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Estimating Lime Equivalence of Animal Manure Ashes and Soil Reaction Kinetics in Southwestern Nigerian Soils: An Incubation Study

Jamiu Azeez*, Olowoboko Blessing, Ajenifuja Debo, Oyegoke Olabisi

Federal University of Agriculture, Department of Soil Science and Land Management, Nigeria

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Abstract

In this study, the liming equivalence (LE) of manures and soil pH kinetics were computed in triplicates, for soil pH measurements after eight weeks of soil incubation using manure ashes and $CaCO_3$. The liming effects of $CaCO_3$ and manure ashes are related to their Ca content. The pH_{KCl} was more reliable for estimating the LE of the soil. The average LE was 0.73, 0.30, 0.26 for goat, cattle, and poultry ashes, respectively in pH_{KCl} and 0.22, -0.22 and 0.15 in pH_{water}. Generally, the estimated LE of the ashes was 0.58 in pH_{KCl} and 0.46 in pH_{water}. The goat manure ash had an LE value of 0.57, followed by the poultry manure ash value of (0.48); the least LE value (0.39) was found by the cattle manure ash. In alluvial soil, pH kinetics was best described by the power- function model (pH_{KCl}), while first-order and power-function models were most appropriate for soils amended with the poultry and cattle manure ash, respectively in pH_{water}. In a sedimentary soil, no single kinetics model could be used to describe the changes in soil pH. The liming equivalence of the ashes was (0.58) in pH_{KCl} and (0.46) in pH_{water}. Their liming equivalences relative to $CaCO_3$ were 57, 48 and 39 %, for goat, poultry and cattle manure ash, respectively. Conformity of the soils to the kinetics model is a function of the solution (electrolyte) used for the pH estimation.

Keywords: soil acidity, calcium carbonate, lime equivalence, manure ash.

1. Introduction

The agricultural productivity of acidic soils is usually characterized by a large number of limitations such as the adverse impacts on the proliferation of soil microbes, fixation of soil nutrients, and the growth retardation and death of plants. The effects of acid rain, aluminum hydrolysis, the application of acid-containing or acid-forming fertilizers to soil acidification are enormous (Fernandez-Calvino and Baath, 2010; Lege, 2012). The most limiting crop-growth factors in acidic soils are the Al and micronutrients' toxicity and the low Ca uptake by plants (Adams, 1984). Consequently, the usage of acidic soils in agriculture is only limited to the cultivation of crops adaptable to high soil Al and micronutrients (Whalen et al., 2002). The widely used options to tackle soil acidity include the application of lime to increase the low pH in the soil. Several minerals and at times synthetic soil-liming materials ($CaCO_3$, CaO, Ca $(OH)_2$, slag, etc.) have been recommended for usage in developed countries with a noticeable success in agricultural yield improvement of the crops. In fact, because of its strong liming potential, $CaCO_3$ has been recommended for use as a standard and reference liming material for evaluating other liming materials (Adams, 1984; Mokolobate and Haynes, 2002; Olowoboko et al., 2018).

The socioeconomic situations of farmers in sub Saharan Africa have forced them to rely solely on the use of ashes from the residue of their burnt bushes as lime. The population explosion in this part of the world has not only made the practice of shifting cultivation impossible, but has also made fallow periods very short, with the subsequent low bush biomass at the end of the short fallow periods. This will invariably produce a low biomass yield and ashes after burning. To a large extent, this has made the problem of soil acidity persistent because of the low ash input, being not enough to neutralize the soil acids.

The practice of organic agriculture and the huge amount of animal waste generated in sub Saharan Africa have made the use of animal manures a relatively cost-effective option in replenishing lost soil nutrients (Sajal and AbulKashem, 2014). Animal manures fertilize the soil and also reduce soil acidity (Mokolobate and Haynes, 2002). Theories have been postulated to explain the liming effects of manures, such as those confirmed by Azeez and Van Averbeke (2012). The effects included proton consumption by functional groups associated with the organic materials (Wong et al., 1998), proton consumption during decarboxylation of organic acid anions which occur during decomposition (Yan et al., 1996), specific adsorption of organic molecules by ligand exchange with the release of OH^- (Hue et al., 1986), and the release of OH ions during reduction reactions associated with localized anaerobic microsites. Moreover, Eghball (1999) and Whalen et al. (2000) maintained that the liming effects of animal manures are essentially attributed to their calcium carbonate and organic acid contents. These gains, however, are not fully enjoyed by farmers because their use of animal manures is restricted because of its low-nutrient concentration and its

* Corresponding author e-mail: azeezjo@funaab.edu.ng

high bulkiness, which at times become worrisome to farmers who lack resources and would rather prefer to cultivate their fields without any amendments.

A new option to the use of animal manures is to burn the manure at suboptimal temperatures to generate ashes (Komiyama, et al., 2013; Olowoboko et al., 2018). Manure ashes are concentrated plant nutrients with a high potential to lime acidic soils. Some studies (unpublished data) have evaluated the agronomic potentials of the use of animal manure ashes, but none has estimated the potential liming effects of these ashes and the changes in their liming value with time, in comparison with the standard reference $CaCO_3$. Hence, this study hypothesizes that based on their Ca content, manure ashes will have an equal liming potential and soil pH dynamics to that of the standard reference $CaCO_3$ lime. Accordingly, the objectives of this study are to compute the lime potential of three animal manure ashes, and evaluate the kinetics of the soil pH as a result of the addition of the manure ashes in an incubation study.

2. Materials and Methods

2.1 Soil and Manure Sample Collection and Preparation

Soil samples with acidic (low pH) reaction were collected at a depth of 0 – 15 cm from two different geologic backgrounds. The samples included: (a) an alluvial soil from Epe and (b) a sedimentary parent material soil from Ijale-papa. The two soil locations are both in the Ogun state, in southwest Nigeria. The collected soil samples were air-dried and screened with a 2 mm sieve.

