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# Soil chemical properties and maize yield after application of organic and inorganic amendments to an acidic soil in southwestern Nigeria

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## Abstract

A factorial experiment with a randomised complete block design (three replicates) was performed to determine the effects of poultry manure (PM), lime (L) and NPK 15-15-15 fertilizer on soil chemical properties, and to determine the effects of their combinations on soil productivity and maize yield. The factors were PM (0, 5 and 10 Mg ha$^{-1}$), L as $CaCO_3$ (0 and 250 kg ha$^{-1}$) and NPK 15-15-15 (0 and 100 kg ha$^{-1}$). The soil had a loamy sand texture. The application of L and PM increased the surface soil pH in a similar fashion. In both years of the experiment, the effective cation exchange capacity (ECEC) of the soil after the combined application of 10 Mg ha$^{-1}$ PM, L and NPK was significantly higher than after the individual application of L or NPK or their combination (5.75-7.65 cmol kg$^{-1}$ compared to 3.36-4.57 cmol kg$^{-1}$). The application of 10 Mg ha$^{-1}$ PM with L and/or NPK reduced the possibility of Mn toxicity, with soil levels ranging from 108 to 136 mg kg$^{-1}$. The combined use of the three amendments gave the highest leaf nutrient concentrations. The highest maize grain yield (4.62 Mg ha$^{-1}$) was obtained with L + 10 Mg ha$^{-1}$ PM; with no amendment the grain yield was 1.9 Mg ha$^{-1}$. The application of PM enhanced the effects of L and NPK in improving soil productivity. However, separate applications of 5 and 10 Mg ha$^{-1}$ PM similarly affected soil productivity; the sandy nature of the soil at depths of 0-20 cm seems to have prevented differences between the two rates from becoming manifested.

**Additional key words**: corn, integrated nutrient management, leaf nutrient concentration, manganese toxicity, poultry manure, soil productivity.

## Resumen

### Propiedades químicas del suelo y producción de maíz tras la aplicación de enmiendas orgánicas e inorgánicas a un suelo ácido en el suroeste de Nigeria

Para determinar los efectos del abono de residuos de aves (PM), de cal (L) y de fertilizante NPK 15-15-15 sobre las propiedades químicas del suelo, y determinar los efectos de sus combinaciones sobre la productividad del suelo y producción del maíz, se llevó a cabo un experimento factorial con un diseño en bloques al azar (tres réplicas). Los factores fueron PM (0, 5 y 10 Mg ha$^{-1}$), L como $CaCO_3$ (0 y 250 kg ha$^{-1}$) y NPK 15-15-15 (0 y 100 kg ha$^{-1}$). El suelo tenía una textura franco arenosa. La aplicación de L y PM aumentó el pH de la superficie del suelo de forma parecida. En los dos años del experimento, la capacidad de cambio de cationes efectiva (ECEC) del suelo tras la aplicación combinada de 10 Mg ha$^{-1}$ PM, L y NPK fue significativamente superior que la de la aplicación individual de L ó NPK o una combinación de ambos (5,75-7,65 cmol kg$^{-1}$ *vs*. 3,36-4,57 cmol kg$^{-1}$). La aplicación de 10 Mg ha$^{-1}$ PM con L y/o NPK redujo la posibilidad de toxicidad con Mn, con niveles de suelo de 108-136 mg kg$^{-1}$. El uso combinado de las tres enmiendas produjo las concentraciones de nutrientes en hoja más altas. La producción de grano más alta en maíz (4,62 Mg ha$^{-1}$) se obtuvo con L + 10 Mg ha$^{-1}$ PM; sin enmiendas se obtuvo 1,9 Mg ha$^{-1}$. La aplicación de PM aumentó los efectos de L y NPK en la mejora de la productividad del suelo. Sin embargo, aplicaciones separadas de 5 y 10 Mg ha$^{-1}$ de PM afectaron de forma similar a la productividad del suelo; la naturaleza arenosa del suelo a profundidades de 0-20 cm parece disminuir las diferencias entre las dos dosis.

