P < 0.05$ and $P < 0.05$.

RESULTS

Decomposition pattern of the different types of pigs' manure in the soil

The decomposition patterns, that is, mass remaining of the different types of pigs' manure are presented in Figure 1. After 15 and 30 days of decomposition, the graphs show similar and slow decomposition rate pattern. In general, at 75 and 90 days of decomposition, almost manure from pigs nourished with recommended diet (T1 with less Azolla) decomposed fast. 76.9 and 61.3% of non-decomposed residues were found after 75 and 90 days of decomposition, respectively. Furthermore, manure from pigs nourished with partially improved diet with Azolla (T2) presented the highest non-decomposed residues. The graph shows that, the decomposition process was uncompleted over the period of experiment. In total, manure T1 presented the highest decomposition rate. No significant differences ($P > 0.05$) were found between manures T3 and T4 during the decomposition periods.

Kinetic of the decomposition and mineralization of the pigs' manures in the soil

Except for the amount of the remaining P, the one component model $y=a*e^{-*kt}$ presented good fit for all parameters (coefficient of determination R^2 over 80%) where y (%) is the mass fraction of the remaining manure in the litter bag ($wi *100/w0$) at a specific time (t), k is the decomposition constant a is a coefficient and t is the time (in days). Table 2 presents the exponential functions describing nutrients that remained in the manures during the decomposition process in the soil at different periods. In general, considering the types of manure the

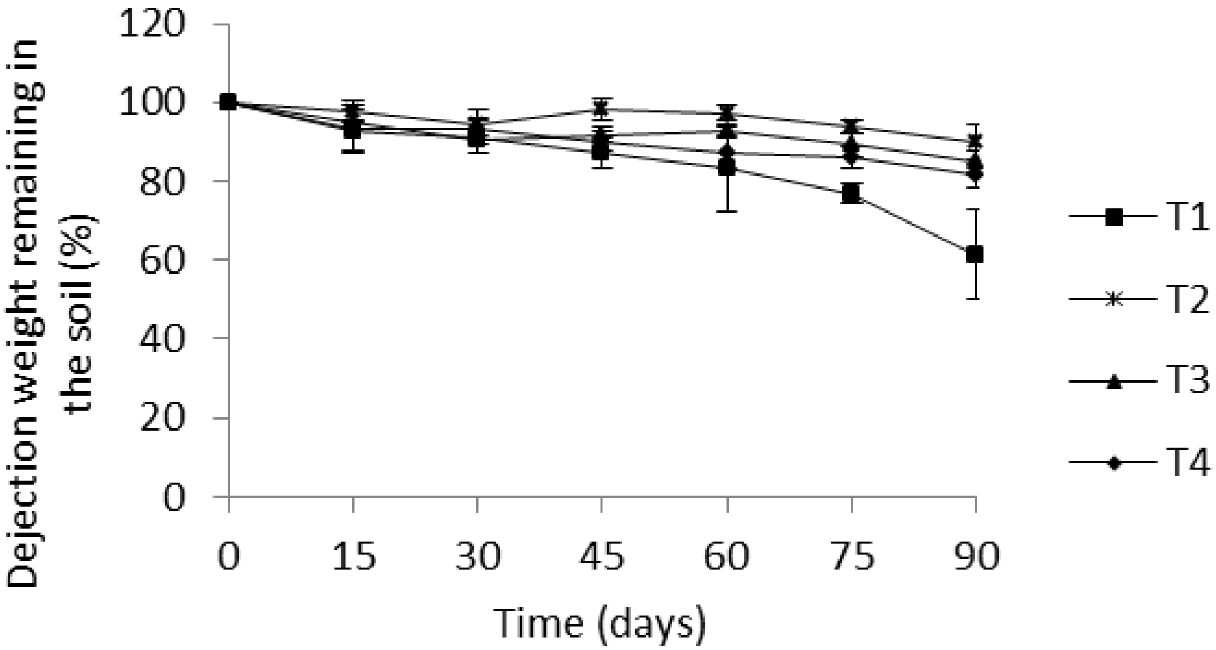

Figure 1. Decomposition pattern in the soil of manures from pigs nourished with different types of diet. Note: T1 = Manure of pigs nourished with recommended diet composition; T2 = Manure of pigs nourished with diet partially improved with *Azolla pinnata*; T3 = manure of pigs nourished with diet improved with *Azolla pinnata*; T4 = manure of pigs nourished with diet improved with cereal bran.