Poultry, goat and cattle manures were collected from the animal farm of the Federal University of Agriculture Abeokuta, Nigeria. The manures were air-dried to a constant weight, then the dried samples were combusted to make manure ashes; the temperature of ashing was determined using an infrared thermometer. The conditions of ashing the manures were earlier reported by Olowoboko et al. (2018).

The poultry (birds) from which the litter without bedding materials was collected were raised in an intensive system of battery cages. They were layer birds provided with all the adequate nutritional and medical care needed. As for the ruminants, the goats and cattle were semi-intensively managed. The pure litters were collected from the animal pens. The animals scavenge for browse plants and grass outside their pens during the day, and stay in shed at nights in their different pens. The feces they produce overnight were then collected, processed, and used for the study as mentioned earlier. The animals consisted of a mixture of matured young males and females.

2.2 Soil and Manure Analyses

The collected soil samples were analyzed for the following properties: Soil pH was estimated in a 1:2 soil: water and KCl solution (for incubated soils) using a glass electrode pH meter (Orion Research Model 201), and the particle-size analysis was done using the hydrometer method (Bouyoucos, 1965). Exchangeable bases were extracted with 1 N ammonium-acetate solution in 1:10 soil: solution ratio. Potassium and sodium were analyzed with a flame photometer, while Ca and Mg were measured with atomic absorption spectrophotometry (Anderson and Ingram 1993). The available P and N were determined by the Bray 1 and micro-Kjeldhal methods respectively. The soil organic matter was determined using the chromic acid oxidation procedure of Walkley and Black (1934) method.

The manure ashes used were digested with nitric and perchloric acids at the ratio of 2:1 (Watanabe et al. 2013), and the digests were analyzed for exchangeable bases according to aforementioned methods. Distilled water was used for extraction to determine the pH of the manure ashes.

2.3 Experimental Design

The study was essentially an incubation experiment arranged in a completely randomized design.

The treatments were replicated thrice and included: control, cattle manure ash, goat manure ash, poultry manure ash, calcium carbonate (standard), all applied at 2.5, 5, 10, 15 and 20 t ha^{-1}.

2.4 Laboratory Incubation

Two-hundred grams of the air-dried soil samples sieved with a 2-mm mesh were dispensed into each incubation plastic container (300 cm^3 capacity) assuming that the mass of furrow slice soil is 2240 t ha^{-1}. Treatments were applied separately in each incubation plastic container and were mixed. The soils and treatment mixtures were watered at a field capacity to initiate microbial activity/mineralization, and were kept in a dark cupboard for eight weeks. The average temperature of the incubation cupboard was 26.5 °C. Soil samples were subsequently taken at 0, 2, 4, 6, and 8 weeks after the treatment incorporation and were analysed for pH in water and calcium chloride ($CaCl_2$).

2.5 Estimation of the Lime Potential of the Manure Ashes

This was estimated by plotting the graph of the values of the soil pH against the corresponding amounts of the amendments (manure ashes and $CaCO_3$). The slope of the equation generated from the linear graph was used as a measurement of the responsiveness of the soil pH values to the addition of ashes and $CaCO_3$ (Figures 1 and 2). Using calcium carbonate as a standard and as a reference-liming material, the slope of the lines generated for each of the amendments were then compared with those of the corresponding $CaCO_3$ treatments. This calculation was used to generate a parameter referred to as 'Lime equivalent' (LE). This parameter was obtained from soil pH data measured from pH in water and KCl. For example, two weeks after incorporating (2 WAI) the ash, the LE of the cattle manure ash, for soil pH measured in water was as follows:

$LE_{(water)(2WAI)}$ = slope of graph of cattle manure $ash_{(2WAI)}$ /slope of the graph of $CaCO_{3\,(2WAI)}$. . . . .(Eq. 1).

The LE values were then computed for soil pH measured after 0, 2, 4, 6, and 8 weeks of the incorporation of the manure ashes to the two soils, for soil pH measurements in water and KCl.

2.6 Estimation of pH Kinetics Model

The pH kinetics was estimated with first-order, second-order, and power-function equations described by Dang et al. (1994) and reported by Azeez and Van Averbeke (2010).

First-order Equation:

$ln\ Qt = ln\ Qe - k_1 t$

k_1 is the first-order rate constant (pH^{-1}), Qt is the changes in pH after t days, Qe is the value of pH at equilibrium, and t is the time ($^{-1}$ day).

Second-order Equation:

$1/Qt = 1/Qe + k_2t$

k_2 is the second-order rate constant $((pH^{-1})^{-1})$, Qt is the changes in pH after t days, Qe is the value of pH at equilibrium, and t is the time ($^{-1}$ day).

Power-function Equation:

$Qt = at^b$

A is the initial pH release rate constant (pH^{-1} day^{-1}), b is the release rate coefficient $((pH^{-1})^{-1})$, and t is the time ($^{-1}$ day).

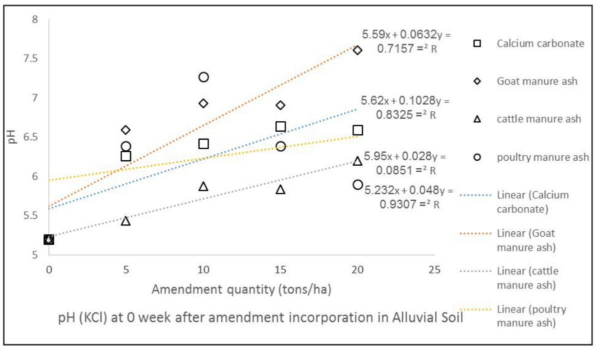

Figure 1. Typical soil pH changes in response to amendment application

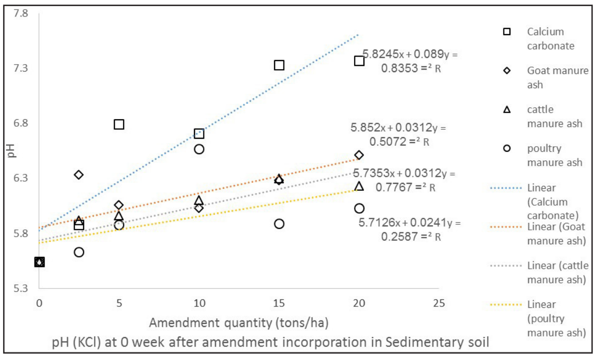

Figure 2. Typical soil pH changes in response to amendment application in sedimentary soil.