**Palabras clave adicionales**: concentración de nutrientes en hoja, estiércol de ave, maíz, manejo integrado de nutrientes, productividad del suelo, toxicidad del manganeso.

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Abbreviations used: AAS (atomic absorption spectrophotometer), ECEC (effective cation exchange capacity), FAO (Food and Agriculture Organization), LSD (least significant difference), NS (non significant), OC (organic carbon), PM (poultry manure), PM5 (5 Mg ha$^{-1}$ PM), PM10 (10 Mg ha$^{-1}$ PM), SOC (soil organic carbon), USDA (United States Department of Agriculture).

## Introduction

Soils in most sub-Saharan African countries are of low fertility and have poor structures (SWMR, 1998). In traditional African agriculture, farmers practice shifting cultivation to allow the productivity of nutrient-depleted soils to be restored. However, the demands for cropland, arising from increasing population pressures, have led to a reduction in and sometimes the complete disappearance of fallowing. According to Melero *et al*. (2007), one of the best ways of restoring soil productivity involves the addition of organic materials. The application of organic amendments such as animal manure, farmyard manure, compost manure and household wastes is therefore imperative if soil fertility is to be improved. The regular addition of amendments such as animal manure and crop residues also helps prevent soil erosion (Hornick and Parr, 1987).

A great deal of research indicates that better nutrient release from organic fertilizer is obtained, and crop requirements during the initial stage of growth and development are better met, if organic and inorganic fertilizers are used together rather than on their own (see, for example, Lombin *et al*., 1991; Prasad, 1996). It thus appears that the intensification of crop production on tropical soils requires the combined use of organic and inorganic fertilizers (Ghosh *et al*., 2004).

Soil acidity or acidification constrains the productivity of most tropical soils (Uexkull 1986; Manna *et al*., 2007), the consequence of Al and Mn toxicities and nutrient deficiencies (Oguntoyinbo *et al*., 1996). Soils with a pH of <5.5 usually have problems of Al toxicity or acidification, but they can be improved with lime, compost or organic manure (Sanchez, 1976; Scherr and Yadav, 1996; Sanchez *et al*., 2003). Although conventional liming materials include $CaCO_3$, quicklime, slaked lime and $MgCO_3$, animal manure has great potential for ameliorating soil acidity, especially for resource-poor farmers. It has been suggested by Mokolobate and Haynes (2002) that in semi-intensive farming systems, organic residues could be incorporated into the soil in plant rows at relatively high rates (e.g., 10–20 Mg $ha^{-1}$) prior to planting, and that this would have a substantial liming effect. Ano and Agwu (2005) also reported that animal manures have a high capacity for increasing soil pH. Research has shown that with liming and the proper use of organic amendments, marginal lands can be restored to high productivity (Hornick and Parr, 1987).

The aims of the present study were to determine the effects of poultry manure (PM), lime (L) and NPK 15-15-15 fertilizer on the chemical properties of the soil, and to determine the effects of their combined use on soil productivity and maize yield.

## Material and methods

### Field experiment

Field experiments were performed in 2004 and 2005 at Ajegunle Farm Settlement, Mile 6, Ajebo road, near Abeokuta (7° 26'N; 3° 48'E), southwestern Nigeria. The mean rainfall in Abeokuta in 2004 and 2005 was 1120 mm, similar to the long-term average. The mean monthly temperature varied from 22.94$^{o}$C in August to 36.32$^{o}$C in March. The soil of the study site, which is underlain by complex Pre-Cambrian basement rocks, has a loamy sand texture and is classified as an Arenic Paleudalf (USDA soil taxonomy criteria) or Chromic Lixisol (FAO soil taxonomy criteria).