Table 2. Exponential functions describing mass loss and nutrients remaining after decomposition of the pigs' manures nourished with different diets.

Types of manure	Parameter	Fitted models[1)]	R^2
	Mass loss	$y = 110.48e^{-0.069t}$	0.86*
	C	$y = 266.67e^{-0.019t}$	0.85*
	N	$y = 15.241e^{-0.059t}$	0.87*
T1 (Recommended diet composition)	P	$y = 4.9686\ e^{-0.077t}$	0.77ns
	K	$y = 4.8813e^{-0.19t}$	0.61ns
	Ca	$y = 5.4606e^{-0.214t}$	0.82*
	Mg	$y = 5.018e^{-0.089t}$	0.66ns
	Mass loss	$y = 101.18e^{-0.014t}$	0.64ns
	C	$y = 302.09e^{-0.019t}$	0.96**
	N	$y = 14.403e^{-0.065t}$	0.83*
T2 (Partially improved diet with *Azolla pinnata*)	P	$y = 4.7498e^{-0.055t}$	0.87*
	K	$y = 4.2837e^{-0.152t}$	0.85*
	Ca	$y = 4.868e^{-0.124t}$	0.69ns
	Mg	$y = 5.5995e^{-0.14t}$	0.97ns
	Mass loss	$y = 99.991e^{-0.021t}$	0.79 ns
	C	$y = 380.06e^{-0.017t}$	0.97**
	N	$y = 16.86e^{-0.087t}$	0.90*
T3 (Improved diet with *Azolla pinnata*)	P	$y = 6.018e^{-0.079t}$	0.88*
	K	$y = 4.2898e^{-0.16t}$	0.81*
	Ca	$y = 4.4464e^{-0.133t}$	0.86*
	Mg	$y = 4.4397e^{-0.086t}$	0.89*

Table 2. Contd.

T4 (Improved diet with cereal bran)	**Mass loss**	$\mathbf{y = 101.56e^{-0.03t}}$	**0.96****
	C	$y = 270.36e^{-0.027t}$	0.95**
	N	$y = 14.319e^{-0.057t}$	0.93*
	P	$y = 5.4557e^{-0.091t}$	0.95*
	K	$y = 6.9717e^{-0.262t}$	0.97**
	Ca	$y = 4.7782e^{-0.164t}$	0.76 ns
	Mg	$y = 5.6245e^{-0.137t}$	0.91*

ns = not significant; * = P < 0.05; ** = P < 0.01 [1):] y = Mass fraction of the remaining manure or nutrients (%) after decomposition at a specific time (t in day).

coefficients of determination varied between 0.64 and 0.96 for the mass losses while it varied from 0.61 to 0.97 for the remaining nutrients regarding the treatments. Therefore, the exponential model was the best way to explain the kinetic of the decomposition and mineralization process of the studied manures in the soil. It was also notice that the initial composition of the diets influenced the decay equation. Thus, a, is constant which varied from one diet to another and from one nutrient to another.

Nutrient remains in the pigs' manures after decomposition regarding the different periods of measurement

Changes in nutrients concentration in the different types of manure during the periods of measurement are presented in Figure 2. Carbon content in the manures varied significantly (P < 0.05) according to the types of pigs' manure. Manure from diet improved with Azolla (T3) showed high carbon content compared with manures from recommended diet composition (T1) and that improved with cereal bran (T4), respectively. Nitrogen content decreased sharply in the different types of manure, although no significant (P > 0.05) difference was found among treatments. Manure from treatment T3 (rich in Azolla) released higher quantity of nitrogen than treatments T1 and T4. The highest amount of Ca and K released were found in treatment T4 while the lowest were found in the treatment T2. As for the amount of phosphorus released, treatment T1 showed the higher amount compared to treatment T2.

