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Processing and Storage Effects on the Concentration of Water-Soluble Phosphorus and Trace Nutrients

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ABSTRACT

Background and Objective: High cost of mineral fertilizers has resulted in increased use of animal manure by smallholder farmers in Nigeria. A study was carried out to process manure as practised by farmers to assess the effect on nutrient concentration as well as water-soluble P. **Materials and Methods:** Four manure types, poultry litter, cow dung, sheep and goat and farmyard manure were used in the research. The different manures were subjected to three treatments, shade drying, sun drying and composting. The materials were sampled at one, two and three-month intervals and analyzed for the amount of water-soluble phosphorus, calcium, magnesium and some micronutrients. Data were subjected to analyses of variance. **Results:** The results showed significant differences ($p<0.05$) in the amount of WSP by sources, processing and storage with the lowest amount of WSP obtained from poultry manure (2162.26 mg kg^{-1}). Sun drying and long storage duration (3 months) were observed to have the lowest WSP concentration of 2009.54 and 2109.95 mg kg^{-1}, respectively. High contents of Ca and micronutrients were observed with composting. **Conclusion:** The results obtained showed that processing and storage of manure plays a significant role in the efficiency of nutrient retention and sun drying of manures could serve as a method to reduce the loss of water soluble phosphorous.

KEYWORDS

Manures, processing, storage, water-soluble P, micronutrients, soil fertility management, pollution

INTRODUCTION

The need to meet the growing demand for food and food security has increased the rate of agricultural intensification[1]. This intensification increases the demand for external sources of nutrient application to soils[2]. Mineral fertilizers, though contribute significantly to boosting yields, their cost of purchase has forced many smallholder farmers to look for alternate sources of fertilizers[3]. Organic fertilizers are readily available and/or can be easily generated by farmers. These materials include farmyard manure, cow dung, poultry, sheep and goat manure etc[4]. A high amount of manure is produced on a daily basis by livestock-based farming systems in Nigeria[5]. Animal manures constitute valuable sources of minerals and can improve and maintain soil quality under continuous cultivation[2,5].

Despite the high production of manures, inadequate farmhands, low financial resources as well as technological know-how influence the duration of storage and processing before use on farmlands. In

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many smallholder farming systems of Northern Nigeria, animal manures are usually left in small piles on the fields directly under the sun. Composting is rarely practised and in fewer cases, manures might be kept under cover[6]. The duration of collection varies and this might influence the quality of the manure in terms of its nutrient content with almost 50% mass loss in quality of manures being reported for Africa[7].

Though there has been a lot of research on the characterization of manures and compost, as well as its effects on the growth of different crops[8], research focused on evaluating different types of manures as influenced by processing on quality is limited. An experiment was carried out to observe the concentration of water-soluble phosphorus (WSP) calcium (Ca), magnesium (Mg), as well as micronutrients (copper, iron, zinc, manganese and lead) under similar small holder's practices (sun-dried and shade dried) as well as composting. The effect of different sources of manure as well as the length of storage was also evaluated.

MATERIALS AND METHODS

Experimental site: The research was carried out at the Department of Soil Science, Bayero University Kano from December, 2016 to October, 2017. The university is located in the Sudan Savannah vegetation characterized by a tropical climate with a dry season ranging from October to April and the wet season from May to September. Average annual rainfall ranges from 600-1000 mm.

Sample collection: Four different types of manure were collected, poultry, cow, sheep and goat manure as well as farmyard manure. All manures were obtained from the Department of Animal Science Teaching and Research Farm, Bayero University Kano.

Experimental layout: Three replications of each treatment were laid out in a Completely Randomized Design (CRD) for each manure type. The treatments were: (i) Manure heaps in the open air (under the sun), (ii) Manure heaps under corrugated zinc shade and (iii) Manure heaps composted in bins.

Sampling: Six 500 g samples of manure were taken from each replicate of each treatment from each of the manure types. The samples included two close to the upper surface of the pile, two from the centre and two from the bottom. These samples were quickly but thoroughly mixed on a plastic film. The samples were packed in polythene bags, sealed and stored before analysis. Samples were collected from each type of manure under the different treatments every 30 days for three consecutive months (90 days). This period is the average time farmers in the area keep manure before application in the field.

Laboratory analysis

Characterization of manure: The pH and electrical conductivity (EC) were determined using the method applied by Mustapha[9]. Organic carbon content was determined using the wet oxidation method of Walkley and Black as outlined by Ramamoorthi and Meena[10] while Total N was determined using the Micro-Kjeldahl digestion method used by Abdulrahman and Mustapha[4].

Determination of water-soluble phosphorus (WSP): Water-soluble P was determined using the phosphomolybdate vanadate yellow colour method used by Zhang *et al.*[11]. About 50 mL of distilled water was added to 3 g of the samples in plastic bottles and shaken for 1 hr, 3 mL of the extract was collected using a pipette into a 25 mL volumetric flask. As 15 mL of distilled water and 5 mL of Yellow reagent (Guandong gnghuo chemical factory, China) were added to the volumetric flask after which the flask was filled to the mark with distilled water and left to stand for 5 min. The concentration of P was determined using a spectrophotometer (spectrum lab, 7525, New life Medical Instrument, England).