The field trial consisted of a factorial experiment (3 x 2 x 2) with a randomised complete block design (three replications). Plot dimensions were 3 x 4 m. The factors were three levels of PM (0, 5, and 10 Mg $ha^{-1}$), two levels of L (0 and 250 kg $ha^{-1}$) and two levels of NPK 15-15-15 fertilizer (0 and 100 kg $ha^{-1}$). The PM used for the experiment was collected from a poultry farm (battery cage system) that had been abandoned for about one year. Lime and PM were applied 3 weeks before planting while the NPK fertilizer was incorporated into the soil two weeks after planting using the ring method. The residual effect of the applied treatments was evaluated in the second year of the experiment. Table 1 shows the chemical properties of the PM used. Two maize (*Zea mays* L.) TZSR-Y seeds were planted per hole at a spacing of 50 x 75 cm. The following treatment combinations were applied: (1) No amendment (control), (2) NPK only, (3) Lime only (L), (4) L + NPK (LNPK), (5) L + PM5 (LPM5), (6) L+ PM5 + NPK (LPM5NPK), (7) L + PM10 (LPM10), (8) L + PM10 + NPK (LPM10 NPK), (9) PM5, (10) PM5 + NPK (PM5NPK), (11) PM10 and (12) PM10 + NPK (PM10NPK).

### Soil analysis

Surface soil (0-20 cm) chemical properties were determined in 2004 before planting. At the end of each harvest in 2004 and 2005, composite soil samples were

**Table 1.** Chemical properties of the poultry manure (PM) used in this study, and quantities of nutrients supplied to the soil

| Parameters | Values | Nutrients supplied to the soil (kg ha$^{-1}$) | |
|---|---|---|---|
| | | 5 Mg ha$^{-1}$ PM | 10 Mg ha$^{-1}$ PM |
| pH | 5.8 | | |
| Organic carbon (g kg$^{-1}$) | 177 | 885 | 1770 |
| Total N (g kg$^{-1}$) | 19.3 | 96.5 | 193 |
| C:N ratio | 9:1 | | |
| P (g kg$^{-1}$) | 28.9 | 144.5 | 298 |
| K (g kg$^{-1}$) | 14.7 | 73.5 | 147 |
| Ca (g kg$^{-1}$) | 21.1 | 105.5 | 221 |
| Mg (g kg$^{-1}$) | 3.5 | 17.5 | 35 |
| Zn (g kg$^{-1}$) | 1.1 | 5.5 | 11 |
| Mn (g kg$^{-1}$) | 0.64 | 3.2 | 6.4 |

collected, processed and used to determine the post-cropping soil chemical properties. Soil pH was determined in $H_2O$ and in 1 N KCl, using 1:1 $H_2O$ or KCl: soil. Organic C was determined by the complete oxidation method (Heanes, 1984). Total N was determined using an adapted auto-analyser method (Technicon, 1979). Exchangeable cations were extracted using 1 M ammonium acetate pH 7.0 and determined by atomic absorption spectrophotometry (AAS). Available phosphorus was determined using Bray-1 P extractant and determined colorimetrically using the molybdenum blue procedure (Bray and Kurtz, 1945). Micronutrients (zinc and manganese) were extracted using 0.1 N HCl before determination by AAS. Particle size analysis was performed using the hydrometer method (Bouyocous, 1951).

### Plant and poultry manure analyses

At tasseling, one ear leaf was randomly collected from five maize plants per plot in 2004. These leaves were oven-dried at 65$^{o}$C and ground in a centrifugal mill. The ground samples and the PM used in the experiment were digested in nitric-perchloric acid mixture and the digest analysed by AAS to determine the K, Ca, Mg, Zn and Mn concentrations. Total P was determined by the vanado-molybdate yellow method (IITA, 1978). Total N in the plant samples and PM was determined by an adapted auto-analyzer method (Technicon, 1979). Maize height, stover, cob and grain yields were measured at harvest.

### Data analysis

The data were analysed using the general linear model (GLM) (SAS, 1988). Means were separated using the least significant difference (LSD) test. Significance was set at $P = 0.05$.

## Results

### Poultry manure and initial soil chemical characteristics

Table 1 shows the chemical properties of the PM. Its phosphorus content was relatively high and the C:N ratio low. Soil pH and nutrient contents were low at the onset of the experiment (Table 2).