2.7 Statistical Analysis

The data collected were subjected to analysis of variance (ANOVA) using statistical analysis system (SAS, 1999). Significant treatment effects were separated using LSD at a 5 % level of probability.

3. Results and Discussion

3.1 Some Properties of the Soils and Manure Ashes Used for the Experiment

Some of the chemical analyses of soils and manure ashes used for the experiment are shown in Table 1. The textural class of both soils were sandy. It is observed that the two experimental soils were acidic in reaction, with very low exchangeable cations. With these pH values, there is the likelihood of micro-nutrient toxicity and low crop performance. Liming is probably the only option that could be used to ameliorate the problems. The soil nitrogen and organic carbon were also low. As expected, the manure ashes were high in pH and cations. Poultry manures had the highest Ca and Mg, followed by goat manure and the least Ca and Mg values were found in the cattle manure. The liming efficacy of these elements is expected to be high in the soils. Similar high amounts of the cations in manure ashes have been reported by Olowoboko et al. (2018). They also reported that the metallic contents of manure ashes are usually higher than the amounts in their respective unashed manure samples. The differences in nutrients in the manures could be attributed to the factors that had influenced the qualities of the manures; such factors include the differences in animal type, age, diet, and management system (Chadwick et al. 2000). The basic pH in the ashes is probably due to the concentration of the basic cations at ashing. The conversion of biomass to ash has been reported to increase cations and other nutrient elements by Lal and Ghuman (1989). Calcium and magnesium salts are added to the feed as additives for body osmotic balance, building of bones, and egg production in poultry (layers) production (Azeez and Van Averbeke, 2010a); this could be the rationale behind the high content of calcium and magnesium in poultry manure ash.

Table 1. Some chemical analyses of soils and manure ashes used for the experiment

	pH	Ca	Mg	Na	K	Al+H	Total N	Org. C
Soil		Cmol(+) kg^{-1}					%	
Epe	6.09	2.23	0.50	0.93	0.24	0.08	0.09	0.13
Ijale papa	5.66	2.52	0.82	0.83	0.29	0.07	0.11	1.25
Manure ash		%					%	
Poultry	10.14	13.43	4.60	1.16	3.32	-	2.58	4.67
Goat	10.48	5.08	3.19	1.39	3.02	-	3.11	5.61
Cattle	11.65	4.68	2.85	1.77	3.63	-	2.79	4.06

3.2 Effect of Manure Ashes and $CaCO_3$ on the Changes in Soil pH Values

Figures 3 and 4 show the changes in soil pH values measured in water and KCl, respectively, with the application of manure ashes and $CaCO_3$ to alluvial soil.

Generally, the addition of $CaCO_3$ to soil (Figure 3) increased the soil pH (water) significantly, except at the application rate of 5 tons/ha. On the other hand, the application of the manure ashes has an erratic pattern of response. For most of the incubation period, the ashes resulted in lower soil pH values compared with the control treatments. This might be due to the leaching of the ashes from the soil or temporary sage of the cations by soil microbes. Cattle manure ash application at 15 and 20 tons/ha and goat manure ash at 15 tons/ha were the only ash treatments that had liming effects on the soils. All the poultry manure ashes were observed to acidify the soil, compared with the control soil.

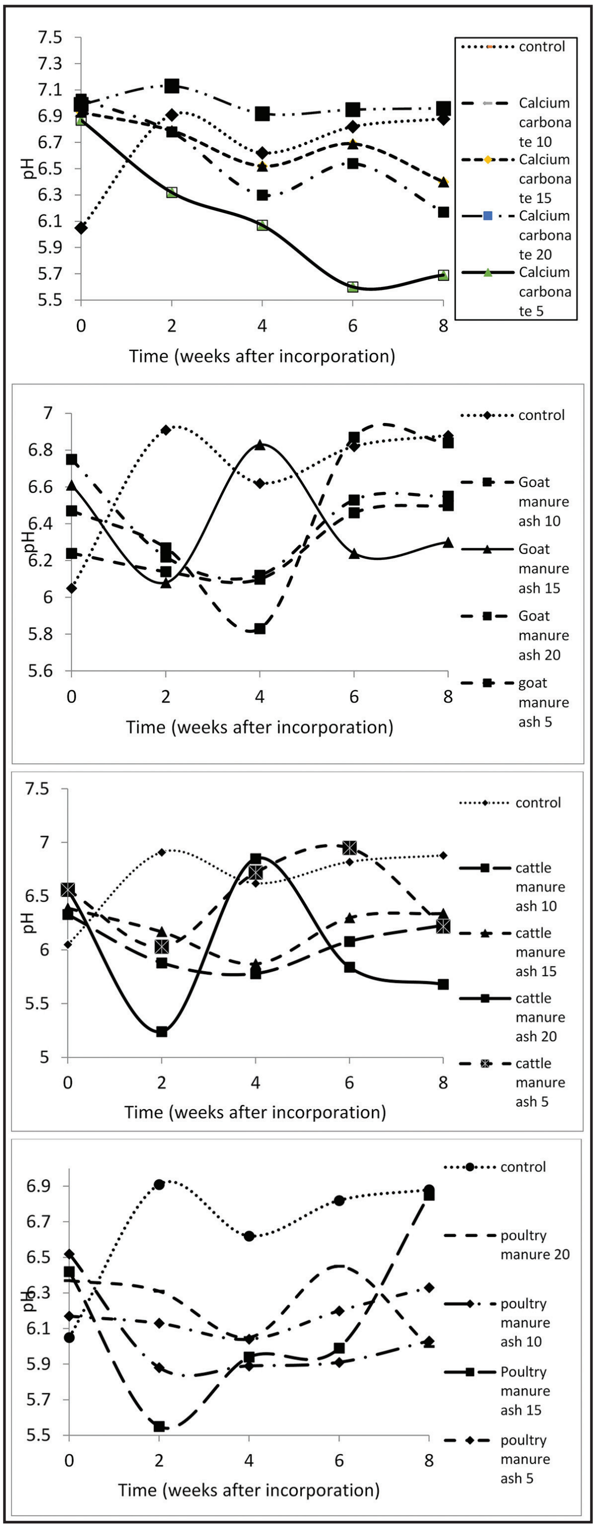

Figure 3. Changes in soil pH $_{(water)}$ with the application of manure ashes and lime in alluvial soil