Determination trace elements: The contents of Copper (Cu), Lead (Pb), Zinc (Zn), Iron (Fe), Manganese (Mn), Calcium (Ca) and Magnesium (Mg) were determined using the methods described by Mustapha[12]. The samples were digested in 30 mL of Aqua regia ($HCl+HNO_3$). After digestion, each sample was allowed to cool down and then transferred to a plastic bottle and diluted with 100 mL of distilled water. The concentration of Ca, Mg, Mn, Cu, Zn and Fe were determined using the atomic absorption spectrophotometer (AAS, Agilent Technologies, 240 ss).

Statistical analysis: Data generated from the laboratory analyses were subjected to analysis of variance using JMP software version 14. Means with significant differences at $p<0.05$ were separated using Fishers protected least significant difference.

RESULTS

Characterization of manures: Nutrient composition of the different manure types before they were subjected to the different treatments. There was no statistical difference in the nutrient analyses of the various manures, although the content of nitrogen in farmyard manure (4.63%) was observed to be the highest while cow dung had the lowest concentration (1.05). Poultry manure was observed to have the highest organic carbon and moisture content of 86.67 and 16.75%, respectively. All the manure sources had alkaline pH (>8). The highest P content was observed in farmyard manure while poultry manure had the lowest content of 2.45 as shown in Table 1.

Effect of source of material, type of processing and duration of storage on the concentration of water-soluble P: There was no significant difference ($p<0.05$) between the sources of material on the concentration of water-soluble P (WSP), though the highest concentration of 2332.91 mg kg^{-1} was observed in sheep and goat manure while poultry had the lowest concentration of 2162.26 mg kg^{-1} (Table 2). Significant differences ($p<0.05$) were observed with processing, with shade-dried manures having the highest amount of 2492.60 mg kg^{-1}. The lowest content of 2009.54 mg kg^{-1} was obtained in the sundried manures. Similarly, no significant difference ($p<0.05$) was observed in the duration of storage, however, higher contents of WSP were observed after 2 months of storage.

Effect of source of material, type of processing and duration of storage on Ca and Mg concentration: The effect of the source of materials, storage type and time on the concentration of Calcium (Ca) and Magnesium (Mg) are presented in Table 3. A significant difference ($p\leq0.05$) was observed in the concentration of calcium with the source of the material, with poultry manure having the highest Ca content of 38.30 cmol kg^{-1}, while farmyard manure (FYM) had the lowest Ca content of 29.55 cmol kg^{-1} (Table 3). A significant difference was also observed with the type of processing with composted manures (41.05 cmol kg^{-1}) having higher levels of Ca when compared to sun-dried (30.90 cmol kg^{-1}) and shade dried (33.05 cmol kg^{-1}). Duration of storage was observed to have no significant effect on the content of Ca though the value of 39.00 cmol kg^{-1} observed in the second month was higher than the 35.15 and 34.14 cmol kg^{-1} obtained in the 1st and 3rd months, respectively. Interaction effects of types of materials and processing were observed to be highly significant ($p<0.001$) while material and duration of storage were significant (0.05). The method of processing and duration of storage was observed to show no significant effects. No significant interaction was observed between processing, material and duration of storage.

A significant difference ($p<0.05$) was observed in the materials in terms of Mg concentration (Table 3). Farmyard manure had the highest content of 5.08 cmol kg^{-1}, while poultry had the lowest content of 4.17 cmol kg^{-1}. A significant difference ($p<0.05$) was obtained with processing whereby the content of magnesium in sun-dried manures (5.33 cmol kg^{-1}) was higher than the amount observed for composted (4.33 cmol kg^{-1}) manures and shade-dried manure (4.58 cmol kg^{-1}). Duration of storage was observed to have no significant difference in the content of Mg, however, higher contents of Mg were obtained in the second month of storage. Highly significant interaction ($p<0.001$) was observed with materials and processing while significant interactions (0.05) were observed between materials and duration, processing and duration as well as between duration, material and processing.

Table 1: Nutrient composition of different manure

Materials	N (%)	P (mg kg^{-1})	OC (%)	EC (ds m^{-1})	pH	MC (%)
CD	1.05	5.23	61.22	0.79	8.73	12.50
SG	4.38	2.85	63.89	1.20	8.65	05.49
FYM	4.63	6.21	60.45	0.92	8.33	14.35
PM	4.34	2.45	86.67	0.95	8.12	16.75

CD: Cow dung, SG: Sheep and goat, FYM: Farmyard manure, PM: Poultry manure, N: Nitrogen, P : Phosphorous, OC: Organic carbon, EC: Electrical conductiviy, MC: Moisture content and $p<0.05$

Table 2: Effect of source of material, storage type and time on the concentration of water-soluble P