### Soil chemical properties after application of amendments

The application of L and PM caused a significant increase in soil pH (compared to the control). The separate use of L and PM also raised soil pH significantly, although no significant difference was observed between the use of L or PM alone (Tables 3 and 4).

Soil organic carbon (SOC) was not significantly affected by nutrient amendment at the end of cropping in 2004, except in the LPM10 treatment, in which it was significantly higher than with the L only treatment (Table 3). However, at the end of cropping in 2005, the

**Table 2.** Surface soil (0-20 cm) particle size distribution and chemical properties before the commencement of the experiment in 2004

| Soil properties | Value |
|---|---|
| Particle size distribution (g kg$^{-1}$) | |
| - Sand | 816 |
| - Silt | 100 |
| - Clay | 84 |
| Soil pH | |
| - In water | 5.3 |
| - In KCl | 5.1 |
| Organic carbon, OC (g kg$^{-1}$) | 6.1 |
| Total N (g kg$^{-1}$) | 0.6 |
| Available P (mg kg$^{-1}$) | 5.36 |
| Exchangeable cations (cmol kg$^{-1}$) | |
| - Ca | 2.14 |
| - Mg | 0.35 |
| - K | 0.37 |
| - Na | 0.39 |
| - Al + H[a] | 0.11 |
| Effective cation exchange capacity (ECEC) | 3.36 |
| Micronutrients (mg kg$^{-1}$) | |
| - Zn | 1.29 |
| - Mn | 42.37 |

[a] H: Hydrogen

combined use of 10 Mg ha$^{-1}$ PM, L and NPK (LPM10NPK) significantly increased the SOC compared to all other treatments (Tables 3 and 4). Though the soil total N was slightly raised in response to the individual amendments, the LPM10NPK treatment significantly increased soil total N compared to plots without manure and the control.

The application of PM led to significantly higher soil-available P concentrations than those obtained in all the inorganic treatments and the control plots (Tables 3 and 4). Significantly higher mean Ca and K values were obtained with the LPM10NPK treatment compared to the control in 2004 (Table 3), and compared to plots treated with inorganic amendments, and compared to the control in 2005 (Table 4). Plots treated with LPM5NPK had exchangeable K values of 0.42 cmol kg$^{-1}$, significantly higher than in the PM5 plot (Table 3). The ECEC values in both years ranged from 2.82-7.65 cmol kg$^{-1}$. The plot treated with LPM10NPK had significantly higher ECEC values than the L and the control plots in 2004 and 2005 (Tables 3 and 4). In 2005, the plots treated with PM10 only had significantly higher mean ECEC values than those treated with PM5. Exchangeable Mg was low and did not differ significantly among the treatments in 2004. Plots treated with the combination of PM and L showed significantly higher Mg concentrations than the controls in 2005.

## Soil micronutrients (Zn and Mn)

Soil micronutrients were determined only at the end of cropping in 2004. The combination of 10 Mg ha$^{-1}$ PM, L and NPK (*i.e.*, LPM10NPK), increased soil-extractable Zn significantly compared to the use of 5 Mg ha$^{-1}$ PM and other soil amendments (Table 5). However, the LPM5NPK treatment led to a significantly higher extractable Zn value than the L and control treatments. The lowest extractable Mn value (108 mg kg$^{-1}$) was obtained in the LPM10 plot; this was significantly lower than the values obtained in the treatments containing 5 Mg ha$^{-1}$ PM. Conversely, the application of 5 Mg ha$^{-1}$ PM raised extractable Mn levels significantly above those recorded for the control plot.

## Maize leaf nutrient concentration

Lime improved the maize leaf N concentration when provided in combination with PM and NPK (Table 6). Compared to the controls, significantly higher N concentrations were obtained when L treatment was thus combined. All plots containing 10 Mg ha$^{-1}$ PM gave leaf N concentrations of 2.30-3.23%, although these values were not significantly higher than those obtained for all 5 Mg ha$^{-1}$ PM plots. The combination of PM, L and NPK gave significantly higher leaf P and K concentrations than any of the other treatments or the control (Table 6).