As shown in the Figure 4, the pH measurement in KCl depicts that the effect of $CaCO_3$ in liming the soil was more pronounced for most of the period under investigation. The application of the lime at all rates resulted in higher soil pH values $_{(KCl)}$ than the control soil except at 2WAI. It was also observed that all the manure ashes limed the soil at inception and at later parts of the incubation period with the exception of soils amended with the poultry manure ash. It was also observed that the soil pH (KCl) was highest in all treatments weeks after the incorporation of all the amendments. Generally, the response pattern of soils treated with manure ash is similar to some minor outliers.

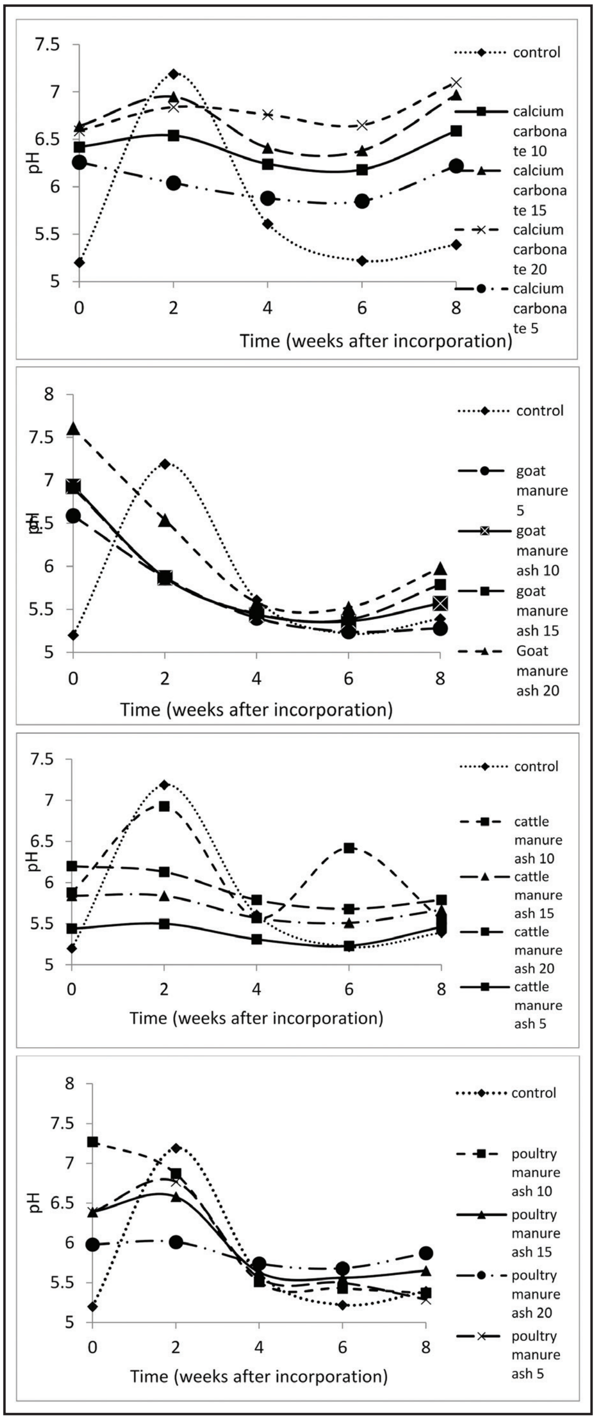

Figure 4. Changes in soil pH $_{(KCl)}$ with the application of manure ashes and lime in alluvial soil

Figures 5 and 6 show the changes in soil pH values measured in water and KCl, respectively, with the application of manure ashes and $CaCO_3$ to sedimentary soils. In Figure 5, it was observed that lime and the manure ashe application significantly increased the soil pH water. In all the ashes, and that application of 10 tons/ha and above had a significant increase in the soil pH. It was also observed that for most of the pH values, the initial soil pH peak was observed at 2 WAI. In soils treated with cattle and poultry manure ashes, the initial high pH at 2WAI was not sustained, and there was a gradual reduction in soil pH with the increase of the incubation time, though, pH values remained higher than the control for most of the rates considered. In soils treated with goat manure ash, the pattern seems erratic, irrespective of the manure ash rates applied.