DISCUSSION

Performance of the one component model $y = ae^{-kt}$ used to predict decomposition and mineralization processes

After testing, numbers of model (exponential, linear, logarithmic and polynomial), exponential one ($y = ae^{-kt}$) provided good fit for the decomposition of the manures studied. Previous studies already focused on exponential equation to describe the kinetic of litter decomposition (Kortleven, 1963; Godshalk, 1977; Hartemink and O'Sullivan, 2001; Kayuki and Wortmann, 2001; Johnson et al., 2007; Wieder et al., 2009; Liu et al., 2009; Rivas et al., 2014). Our results corroborate those of Kayuki and Wortmann (2001). Furthermore, Adair et al. (2008) already reported that, several factors must be taken into account before a model can give a precise prediction of the decomposition process. This is so relevant that Hartemink and O'Sullivan (2001) introduced in their model abiotic parameters for good prediction of the decomposition rate. The model proposed by Hartemink and O'Sullivan (2001) is efficient for long term decomposition with materials rich in lignin, hemicellulose and polyphenol. Therefore, it cannot be a suitable model to predict decomposition process with product poor in carbon as pig manure. Equation used in the present study regarding the types of manure has the merit to contribute in better prediction of the decomposition in the soil for the improvement of soil property to enhance crop production. By managing this model in a better way, one can overlap plants nutrient requirement and the amount of nutrient released.

Nutrient release patterns regarding the quality of manures

On the whole, nutrient released after the decomposition process are regular over the time, probably due to the same microorganism population in the decomposition bag. Our results have shown that for N, due to the quality of the material in decomposition in all treatments, one can predict mineralization to the detriment of immobilization. Our results are in agreement with those of Smith et al. (1998). These authors found in the earlier stage of decomposition a slow decay rate due to bag with 1 mm mesh size used which had excluded soil macrofauna during the decomposition process. Furthermore, our results with this nutrient is in accordance with study on chicken manure. In fact, Chen