Leaf Ca and Mg concentrations were generally higher in all PM10 plots, whether jointly used with L and/or NPK, than in all PM5 plots and the control. Significantly higher leaf Mn concentrations were obtained with NPK compared to L, LNPK, PM5 and LPM10.

## Maize performance

The application of L or NPK plus 10 Mg ha$^{-1}$ PM significantly improved plant height, stover and cob yields

**Table 3.** Individual and combined effects of organic and inorganic amendments on soil (0-20 cm) chemical properties in 2004

| Treatments | pH ($H_2$0) | pH (KCl) | SOC (g $kg^{-1}$) | N (g $kg^{-1}$) | P (mg $kg^{-1}$) | Exchangeable cations (cmol $kg^{-1}$) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Ca | Mg | K | Na | Al + H | ECEC |
| Control | 5.5 | 5.1 | 6.9 | 0.6 | 9.1 | 2.06 | 0.46 | 0.14 | 0.05 | 0.11 | 2.82 |
| NPK | 5.9 | 5.3 | 7.0 | 0.8 | 9.3 | 2.31 | 0.68 | 0.31 | 0.07 | 0.12 | 3.49 |
| L | 6.3 | 5.2 | 6.4 | 0.6 | 8.5 | 2.33 | 0.69 | 0.17 | 0.05 | 0.12 | 3.36 |
| LNPK | 6.2 | 5.4 | 6.6 | 0.9 | 11.7 | 2.35 | 0.92 | 0.31 | 0.87 | 0.12 | 4.57 |
| LPM5 | 6.3 | 5.7 | 8.9 | 0.9 | 12.2 | 2.94 | 0.94 | 0.42 | 0.14 | 0.12 | 4.56 |
| LPM5NPK | 6.9 | 6.2 | 9.0 | 1.1 | 11.1 | 3.02 | 0.77 | 0.42 | 0.12 | 0.14 | 4.47 |
| LPM10 | 6.4 | 5.8 | 9.6 | 1.0 | 15.1 | 3.14 | 0.92 | 0.38 | 0.09 | 0.13 | 4.66 |
| LPM10NPK | 6.5 | 5.9 | 6.5 | 1.2 | 15.2 | 3.87 | 1.00 | 0.61 | 0.14 | 0.13 | 5.75 |
| PM5 | 6.1 | 5.4 | 7.3 | 0.8 | 12.5 | 2.81 | 0.73 | 0.23 | 0.13 | 0.12 | 4.02 |
| PM5NPK | 6.1 | 5.6 | 7.0 | 0.9 | 11.8 | 2.79 | 0.87 | 0.40 | 0.10 | 0.12 | 4.28 |
| PM10 | 6.1 | 5.7 | 7.7 | 0.9 | 13.2 | 2.62 | 0.67 | 0.31 | 0.80 | 0.12 | 4.52 |
| PM10NPK | 6.3 | 5.7 | 7.2 | 1.1 | 17.65 | 2.63 | 0.66 | 0.44 | 0.14 | 0.12 | 3.99 |
| LSD ($P < 0.05$) | 0.66 | 0.7 | 2.9 | 0.2 | 6.2 | 1.70 | NS | 0.15 | 0.03 | 0.01 | 2.28 |

No amendment (control); NPK only (NPK); Lime only (L); Lime+NPK (LNPK), 5 Mg $ha^{-1}$ Poultry manure (PM5); PM5+NPK (PM5NPK); Lime+PM5 (LPM5); Lime+PM5+NPK (LPM5NPK); 10 Mg $ha^{-1}$ Poultry manure (PM10); PM10+NPK (PM10NPK); Lime+PM10 (LPM10); Lime+PM10+NPK (LPM10NPK)

compared to the control (Table 7). The LPM10 plot gave the highest grain yield of 4.62 Mg $ha^{-1}$, followed by a yield of 4.02 Mg $ha^{-1}$ observed with PM10NPK (similar to the yield obtained with LPM10NPK). A significantly lower grain yield was obtained with the LNPK treatment than with the NPK only treatment.