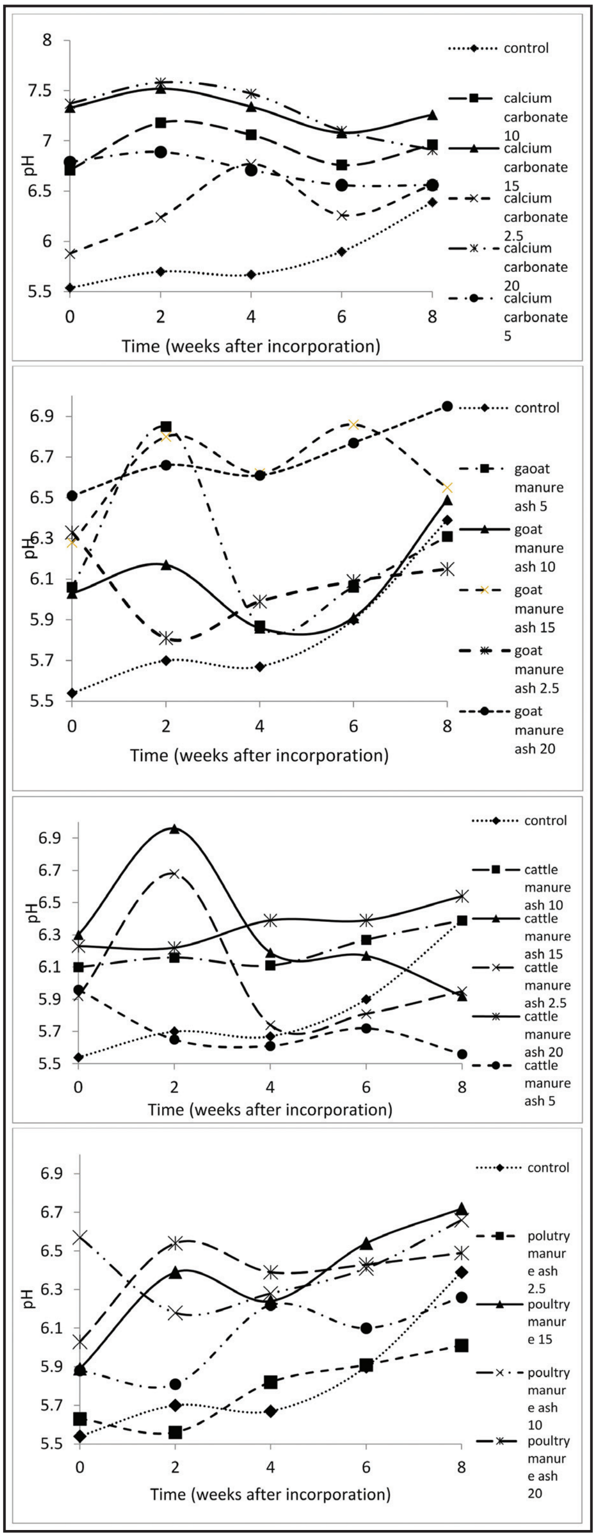

Figure 5. Changes in soil pH $_{(water)}$ with the application of manure ashes and lime in sedimentary soil

The pattern observed for soil pH $_{KCl}$ (Figure 6) was also inconsistent. The application of lime and the ashes increased the soil pH. However, there were two peaks in the graphs, at 2 and 6 WAI. Irrespective of the manure ash rates (except in 5 tons/ha cattle manure), their application significantly limed the soils. The differences observed between the soils might be a reflection of their parent materials and the initial soil pH values.

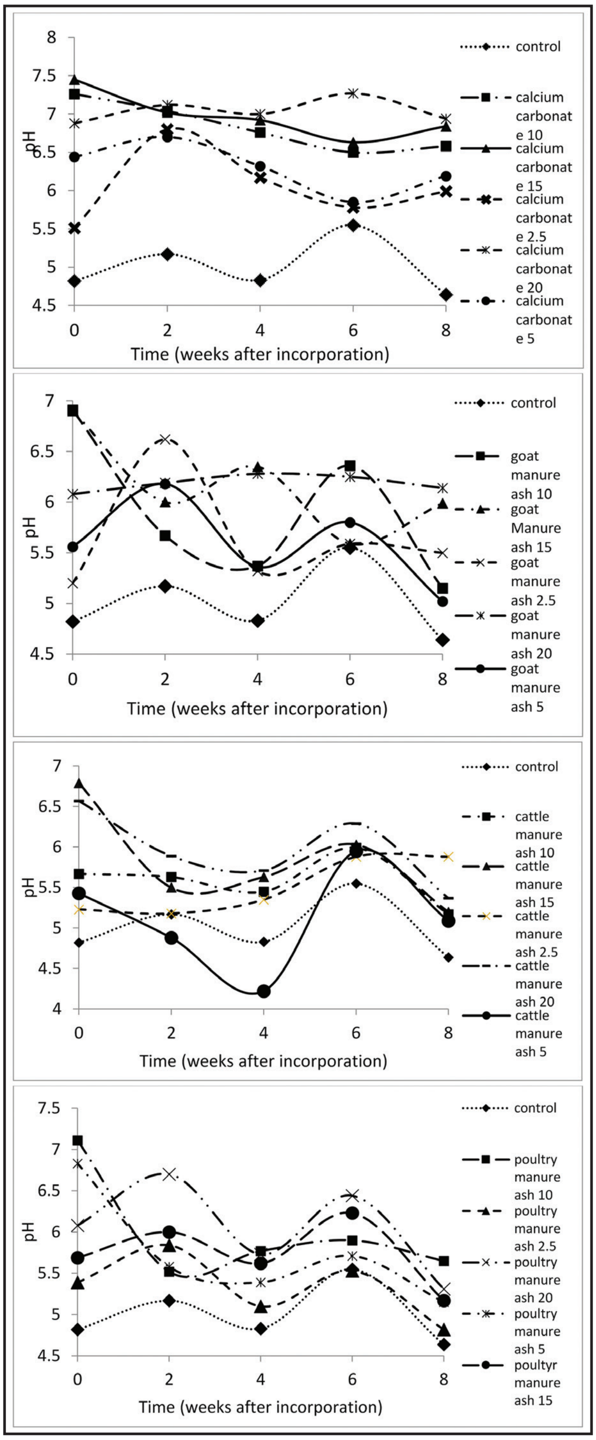

Figure 6. Changes in soil pH $_{(KCl)}$ with the application of manure ashes and lime in sedimentary soil

The $CaCO_3$ and the manure ashes applied limed the soil. This liming effect is closely related to the Ca contents of the amendments. The ashes have high amounts of Ca and Mg that are noted for soil liming. Their content, however, might not be a guarantee for liming, particularly if the cations are not bioavailable or soluble enough to neutralize and displace the Al and H content from the soil colloidal surfaces. The pH in KCl seems more reliable, since most of the H in the exchange sites are displaced by the K in solution, which is the reason for the uniformity in pattern. However, this might not be possible in the pH measured in distilled water. Two weeks seem critical in the measurement of the liming effects of the amendments. Microbial-mediated reactions with the manure ashes most likely reach equilibrium stability at two weeks. This time duration seems critical for microbial-mediated processes in the soil. Azeez and van Averbeke (2010b) also reported that two weeks is critical for the release of nutrients from manure-amended soils in South Africa.