Treatment	WSP (mg kg^{-1})
Material	
Poultry	2162.26
Sheep and goat manure	2332.91
Cow dung	2163.57
Farmyard manure	2200.01
SED	109.19
Processing	
Composted	2141.91^{ab}
Sun-dried	2009.54^{b}
Shade dried	2492.60^{a}
SED	106.92
Duration	
1 month	2192.15
2 months	2346.95
3 months	2104.95
SED	94.49
Interaction	
M×P	NS
M×D	NS
P×D	NS
D×M×P	NS

Means followed by the same letter are not statistically different at 5% level of probability, M: Source of materials, P: Processing, D: Duration of storage,WSP: Water soluble phosphorus, SED: Standard error of difference and NS: Not significant

Table 3: Effect of source of material, storage type and time on Ca and Mg

Treatment	Ca (cmol kg^{-1})	Mg (cmol kg^{-1})
Material		
Poultry	38.30^{a}	4.17^{b}
Sheep and goat manure	36.60^{a}	4.67^{ab}
Cow dung	35.55^{ab}	5.00^{ab}
Farmyard manure	29.55^{b}	5.08^{a}
SED	2.55	0.33
Processing		
Composted	41.05^{a}	4.33^{b}
Sun-dried	30.90^{b}	5.33^{a}
Shade dried	33.05^{b}	4.58^{b}
SED	02.20	0.25
Duration	00.00	
1 month	34.14	4.58
2 months	39.00	4.92
3 months	35.15	4.67
SED	2.20	0.25
Interaction		
M×P	**	**
M×D	*	*
P×D	NS	*
D×M×P	NS	*

Means followed by the same letter are not statistically different at a 5% level of probability, *,**Significant at 5 and 1% level of probability, respectively, SM: Source of materials, P: Processing, D: Duration of storage, NS: Not significant and SED: Standard error of difference

The result of the interaction between materials and the processing of Ca content was shown in Fig. 1. When the manures were composted, the highest amount of 56.45 cmol kg^{-1} Ca was obtained in poultry manure with FYM having the lowest content of 28.9 cmol kg^{-1}. When the materials were shade dried, sheep and goat manure had the highest Ca of 36.8 cmol kg^{-1} while FYM had the lowest content of 27.00 cmol kg^{-1}. Sun-drying resulted in cow dung having the highest content of 42.15 cmol kg^{-1} Ca while poultry had the lowest content of 22.65 cmol kg^{-1}. Interaction effects between material and duration of storage showed poultry manure had the highest Ca content (44.80 cmol kg^{-1}) in the first month while cow dung (39.45 cmol kg^{-1}) had the highest in the second month of storage (Fig. 2). By the third month of storage, sheep and goat had the highest (41.30 cmol kg^{-1}) with FYM having the lowest content of 31.35 cmol kg^{-1} Ca.

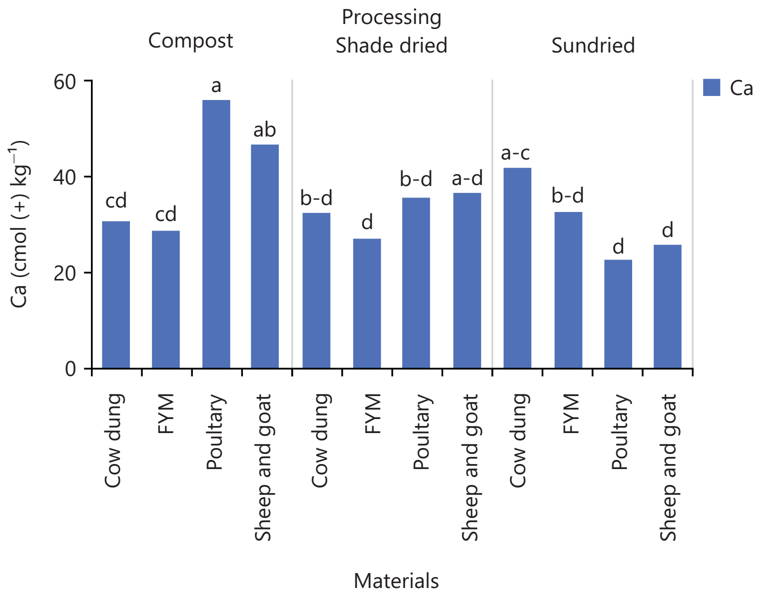

Fig. 1: Interactions effects of processing and materials on calcium content
Small alphabets represents means comparison