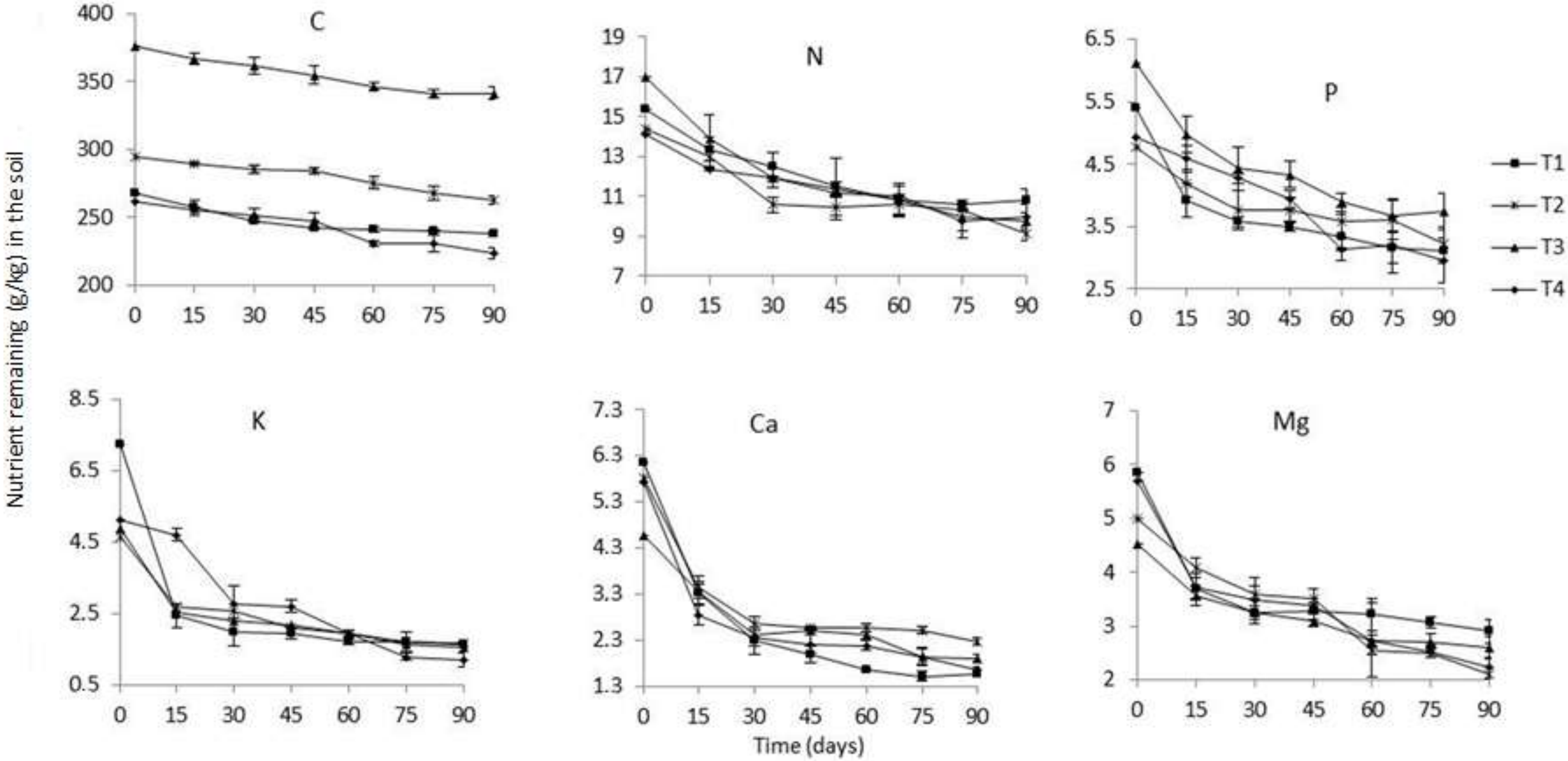

Figure 2. Changes in nutrient concentration (g kg^{-1}) during decomposition process of manures from pigs nourished with different diets Notes: T1: pigs nourished with recommended diet composition; T2: pigs nourished with diet partially improved with *Azolla pinnata*; T3: pigs nourished with diet improved with *Azolla pinnata*; T4: pigs nourished with diet improved with cereal bran.

et al. (2015) found a gradual decrease of C/N ratio of chicken litter after several months' storage, while N showed some fluctuation. Soil moisture content plays an important role in the decomposition process of the organic material. As a matter of fact, Deressa (2015) working on soil treated with improved cattle slurry manure with additive manure found similar carbon and nitrogen mineralization patterns. The author concluded that both temperature and soil moisture affect carbon and nitrogen mineralization. It can be concluded that the exponential model used in this study described well the N release pattern as indicated by significant ($P < 0.05$) R^2 value found.

The present results with the amount of P released are similar to those of Kayuki and Wortmann (2001). These authors explained the low amount of P released by high lignin and polyphenol content in the plant material in decomposition. Despite the low P released in the pigs' manures, the exponential model accounted for value > 85% for all treatments except manure T1. As all of the diets containing Azolla, rice bran and wheat bran, the low amount of P released during our experiment could be probably due to recalcitrant fraction in the plant material such as lignin and polyphenols.

The patterns of the amount of K released were similar in all treatments. At the end of the experiment 70 to 80% of the initial K content in all the manures was released showing the easiness of K to be released in the pigs' dejection. This result backs up those of Swift et al. (1981), Palm and Sanchez (1990), Tian et al. (1992), Thomas and Asakawa (1993), and Kayuki and Wortmann (2001). Furthermore, the coefficients of determination R^2 varied between 0.61 and 0.97, this shows the performance of the exponential model to predict the amount of K which will be released during the mineralization process. This finding is important in agriculture as it allows better estimation of the quantity of the pig manure to be applied in order to satisfy plant requirement during stage of growth and development. Furthermore, knowing the fast leaching of K (Saïdou et al., 2003), a good management practice is required as farmers could overlap plant requirement to the period that sufficient amount of the nutrient will be released.