The pattern of liming differs among the different manures and their ashes. This could be a reflection of the feeding pattern of the animals and the management practices employed in the raising of the animals. The poultry manure used for the study is taken from layer birds raised intensively using a battery cage system. The cattle and goat manures were sourced from animals that scavenge (open grazing) during the day, but stay in shed at nights. The manures were collected from the open sheds. Additionally, the birds were fed with compound feeds in which the nutrient requirements of the birds are adequately met, while the ruminants scout for browse plants daily. These could have affected the manural quality of the animal wastes, and hence, their cation contents. This will invariably affect their liming effectiveness when used raw as manure or when applied as ashes.

3.3 Kinetics of Soil pH after Incorporation of Manure Ashes and $CaCO_3$

The parameters estimates of the equation employed in describing the soil pH kinetics in alluvial and sedimentary soils with and without amendments are shown in Tables 2 and 3 with the R^2 used as the criteria to determine the best equation for describing the changes in soil pH with time. Table 2 shows that for pH_{water} of the alluvial soil, the first-order equation was able to capture the changes in soils amended with poultry manure ash, while the power-function equation was preferred for soils amended with cattle manure ash. This implies that changes in pH with the increasing of time followed solely a linear pattern with the addition of poultry manure ash, while the addition of cattle manure ash allowed a nonlinear increase or decrease in pH as the weeks progressed. Soil amended with calcium carbonate (5t/ha, 10t/ha) and goat manure ash (15t/ha and 20 t/ha) had their pH following a curvilinear pattern with the increasing of weeks. This means that these pH changes were not consistent with time, and the fluctuations in pH were a result of soil and amendment characteristics. This is agreement with the findings of Abbasi et al., 2007 who observed inconsistency (increased or decrease with time) in the pattern of total mineral N of three organic manures in an incubation experiment. The type of the extracting solution affected the kinetics of pH, since they differ with varying extracting solutions. pH changes in almost all of the amended soils were inconsistent, and, hence, followed a nonlinear pattern. This is seen as they were best described by the power-function kinetics model, no plausible scientific reason is adduced for this. Soils amended with poultry manure ash at 15t/ha and 5t/ha and the cattle manure ash at 10t/ha had the second-order equation as the best model for expressing the pH kinetics. However, in the control soil, the first-order equation was preferred signifying linear changes in pH with time. The highest and lowest R^2 among others for pH_{water} were observed in power-function model as 0.943 (calcium carbonate 5t/ha) and in first-order equation as 0.009 (cattle manure ash 5t/ha) respectively. However, the power-function kinetics model showed the highest and lowest R^2 of 0.979 (goat manure ash 5t/ha) and 0.015 (calcium carbonate 10t/ha) in $pH_{KCl.}$

Table 2. pH mineralization kinetics of an alluvial soil applied with or without manure ashes and $CaCO_3$

	$pH_{(water)}$							$pH_{(KCl)}$						
	first order		Second order		Power function			first order		Second order		Power function		
Treatment (t/ha)	K_1	R^2	K_2	R^2	a	b	R^2	K_1	R^2	K_2	R^2	a	b	R^2
Control	0.012	0.487	0.003	0.49	6.181	0.053	0.698	0.012	0.084	0.003	0.076	5.776	-0.01	0.006
Calcium carbonate 10	-0.014	0.782	0.004	0.779	7.068	-0.05	0.807	0.000	0.000	0.00008	0.001	6.427	0.000	0.015
Calcium carbonate 15	-0.008	0.754	0.002	0.752	6.956	-0.03	0.746	0.000	0.001	0.000	0.001	6.676	0.000	0.000
Calcium carbonate 20	-0.001	0.213	0.000	0.214	7.036	0.000	0.13	0.006	0.431	0.000	0.428	6.595	0.02	0.385
Calcium carbonate 5	-0.024	0.899	0.007	0.901	6.918	0.000	0.943	-0.002	0.051	0.000	0.052	6.185	-0.01	0.209
Cattle manure ash 10	0.00008	0.00004	0.00005	0.000	6.161	-0.01	0.082	-0.009	0.099	0.003	0.103	6.199	-0.01	0.026
Cattle manure ash 15	0.000	0.000	0.00008	0.000	6.283	0.000	0.045	-0.005	0.482	0.001	0.476	5.865	-0.02	0.556
Cattle manure ash 20	0.009	0.067	0.002	0.056	6.325	-0.03	0.091	-0.01	0.751	0.003	0.747	6.245	-0.04	0.791
Cattle manure ash 5	0.001	0.009	0.000	0.008	6.435	0.005	0.008	-0.002	0.103	0.000	0.103	5.456	0.000	0.148
Goat manure ash 10	0.01	0.222	-0.002	0.203	6.259	0.021	0.073	-0.026	0.636	0.008	0.639	6.779	-0.11	0.97
Goat manure ash 15	-0.003	0.055	0.001	0.053	6.53	-0.01	0.067	-0.022	0.487	0.006	0.476	6.717	-0.1	0.88
Goat manure ash 20	0.000	0.002	0.000	0.0012	6.56	-0.01	0.104	-0.032	0.6	0.009	0.582	7.491	-0.13	0.813
Goat manure ash 5	0.006	0.519	-0.001	0.518	6.137	0.017	0.271	0.027	0.827	0.009	0.841	6.57	-0.11	0.97
Poultry manure 20	-0.004	0.231	0.001	0.23	6.382	-0.01	0.216	-0.004	0.357	0.001	0.353	6.7	-0.09	0.617
Poultry manure ash 10	-0.007	0.297	0.002	0.288	6.371	-0.03	0.593	-0.042	0.836	0.012	0.84	7.469	-0.15	0.862
Poultry manure ash 15	0.01	0.163	0.003	0.157	6.038	0.011	0.015	-0.02	0.672	0.006	0.676	6.57	-0.07	0.672
Poultry manure ash 5	0.003	0.333	0.000	0.327	6.115	0.006	0.12	-0.029	0.752	0.009	0.774	6.005	-0.01	0.425