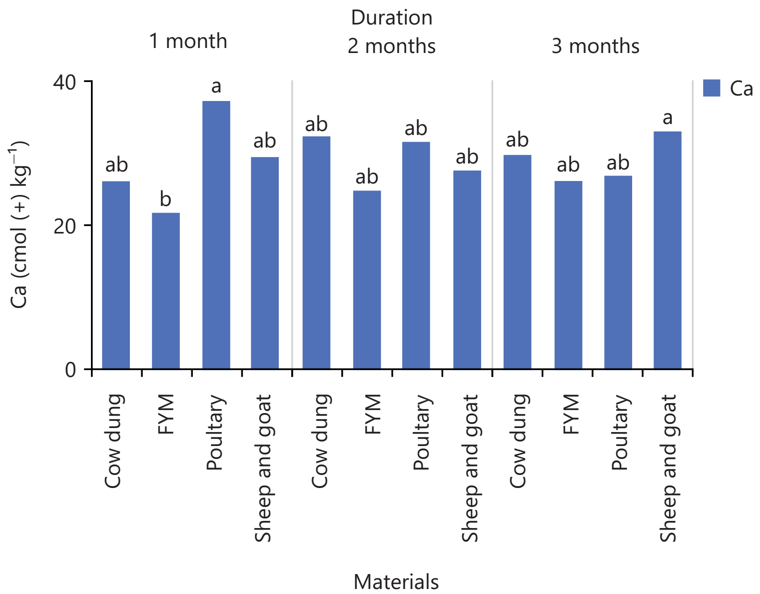

Fig. 2: Interactions effects of duration of storage and materials on calcium content
Small alphabet represents means comparison

Interaction effects between materials and processing on Mg content as shown in Fig. 3 indicated FYM had the highest content of Mg when composted and sundried, 6.17 and 5.33 cmol kg^{-1}, repectively. When shade dried, the highest of Mg was obtained with shade drying 5.25 cmol kg^{-1}. The results of the interaction between material and duration of storage indicated that FYM had the highest Mg content of 5.25 cmol kg^{-1} in both the first and second month of storage while sheep and goat manure had the highest content of 5.5 cmol kg^{-1} by the third month (Fig. 4). The interaction between processing and duration of storage showed that composted manure had the highest content of Mg in the first and second months (5.50 and 5.91 cmol kg^{-1}, respectively) while sun-dried manure had the highest content of 4.83 cmol kg^{-1} by the third month (Fig. 5). The results of the interactions between processing, material

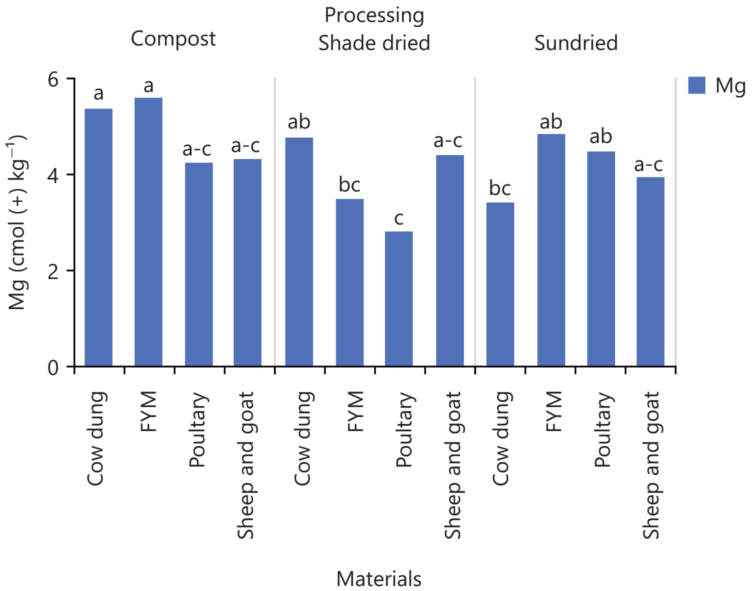

Fig. 3: Interactions effects of processing and materials on magnesium content
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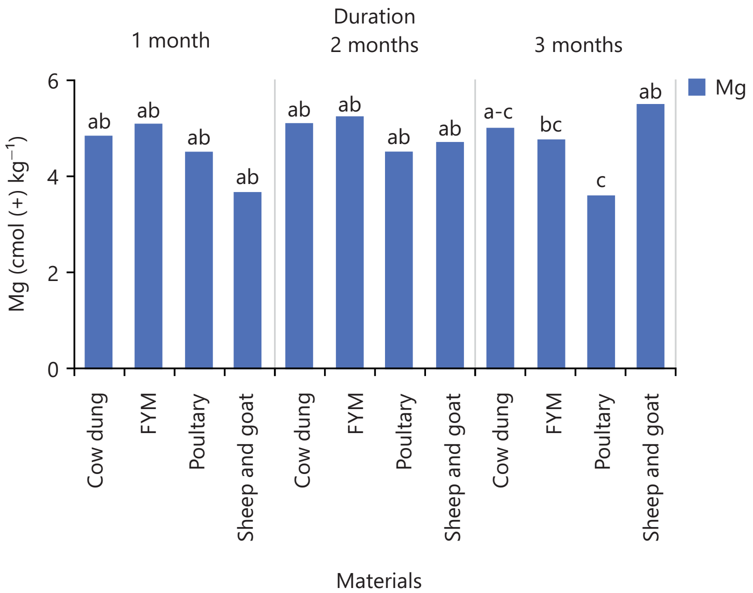

Fig. 4: Interactions effects of duration of storage and materials on magnesium content
Small alphabet represents means comparison

and duration of storage were statistically similar, that the highest content of magnesium (6.83 cmol kg^{-1}) was obtained when sheep and goat manure was composted at 2 months of storage (Fig. 6).