## Discussion

The total P, K and Ca contents of the PM used in this study were adequate (Landon, 1984), but the total N and micronutrient contents were very low (Hsieh and Hsieh, 1990). The low total N content (Table 1) may be attribu-

**Table 4.** Individual and combined effects of organic and inorganic amendments on soil (0-20 cm depth) chemical properties in 2005

| Treatments | pH ($H_2$0) | pH (KCl) | SOC (g $kg^{-1}$) | N (g $kg^{-1}$) | P (mg $kg^{-1}$) | Exchangeable cations (cmol $kg^{-1}$) | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | | | Ca | Mg | K | Na | Al + H | ECEC |
| Control | 5.9 | 4.7 | 7.4 | 0.6 | 6.9 | 2.07 | 0.86 | 0.19 | 0.03 | 0.12 | 3.62 |
| NPK | 6.3 | 4.7 | 8.4 | 0.6 | 9.2 | 2.41 | 0.92 | 0.25 | 0.04 | 0.12 | 3.40 |
| L | 6.3 | 5.0 | 9.6 | 0.8 | 5.8 | 2.67 | 1.01 | 0.26 | 0.04 | 0.12 | 4.09 |
| LNPK | 6.4 | 5.0 | 7.7 | 0.6 | 8.4 | 2.86 | 0.98 | 0.30 | 0.06 | 0.13 | 4.34 |
| LPM5 | 6.5 | 5.1 | 12.7 | 0.9 | 14.7 | 4.00 | 1.75 | 0.33 | 0.13 | 0.13 | 6.34 |
| LPM5NPK | 6.8 | 5.1 | 10.5 | 0.8 | 14.8 | 4.07 | 1.79 | 0.40 | 0.16 | 0.14 | 6.56 |
| LPM10 | 6.9 | 5.2 | 12.5 | 1.0 | 16.0 | 4.59 | 1.57 | 0.45 | 0.10 | 0.14 | 6.83 |
| LPM10NPK | 6.8 | 5.5 | 17.7 | 1.2 | 28.2 | 5.01 | 1.76 | 0.59 | 0.16 | 0.14 | 7.65 |
| PM5 | 6.3 | 5.1 | 8.8 | 0.7 | 14.2 | 3.02 | 1.25 | 0.39 | 0.13 | 0.12 | 4.91 |
| PM5NPK | 6.6 | 4.8 | 12.0 | 0.9 | 14.8 | 2.98 | 1.29 | 0.35 | 0.09 | 0.13 | 4.84 |
| PM10 | 6.4 | 5.1 | 12.0 | 0.8 | 17.8 | 4.24 | 1.69 | 0.42 | 0.10 | 0.13 | 6.58 |
| PM10NPK | 6.6 | 5.1 | 11.9 | 1.0 | 17.9 | 4.47 | 1.64 | 0.30 | 0.15 | 0.13 | 6.69 |
| LSD ($P < 0.05$) | 0.24 | 0.29 | 2.8 | 0.2 | 4.8 | 0.61 | 0.53 | 0.05 | 0.04 | 0.01 | 0.88 |

Treatments: see Table 3.

**Table 5.** Individual and combined effects of organic and inorganic amendments on soil (0-20 cm) Zn and Mn in 2004

| Treatments | Micronutrients (mg $kg^{-1}$) | |
|---|---|---|
| | Zn | Mn |
| Control | 2.5 | 122.9 |
| NPK | 3.3 | 151.5 |
| L | 3.0 | 113.1 |
| LNPK | 3.5 | 150.7 |
| LPM5 | 3.3 | 133.1 |
| LPM5NPK | 3.6 | 153.3 |
| LPM10 | 3.9 | 108.8 |
| LPM10NPK | 4.5 | 116.6 |
| PM5 | 3.2 | 159.9 |
| PM5NPK | 3.9 | 125.4 |
| PM10 | 3.8 | 136.3 |
| PM10NPK | 4.0 | 124.7 |
| LSD ($P < 0.05$) | 0.5 | 21.3 |