In the sedimentary soil, (Table 3) the kinetics of pH in water and calcium chloride was not consistent among amendment rates since none of these kinetics models could solely describe the pH changes for any of the applied amendments. However, it was observed that the kinetics model was affected by the extracting solution used for the pH determination. This was noticed when the kinetics model that best captured the changes in pH $_{water}$ was distorted when applied to the same amended soil in pH $_{KCl}$. The power-function model captured the changes only in soils amended with poultry manure at 20t/ha, 15t/ha and calcium carbonate at 2.5t/ha, 10t/ha, while a linear pattern described pH changes in soils amended with the cattle manure ash at all rates except 5t/ha for pH $_{water}$. pH kinetics in the control and in the soils amended with calcium carbonate were best described by the power-function model signifying a nonlinear response of soil pH as the weeks progressed whereas the first-order function was the best fit for cattle manure ash (2.5t/ha, 5t/ha and 10t/ha), goat manure ash (2.5t/ha) and poultry manure ash (10t/ha) in pH $_{KCl}$. Among all the kinetics' models, the highest and lowest R^2 were observed with first-order equation at 1.90 (cattle manure ash at 15t/ha) and with the power-function model at 0.08 (calcium carbonate at 10t/ha) respectively for pH $_{water}$. Conversely, in pH $_{KCl}$, the highest and lowest R^2 of 0.901 (cattle manure ash at 10t/ha) and of 0.008 (goat manure ash at 2.5t/ha) respectively were recorded. The rate constant of the second-order model (K_2) was positive for almost all of the amended soils while the rate constant of the first-order (K_1) and power-function (b) models had both positive and negative values. The wide variation in the rate constant of the manure ashes and calcium carbonate could be attributed to the differences in amendment characteristics.

Table 3. pH mineralization kinetics of a sedimentary soil applied with or without manure ashes and $CaCO_3$

	$pH_{(water)}$							$pH_{(KCl)}$						
	first order		Second order		Power function			first order		Second order		Power function		
Treatment (t/ha)	K_1	R^2	K_2	R^2	a	b	R^2	K_1	R^2	K_2	R^2	a	b	R^2
Control	0.016	0.823	0.005	0.835	5.444	0.05	0.615	0.000	0.000	0.000	0.001	4.921	0.01	0.016
Calcium carbonate 10	0.000	0.005	0.000	0.006	7.419	0.09	0.08	0.013	0.89	0.003	0.889	7.314	-0.05	0.901
Calcium carbonate 15	-0.004	0.333	0.001	0.33	7.419	-0.01	0.208	-0.011	0.703	0.003	0.701	7.42	-0.04	0.867
Calcium carbonate 2.5	0.011	0.426	0.003	0.441	5.934	0.0047	0.594	0.000	0.00008	0.000	0.01	5.85	0.022	0.058
Calcium carbonate 20	-0.009	0.651	0.002	0.651	7.547	-0.02	0.358	0.001	0.0075	0.000	0.076	6.93	0.011	0.195
Calcium carbonate 5	-0.005	0.751	0.000	0.754	6.87	-0.01	0.542	-0.01	0.458	0.003	0.462	6.595	-0.03	0.35
Cattle manure ash 10	0.005	0.787	0.001	0.787	6.06	0.017	0.574	-0.006	0.128	0.002	0.147	5.709	-0.01	0.077
Cattle manure ash 15	-0.0012	1.901	0.003	0.402	6.574	-0.03	0.204	-0.022	0.464	0.006	0.463	6.58	-0.09	0.602
Cattle manure ash 2.5	-0.006	0.113	0.001	0.112	6.13	-0.01	0.049	0.018	0.824	0.006	0.463	5.082	0.057	0.621
Cattle manure ash 20	0.006	0.885	0.001	0.885	6.179	0.02	0.713	-0.016	0.451	0.005	0.458	6.503	-0.06	0.502
Cattle manure ash 5	-0.006	0.543	0.002	0.544	5.91	-0.02	0.736	0.003	0.007	-0.001	0.005	5.155	-0.01	0.005
Goat manure ash 5	0.002	0.012	0.000	0.009	6.24	0.000	0.001	-0.013	0.29	0.004	0.306	5.822	-0.03	0.127
Goat manure ash 10	0.005	0.161	-0.001	0.151	5.989	0.012	0.064	-0.023	0.377	0.000	0.381	6.701	-0.09	0.493
Goat manure ash 15	0.004	0.177	0.001	0.183	6.392	0.025	0.398	-0.017	0.506	0.005	0.494	6.795	-0.07	0.648
Goat manure ash 2.5	0.000	0.002	0.000	0.001	6.17	-0.01	0.106	-0.002	0.008	0.000	0.004	5.554	0.009	0.007
Goat manure ash 20	0.007	0.867	0.002	0.869	6.47	0.024	0.727	0.01	0.124	0.000	0.126	6.112	0.008	0.347
Poultry manure ash 2.5	0.009	0.862	0.003	0.857	5.54	0.03	0.625	-0.013	0.353	0.005	0.367	5.603	-0.03	0.191
Poultry manure 15	0.014	0.816	0.004	0.809	5.903	0.053	0.85	-0.007	0.118	0.002	0.138	5.847	-0.01	0.052
Poultry manure ash 10	0.003	0.106	0	0.106	6.409	0.001	0	-0.019	0.376	0.005	0.359	6.767	-0.09	0.626
Poultry manure ash 20	0.006	0.407	0.001	0.412	6.119	0.029	0.64	-0.015	0.281	0.005	0.3	6.366	-0.03	0.137
Poultry manure ash 5	0.008	0.679	-0.002	0.678	5.81	0.029	0.507	0.027	0.629	0.008	0.641	6.649	-0.11	0.812

3.4 Changes in the Lime Equivalence of Manure Ashes with Time of Incorporation

The dynamics of the Lime equivalence (LE) values of the manure ashes are shown in Figures 7-10. The LE values of the ashes as measurements in soil pH (water) for the alluvial soil, shown in Figure 7, revealed that cattle manure ash (at 2, 6 and 8 WAI) and goat manure ash (at 6 and 8 WAI), actually acidify the soil compared with the effects of $CaCO_3$. However, for the soil pH in KCl (Figure 8), negative LE was only observed in soils amended with poultry manure ash at 2WAI. After the incorporation of the ashes, other week durations had positive effects on increasing LE, though this was not consistent with time. As shown in Figures 7 and 8, the average LE across weeks of investigation was highest with the goat manure ash (0.73), followed by the cattle manure (0.30). However, it was least with poultry manure (0.26) in pH $_{KCl}$. Their corresponding values are 0.22, -0.22 and 0.15, in pH $_{water}$.