Effect of source of material, type of processing and duration of storage on trace elements concentration: A significant difference was observed in the amount of Cu in the different materials ($p \leq 0.05$) (Table 4). Poultry manure was observed to have the highest Cu content of 22.42 mg kg^{-1} with cow dung having the lowest content (11.14 mg kg^{-1}). There was no significant difference ($p<0.05$) between processing and duration of storage. Highly significant ($p \leq 0.001$) interactions were observed between materials and processing and also between duration, material and processing.

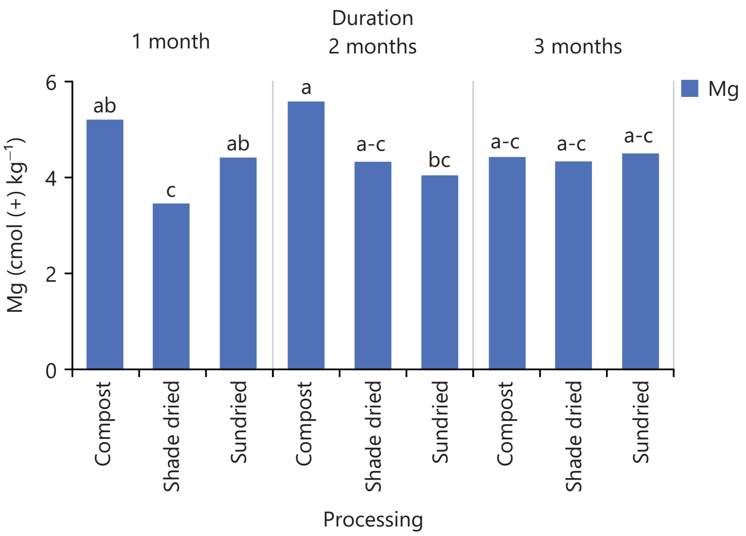

Fig. 5: Interactions effects of duration of storage and processing on magnesium content
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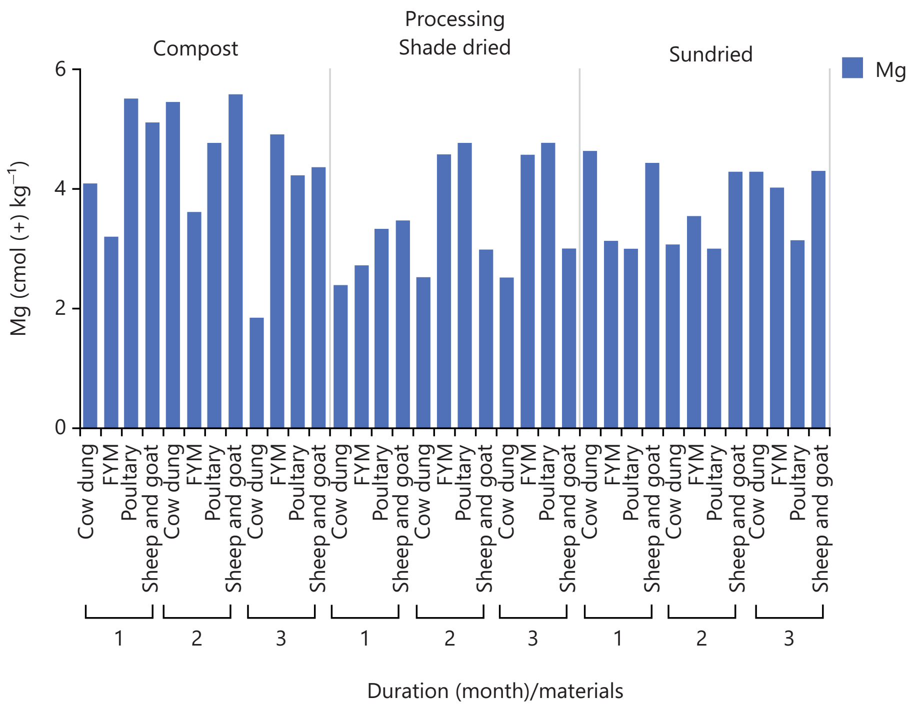

Fig. 6: Interactions effects of duration of storage, processing and materials on magnesium content

Interactions were observed to be significant ($p \leq 0.05$) for material and duration as well as processing and duration.

Iron showed no significant difference ($p \leq 0.05$) in its concentration with the different materials used, however, cow dung had the highest content of 0.20 mg kg^{-1} while the lowest content of 0.15 mg kg^{-1} was observed in poultry. A degree of difference ($p \leq 0.05$) in Fe content was observed with processing, whereby sun-dried manures (0.20 mg kg^{-1}) had higher contents of Fe when compared with composted manure (0.18 mg kg^{-1}) and shade-dried manure (0.15 mg kg^{-1}). There was no observed significant difference ($p \leq 0.05$) with the duration of storage. Significant differences ($p \leq 0.05$) with sources of manure were observed in the concentration of Mn. The highest value of 69.70 mg kg^{-1} was observed in FYM while cow dung had the lowest content of 43.60 mg kg^{-1}. There were no observed significant differences in processing and duration of storage. The concentration of Pb and Zn showed no significant differences ($p \leq 0.05$) with materials, processing and duration of storage.