Treatments: see Table 3.

ted to its volatilisation during the long period during which the manure was left in the poultry house. The low C:N ratio indicated that the mineralisation of the manure exceeded its immobilization. The amount of Ca supplied to the soil by L ($CaCO_3$) applied at the rate of 250 kg $ha^{-1}$ was 100 kg $ha^{-1}$. The experimental site was chemically degraded, as shown by its acidity (pH = 5.1-5.3) and the poor nutrient status of the soil at the beginning of the experiment (Table 2).

The higher pH values observed after adding the organic manure indicates that PM has a tendency to neutralise soil acidity; in fact, the post-planting pH of the manure-treated plots did not differ significantly ($P < 0.05$) from that recorded for the L plots (Tables 3 and 4). This implies that PM is a good substitute for L in terms of its capacity to ameliorate soil acidity. The high Ca content of the PM used was probably responsible for this effect, although increases in the pH of soils amended with organic manure have also been related to the addition of basic cations (Cavallaro *et al*., 1993; Kingery *et al*., 1994; Ano and Agwu, 2005; Melero *et al*., 2007). Some authors such as Yaduvanshi (2003) have also reported a reduction in soil pH following the application of animal manure due to the production of $CO_2$ and organic acids during decomposition. Thus, the effect of PM on soil pH depends greatly on the latter's characteristics and condition. The production of organic acids was not important with the PM used in this study.

The significant increase in soil organic C by the end of the second cropping in 2005 showed that the organic manure might be effective if left for two years. Soil organic matter usually increases with time after substantial applications of organic amendments (Kingery *et al*., 1994; Nyakatawa *et al*., 2001; Melero *et al*., 2006).

Though soil total N was higher in the amended than in the un-amended plots, the contribution of the PM to soil total N content was quite weak. The small amount of N contributed by PM may be due to its exposure to the atmosphere (de Wit *et al.*, 1995) during the period it was left in the poultry house.

The significant increase in soil-available P in the manured plots was not unexpected as the manure used was very rich in total P. The increase in available P in the manured plots might also be owed to high microbial activity induced by the addition of organic residues, which might speed up phosphorus cycling (Parham *et al*., 2002).

The significantly higher ECEC values recorded in the PM10-treated plots may be attributed to the high Ca contents observed in the plots where 10 Mg $ha^{-1}$ PM was applied, a consequence of the release of Ca from the PM. The higher exchangeable Ca content obtained with the LPM10NPK treatment was due to the contribution of Ca by the L and PM. Exchangeable Mg was insignificantly affected by these treatments. Ano and Agwu (2005) reported that animal manure significantly increased exchangeable Ca but not exchangeable Mg.

Generally, the higher organic C, available P and ECEC values recorded in 2005 than in 2004 may be attributed to the fact that maize plant residue from the first planting season was spread evenly on each plot to decompose. This would have contributed to the overall effect of PM applied.

The Zn and Mg contents of the soil after amendment were low and high respectively (Table 5). The low Zn content is attributable to the increase in soil Ca content due to the liming effects associated with PM and $CaCO_3$ application. It has been reported that Zn disorders are common when soil becomes more calcareous (Landon, 1984), a consequence of the formation of very sparingly soluble complexes and carbonates (Lucas and Knezek, 1972). The fact that the application of animal manure can result in Mn toxicity has always been one of the arguments against its use. Though, the use of 5 Mg $ha^{-1}$ PM in this study caused this problem, the application of 10 Mg $ha^{-1}$ PM contributed less Mn to the soil, especially when used in combination with L. This might be due to the high buffering capacity associated with hig-