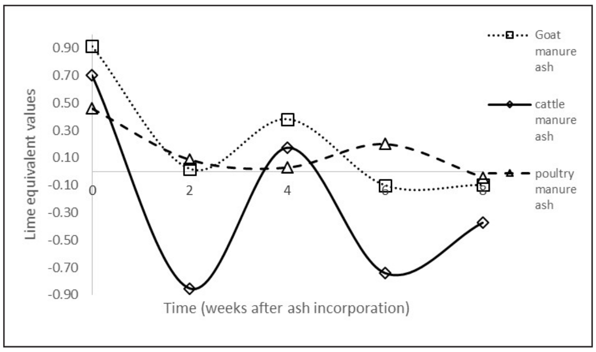

Figure 7. Changes in Lime Equivalent of manure ashes in alluvial soil, pH in water

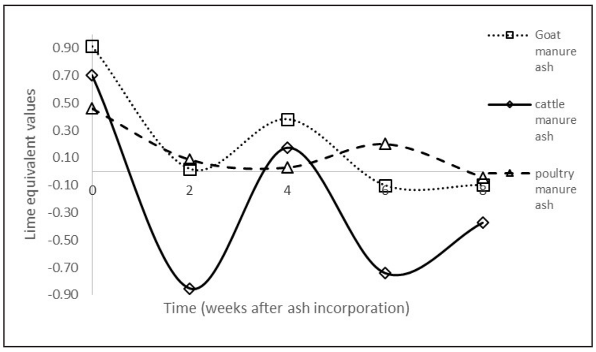

Figure 8. Changes in Lime Equivalent of manure ashes in alluvial soil, pH in KCl

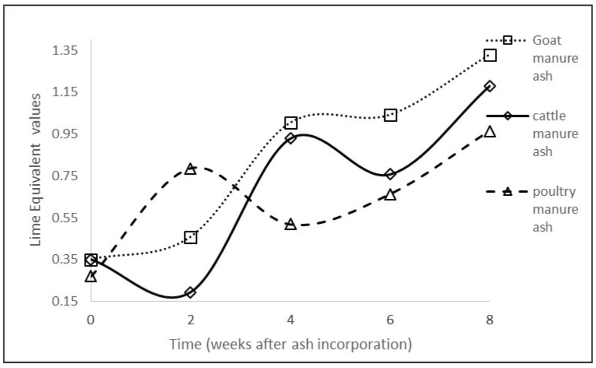

Figure 9. Changes in Lime Equivalent of manure ashes in sedimentary soil, pH in water

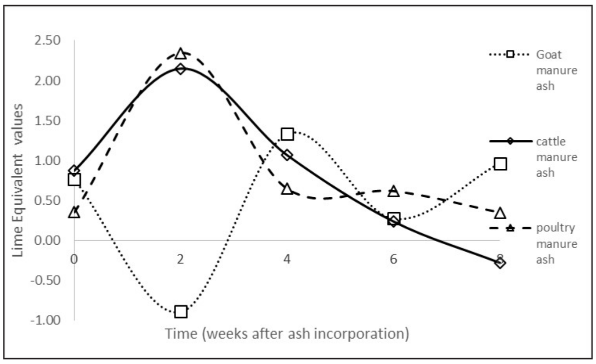

Figure 10. Changes in Lime Equivalent of manure ashes in sedimentary soil, pH in KCl

Lime equivalence for the ashes in the sedimentary soil estimated in pH $_{water}$ is shown in Figure 9. It was observed that all the ashes had increased LE with the time of incorporation. The highest LE values were recorded at 8 WAI. The LE values are in the following order: goat manure ash (0.84) > cattle manure ash (0.68) > poultry manure ash (0.64). The pattern observed in Figure 10 shows that the LE of the ashes had its peaks at 2WAI for poultry and cattle manure ashes, while it was negative for the goat manure ash. The values increased for the goat manure ash, but they were reduced with time consistently concerning the other two ashes. The average LE values across the weeks of incorporation were 0.86, 0.81 and 0.49, for the poultry manure ash, cattle manure ash, and goat manure ash, respectively. The results recorded in the above figures signify that the manure ashes have the ability to lime the soil. However, the magnitude of their liming potential depends on the medium in which the soil pH is determined. It was generally observed that the LE of the ashes was higher with pH values recorded in pH $_{KCl}$ (0.58) and lower in pH $_{water}$ (0.46). Goat manure ash was also seen to have a consistently higher LE values irrespective of the media of pH measurement. Overall, goat manure ash has an LE value of 0.57. it was followed by poultry manure ash at (0.48) and the least LE value (0.39) was found for the cattle manure ash.

4. Conclusions

Manure ashes have a liming potential in comparison with conventional lime. Values of liming equivalence of the ashes were higher in pH values recorded in pH $_{KCl}$ (0.58) and lower in pH $_{water}$ (0.46). Their liming equivalence values are 57 %, 48 %, and 39 %, for the goat, poultry and cattle manure ash, respectively. In the alluvial soil, pH changes in almost all of the amended soils were best described by the power-function kinetics model in pH $_{KCl}$, while the first-order and power-function models were most appropriate for soils amended with poultry manure ash and cattle manure ash, respectively for pH $_{water.}$ However, in the sedimentary soil, pH kinetics was not consistent among amendment rates, as the kinetics models could not solely describe the pH changes for any of the applied amendments. The ability of pH-kinetics models to describe soil pH changes was dependent on the type of the extracting solution used for pH determination, which could, however, be verified on the field.

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