The results of the interaction between material and processing on the concentration of Cu revealed that poultry manure had the highest content of Cu when shade-dried (20.85 mg kg^{-1}) and composted (20.67 mg kg^{-1}) or sundried (25.74 mg kg^{-1}) (Fig. 7). Similar trends were observed with poultry in the results of interaction between material and duration (Fig. 8). The results of the interaction presented in Fig. 9 showed that sun-dried manures resulted in the highest Cu content of 18.75 mg kg^{-1} in the first month, while shade-dried manure had the highest content of 18.39 mg Cu kg^{-1} by the second month. The results from the third month showed that composted manure gave the highest Cu concentration of 16.29 mg kg^{-1}. The interactions between material, processing and duration showed that sun-dried poultry manure had the highest content of 30.22 mg kg^{-1} in the first month. The lowest results of 4.30 mg kg^{-1} were obtained from sun-dried cow dung in the first month (Fig. 10). The highest Mn content was observed at 3 months in FYM (Fig. 11).

Generally, all the micronutrients are within the limits of the World Health Organization (Table 5).

Table 4: The effect of the Source of material, storage type and time on heavy metals

Treatment	Cu (mg kg^{-1})	Fe (mg kg^{-1})	Mn (mg kg^{-1})	Pb (mg kg^{-1})	Zn (mg kg^{-1})
Material					
Poultry	22.42[a]	0.15	57.20[ab]	73.20	45.00
Sheep and goat manure	14.56[b]	0.18	49.30[b]	105.10	71.00
Cow dung	11.14[c]	0.20	43.60[b]	70.60	148.00
Farmyard manure	14.92[b]	0.18	69.70[a]	67.00	68.00
SED	01.19	0.02	07.11	19.96	25.30
Processing					
Composted	14.34	0.18[ab]	51.60	94.60	85.00
Sun-dried	16.48	0.20[a]	51.10	77.80	74.00
Shade dried	16.47	0.15[b]	62.20	64.50	90.00
SED	01.03	0.019	06.160	17.28	21.90
Duration					
1 month	15.45	0.17	55.60	67.20	64.00
2 months	16.46	0.19	60.00	90.20	75.00
3 months	15.37	0.18	49.20	79.50	110.00
SED	01.03	0.018	06.160	17.28	21.90
Interaction					
M×P	**	NS	NS	NS	NS
M×D	*	NS	*	NS	NS
P×D	*	NS	NS	NS	NS
D×M×P	**	NS	NS	NS	NS

Means followed by the same letter are not statistically different at a 5% level of probability, *,**Significant at 5 and 1% level of probability, respectively, M: Source of materials, P: Processing D: Duration of storage and NS: Not significant

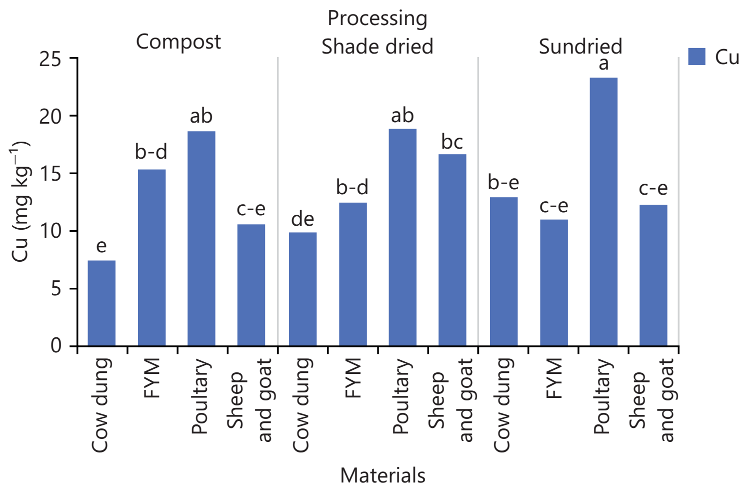

Fig. 7: Interactions effects of processing and materials on copper content
Small alphabets represents means comparison