Concerning the amount of Ca released, our results are almost opposite with those of Swift et al. (1981) who studied plant material decomposition. In fact, these authors found a slow release of Ca from plant material in decomposition even those of leguminous. This could be explained by the nature of the manures tested which undergo primary transformation in the animal digestive tube under the effect of some microorganisms. This transformation in the animal stomach could have led to a quick Ca release while slow release of Ca is mostly observed with plant materials (they are rich in lignin, phenol, polyphenol) that decompose slowly in the soil due to their high C/N ratio.

The release of Mg was rapid after the first fortnight. Our results are not in agreement with those of Swift et al. (1981) who found a slow release of Mg in plant materials. However, one could explain this difference by the nature of the manures compared with plant materials.

Finally, the present study apart from its short duration, the results showed relatively moderate (N and P) to high (K, Ca and Mg) released. Weather condition had probably played an important role as the bag mesh sizes were small which has probably enhanced microorganism activity. However, as mentioned by Salanitro et al. (1977), pig slurry contains about 3 to 6 × 10^{10} bacteria per gram and these microorganisms play key role in the mineralization process. Furthermore, slow release of C, N and P was found in the soil compared to K, Ca and Mg. This is an interesting result knowing the characteristic of N and P in tropical soils especially in ferralitic soil. In fact, a fast released of N could lead to N leaching and volatilization (as NH_3) to the detriment of the plant when the rooting system is not yet well developed to benefit the total amount of N released rapidly. Furthermore, tropical ferralitic acid soils were known for their low available P content (Mokwunye and Bationo, 2002; Koné et al., 2009, 2010) due to the fact that major portion of the ion exchange complex of the African soils is formed by the oxides (and hydroxides) of iron and aluminum responsible for the fixation of soluble P. Therefore a slow released of this nutrient may be favorable for the plant. The fast released of K, Ca and Mg will be in the disadvantage of the plants as in 90 days decomposition of the manures, more than 50% of the initial content of these nutrients will be probably lost through leaching or erosion. A good management of pigs' manure to sustain plant production in the ferralitic soil could be a splitting supply in order to overlap plant nutrient requirement with the amount of nutrient effectively released.

Conclusion

The present study has shown that the single component exponential decomposition model $y = a*e^{-kt}$ was a good function to predict the decomposition and mineralization processes of pigs' manures. This model was also accurate to describe the amount of nutrients release during the mineralization process. More N was released with treatment T3 (manure from pigs nourished with diet enriched with Azolla) compared with treatment T4 (manure from pigs nourished with diet improved with cereal bran). The release of P was higher in manure T1 than in manure T2 after 12 weeks. Potassium release was most rapid in manure T1 compared to manures T3 and T2 after the first two weeks of decomposition. Calcium was released slowly than P and easier than N. Manure T1 released the highest amount of Ca while, the lowest was found in treatment T2.

In general, for all of the manures studied, C, N and P were released slowly in the soil compared with K, Ca and Mg. This is an interesting result knowing the low level of N and P in ferralitic soil. For a good management of this manure, one must split the quantity to be applied due to the fast release of certain nutrients.

Conflict of Interests

The authors have not declared any conflict of interests.

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REFERENCES

Accodji JMM, Fiogbé ED, Gangbazo KH (2009). Essai de Valorisation d'Azolla (*Azolla Microphylla* Kaulf) dans la production porcine en zone humide. Int. J. Biol. Chem. Sci. 3(5):890-898.

Adair EC, Parton WJ, Del Grosso SJ, Silver WL, Harmon ME, Hall SA, Burkes IC, Hart SC (2008). Simple three pool model accurately describes patterns of long term litter decomposition in diverse climate. Glob. Change Biol. 14:2636-2660.