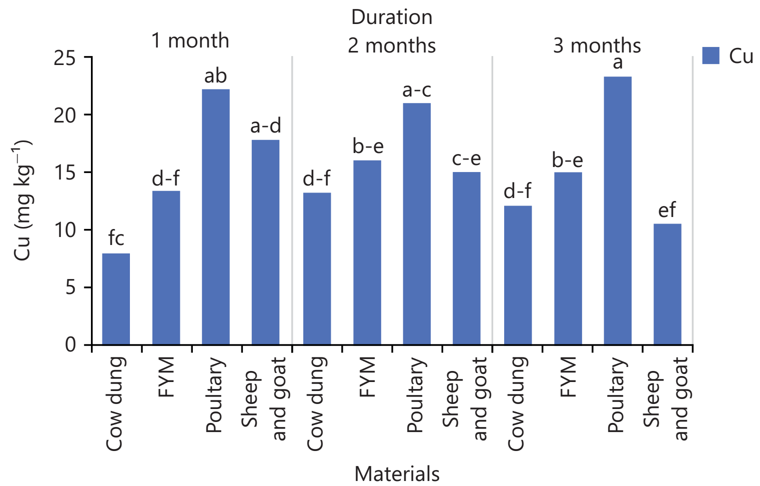

Fig. 8: Interactions effects of duration of storage and materials on copper content
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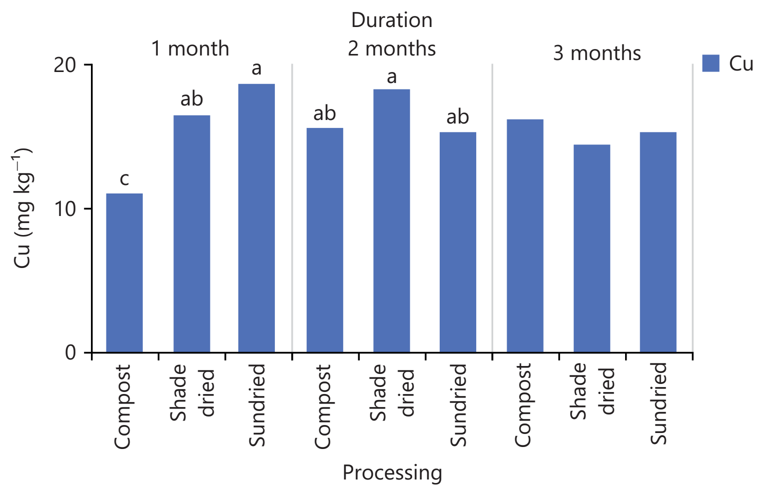

Fig. 9: Interactions effects of processing and duration of storage on copper content
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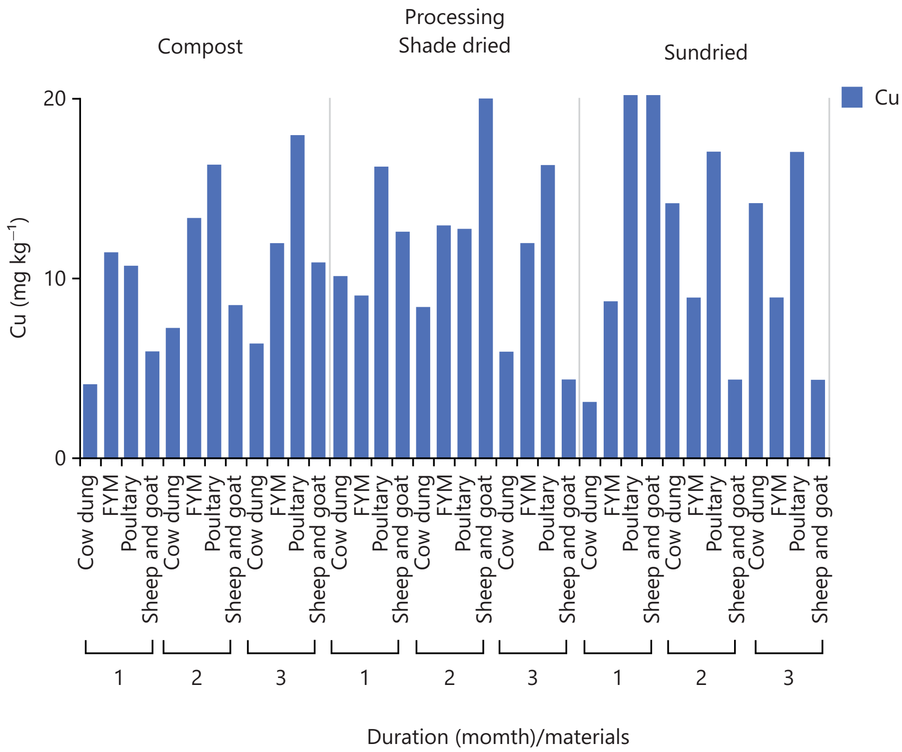

Fig. 10: Interactions effects of processing, duration of storage and materials on copper content

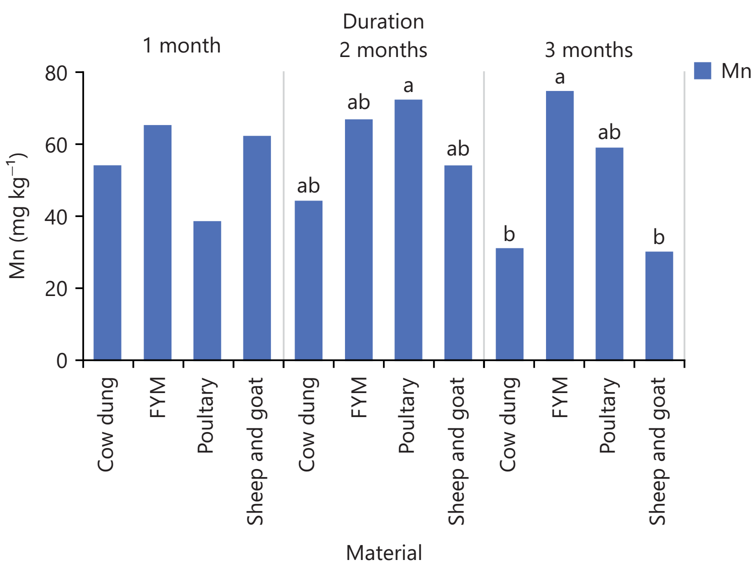

Fig. 11: Interactions effects of duration of storage and materials on manganese content
Small alphabets represents means comparison

Table 5: WHO limits for micronutrients in manure

Parameter	WHO limits
Cu	90.26
Pb	200-400
Mn	300-1300
Zn	800-1200

WHO: World Health Organisation and table culled from Yari *et al.*[13]

DISCUSSION

The nutrient content of any manure at time of use as well as its ability to provide the necessary nutrients for plant growth depends on its initial content as well as the methods of processing and storage. However, for most manure, the specie of an animal, type and quality of feed have a great influence on the nutrient content of the produced manure. This is pronounced from the observed results in the nutrient composition of the different animals. Processing and the storage method used were also seen to have had an influence on the nutrient composition. Wide variations in the nutrient content of the different types of manure were observed which could be due to the differences in origin, microbial population, rate/level of decomposition as well as the extent of exposure to natural elements such as rainfall and temperature[14,15]. The chemical composition of the samples may have influenced the concentration of nutrients observed[15]. Generally, the high pH observed with some of the materials could be used as a measure of its higher micronutrient availability as suggested by Almeida *et al.*[14]. The low content of nitrogen observed in poultry manure was attributed to its ammonification by bacteria during its production[16].

Significant variations were obtained in the amount of WSP in the different animal manure probably as a result of differences in animals, age, beddings, diets as well as the method of handling the manures[17]. The determination of WSP is of key importance in manure management and use as it can be used as a key indicator of the fraction that can be utilized by microbes, available for plant use, rate of transformation as well as, a potential contributor to run-off or groundwater contamination[6]. The high amount of water-soluble P observed in sheep and goat manures might be related to the high level of P in the feed[18]. The low content observed in poultry of low P content in feeds, while the contents in cow dung might be a result of the ability to digest plant phytate[18].

The lower contents of WSP observed with sundried manures may be attributed to thermal energy which increased the rate of P reactions with a consequent decrease in its solubility. The high temperature might also lead to the transfer of P to strongly bound forms and thus, decrease its solubility[19]. The reduction in WSP with sun drying of manures may also be due to P immobilization due to increased microbial uptake[17]. Though WSP content was statically similar with time, the lower contents observed in the 3 months of storage were attributed to its increased affinity in exchange sites as well as transformations to more stable forms that could decrease pollution potential[19].

The high amount of Ca observed in the poultry manure was expected and may probably be due to the use of Ca additives in the feeds of birds as well as the alkaline condition of the material[18]. The high Ca content in all the manures is also an indication of their effective use as a nutrient source[20]. The high amount of Ca in composted manures may be a result of its increased mineralization and a possible decreased breakdown of Mg fractions[21]. The low contents of Mg and Ca with were attributed to the decline in the dry mass of manures[22].

Contents of micronutrients are a reflection of feed and efficient feed conversion[23]. The high micronutrient contents observed in all the different types of manures are related to their uses as additions to animal feeds for enhanced feeding, prevention of diseases as well as uses in footbath[23,24]. The high content in manures may also be due to the expulsion of almost 95% of contents by the gut of animals[24]. Low availability of manures is expected with time due to the formation of more stable metal complexes, however, the results observed with zinc, Fe and Pb showed opposite trends as concentration was higher with time and could be an indication of change from more stable forms to extractable forms[25]. Though the nutrient composition of the manure, time of application, as well as its potentials to supply plant nutrients, depend on proper manure management. The results obtained in this study showed that the concentration of water-soluble P decreases with storage (3 months) as well as under sun-drying thus indicating a possible reduction in the amount of P that could be lost from farm lands through surface run-off or leaching. Generally, the duration of storage was observed to increase the overall quality of the manures. Further research on increasing the storage time as trainings on manure management for farmers in Nigeria could be of great importance to sustain production as well as preserve or maintain the quality of the environment.

CONCLUSION

Processing and storage of manure play a significant role in the efficiency of nutrient retention for smallholder farming systems and could be a way of nutrient loss or recycling. The results from this research indicate sun drying or composting for 3 months could serve as a method to reduce the loss of WSP. The contents of Ca and Mg were also improved by composting and sun-drying though concentration was better in the second month of storage. However, it should be noted that in real-time scenarios, farmers add fresh manures throughout and thus similar results as observed with the first month of storage could be gotten. Manure management programmes should be advocated for to increase overall soil health.

SIGNIFICANCE STATEMENT

This study determined the effect of processing and handling on the quality of manures. This research addresses the problems of manure management by smallholder farmers and assesses the effect of the management on the concentration and availability of some nutrients over a 3 month period. Composting and sun-drying were observed to increase the concentration of Mg and Ca and reduce the loss of water-soluble P.

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