Amadji LG, Saïdou A, Chitou L (2009). Recycling of organic residues in compost to improve coastal sandy soil properties and cabbage shoot in Benin. Int. J. Biol. Chem. Sci. 3(2):192-202.

Bernal MP, Albuquerque JA, Moral R (2009). Composting of animal manures and chemical criteria for compost maturity assessment: A review. Bioresour. Technol. 100:5444-5453.

Bokossa HKJ, Saïdou A, Sossoukpe E, Fiogbé ED, Kossou D (2014a). Decomposition and mineralization effect of various sources of pig manure on water quality and nutrients availability for agro-fish system in Benin. Agric. Sci. 5:1194-1206.

Bokossa HKJ, Saïdou A, Fiogbé ED, Kossou D (2014b). Decomposition rate of pigs' manures and nutrient release pattern in wetland condition. Agric. For. Fish. 3(4):271-278.

Chen Z, Wang H, Ionita C, Luo F, Jiang X (2015). Effects of chicken litter storage time and ammonia content on thermal resistance of desiccation-adapted *Salmonella* spp. Appl. Environ. Microbiol. 81(19):6883-6889.

Cordovil CMDS, Cabral F, Coutinho J (2007). Potential mineralization of nitrogen from organic wastes to ryegrass and wheat crops. Bioresour. Technol. 98:3265-3268.

Deressa A (2015). Effects of soil moisture and temperature on carbon and nitrogen mineralization in grassland soils fertilized with improved cattle slurry manure with and without manure additive. J. Environ. Hum. 2(1):2373-8332.

Evers GW (2002). Ryegrass–Bermuda grass production and nutrient uptake when combining nitrogen fertilizer with broiler litter. Agron. J. 94:905-910.

Follett RF, Delgado JA (2002). Nitrogen fate and transport in agricultural systems. J. Soil Water Conserv. 57:402-408.

Godshalk GL (1977). Decomposition of aquatic plants in lakes". PhD Thesis, Michigan State University, Department of Botany and Plant pathology. pp. 49-61.

Handayanto E, Cadisch G, Giller KE (1994). Nitrogen release from pruning of legume hedgerow trees in relation to quality of the pruning and incubation method. Plant Soil 160:237-248.

Hartemink EA, O' Sullivan JN (2001). Leaf Litter decomposition of *Piper aduncum*, *Gliricidia sepium*, and *Imperata cylindrica* in the humid lowland of Papua New Guinea. Plant Soil 230:115-124.

Hénin S, Dupuis M (1945). Essai de bilan de la matière organique du sol. In: Ann. Agronomiques 15(1):29.

Inckel M, Peter S, Tersmette T, Veldskamp T (2007). Fabrication et utilisation du compost. Série Agro Doc. N°8: 71 p.

Johnson MF, Barbour NW, Weyer SL (2007). Chemical composition of crop biomass impacts its decomposition. Soil Sci. Soc. Am. J. 71:155-162.

Kaleem M, Abbasi A, Munazza H, Abdul K, Khan SR (2007). Mineralization of three organic manures used as nitrogen source in a soil incubated under laboratory conditions. Commun. Soil Sci. Plant Anal. 38(13-14):1691-1711.

Kayuki CK, Wortmann SC (2001). Plant materials for soil fertility management in sub-humid tropical areas. Agron. J. 93:929-935.

Koné B, Saïdou A, Camara M, Diatta S (2010). Effet de différentes sources de phosphate sur le rendement du riz sur sols acides. Agron. Afr. 22(1): 55-63.

Koné B, Diatta S, Saïdou A, Akintayo I, Cissé B (2009). Réponses des variétés interspécifiques du riz de plateau aux applications de phosphate en zone de forêt au Nigeria. Can. J. Soil Sci. 89:555-565.

Kortleven J (1963). Quantitative aspects of humus accumulation and decomposition. Landbk. Onderz. 69.1. Pudoc. Wageningen 109 p.

Liu LL, King JS, Giardina CH, Booker FL (2009). The influence of chemistry, production and community composition on leaf litter decomposition under elevated CO_2 and trophospheric O_3 in a Northern Hardwood ecosystem. Ecosystems 12:401-416.

Lupwayi NZ, Haque I (1998). Mineralization of N, P, K, Ca and Mg from Sesbania and Leucaena leaves varying in chemical composition. Soil Biol. Biochem. 30:337-343

Merckx R, Diels J, Vanlauwe B, Sanginga N, Denef K, Oorts K (2001). Soil organic matter and soil fertility. Sustain. Soil Fertil. West Afr. (sustainingsoilf). pp. 69-89.

Merckx R (2002). Process research and soil fertility in Africa: Who cares? In: Vanlauwe B, Diels J, Sanginga N, Merckx R (Eds.). Integrated plant nutrient management in Sub-Saharan Africa: from concept to practice. pp. 97-111.

Mokwunye U, Bationo A (2002). Meeting the phosphorus needs of the soils and crops of West Africa: The role of indigenous phosphate rocks? In: Vanlauwe B, Diels J, Sanginga N, Merckx R (Eds.). Integrated plant nutrient management in Sub-Saharan Africa: from concept to practice. pp. 209-224.

Mwiinga RD, Kwesiga FR, Kamara CS (1994). Decomposition of leaves of six multipurpose tree species in Chipata Zambia. For. Ecol. Manag. 64: 209-216.

Oglesby KA, Fownes JH (1992). Effects of chemical composition on nitrogen mineralization from green manures of seven tropical leguminous trees. Plant Soil 143:127-132.

Palm CA, Sanchez PA (1991). Nitrogen release from the leaves of some tropical legumes as affected by their lignin and polyphenolic contents. Soil Biol. Biochem. 23:83-88.

Palm CA, Sanchez PA (1990). Decomposition and nutrient release patterns of leaves of some of three tropical legumes. Biotropica 22:330-338.

Pilar F, Castellar I, Navarro J (2005). Nitrate leaching in pepper cultivation with organic manure and supplementary additions of mineral fertilizer. Commun. Soil Sci. Plant Anal. 36:2889-2899.

Rivas FA, Tabatabai MA, Olk DC, Thompson ML (2014). Kinetics of short-term carbon mineralization in roots of biofuel crops in soils. Biol. Fertil. Soil 50:527-535.

Saïdou A, Janssen B, Temminghoff EJM (2003). Effects of soil properties, mulch and NPK fertiliser on maize yields and nutrient budgets on ferralitic soils in southern Benin Agri. Ecosyst. Env. 100: 265-273.

Salanitro JP, Blake IG, Muirhead PA (1977). Isolation and identification of fecal bacteria from adult swine. Appl. Environ. Microbiol. 33:79-84

Smith CKH, Gholz L, De Assis Oliveira F (1998). Fine litter chemistry, early-stage decay and nitrogen dynamics under plantations and primary forest in lowland Amazonia. Soil Biol. Biochem. 30(14):2159-2169.

Swift MJ, Russel SA, Perfect TJ (1981). Decomposition and mineral nutrient dynamics of plant litter in a regenerating bush fallow in sub-humid tropical Africa. J. Ecol. 69:981-995.

Tian G, Kang BT, Brussaard L (1992). Biological effects of plant residues with contrasting chemical composition under humid tropical conditions decomposition and nutrient release. Soil Biol. Biochem. 24:1051-1060.

Thomas RJ, Asakawa NM (1993). Decomposition of leaf litter from tropical forage grasses and legumes. Soil Biol. Biochem. 25:1351-1361.

Vagstad N, Broch-Due A, Lyngstad I (2001). Direct and residual effects of pulp and paper mill sludge on crop yield and soil mineral N. Soil Use Manag. 17:173-178.

Vasconcelos E, Cabral F, Cordovil CMDS (1999). Wheat yield and leachability of phosphorus and nitrogen in pig slurry amended soils. Commun. Soil Sci. Plant Anal. 30:2245-2257.

Wieder WR, Cleveland CC, Townsend AR (2009). Controls over leaf litter decomposition in wet tropical forests. Ecology 90(12):3333-3341.

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