**Table 6.** Maize TZSR-Y leaf nutrient concentration as affected by individual and combined organic and inorganic soil amendments

| Treatments | Nutrients (%) | | | Nutrients (mg kg$^{-1}$) | | | |
|---|---|---|---|---|---|---|---|
| | **N** | **P** | **K** | **Ca** | **Mg** | **Zn** | **Mn** |
| Control | 1.71 | 0.31 | 1.39 | 0.33 | 0.12 | 66.17 | 34.33 |
| NPK | 2.38 | 0.83 | 1.74 | 0.39 | 0.13 | 79.60 | 45.00 |
| L | 2.17 | 0.34 | 1.49 | 0.34 | 0.14 | 42.40 | 34.50 |
| LNPK | 1.73 | 0.41 | 1.67 | 0.40 | 0.13 | 76.03 | 33.50 |
| LPM5 | 2.24 | 0.49 | 1.70 | 0.35 | 0.14 | 83.00 | 41.00 |
| LPM5NPK | 2.77 | 0.69 | 2.24 | 0.40 | 0.16 | 101.40 | 38.33 |
| LPM10 | 2.98 | 0.74 | 1.66 | 0.49 | 0.18 | 69.33 | 35.33 |
| LPM10NPK | 3.23 | 2.03 | 1.93 | 0.52 | 0.16 | 62.23 | 40.00 |
| PM5 | 1.88 | 0.37 | 1.70 | 0.40 | 0.13 | 68.73 | 36.17 |
| PM5NPK | 2.42 | 0.66 | 1.77 | 0.44 | 0.13 | 109.83 | 38.33 |
| PM10 | 2.30 | 0.77 | 1.77 | 0.44 | 0.19 | 67.53 | 37.67 |
| PM10NPK | 2.41 | 1.01 | 1.91 | 0.52 | 0.16 | 56.23 | 37.83 |
| LSD ($P < 0.05$) | 0.77 | 1.25 | 0.17 | 0.06 | 0.03 | 9.96 | 8.24 |

Treatments: see Table 3.

her rates of PM application. Landon (1984) indicated that soil Mn concentration decreases as soil pH increases from 5.0–8.0. Therefore, less Mn should be expected in the soil when higher rate of manure are applied, thus reducing the chances of Mn toxicity.

Compared to the PM5 treatment, the higher leaf N concentration recorded in the LPM10NPK treatment implies greater nutrient release to the soil occurs with greater quantities of manure (Table 6). Motavalli *et al.* (2003) also found a significant increase in N uptake at the highest rate (20 Mg ha$^{-1}$) of PM application. The significantly higher leaf P and K concentrations obtained from the combined use of L, PM10 and NPK means that inorganic P (and K) fertilizers are utilized more efficiently by crops when applied in combination with organic materials (Hue, 1990). Higher Ca and Mg concentrations in the leaves of plots treated with PM10 may be due to the high Ca and Mg content of the manure used.

**Table 7.** Maize TZSR-Y yield as affected by individual and combined organic and inorganic soil amendments in 2004

| Treatments | Plant height (m) | Stover yield (Mg ha$^{-1}$) | Cob yield (Mg ha$^{-1}$) | Grain yield (Mg ha$^{-1}$) |
|---|---|---|---|---|
| Control | 2.15 | 2.57 | 3.73 | 1.90 |
| NPK | 2.28 | 7.42 | 5.72 | 3.16 |
| L | 2.23 | 5.32 | 3.77 | 2.30 |
| LNPK | 2.32 | 4.86 | 3.71 | 1.61 |
| LPM5 | 2.33 | 5.55 | 4.61 | 3.15 |
| LPM5NPK | 2.31 | 7.34 | 5.04 | 2.96 |
| LPM10 | 2.39 | 7.59 | 7.23 | 4.62 |
| LPM10NPK | 2.38 | 7.37 | 6.71 | 4.00 |
| PM5 | 2.36 | 6.81 | 6.54 | 3.72 |
| PM5NPK | 2.21 | 6.37 | 5.05 | 2.84 |
| PM10 | 2.28 | 5.62 | 4.77 | 2.95 |
| PM10NPK | 2.45 | 9.12 | 7.28 | 4.02 |
| LSD ($P < 0.05$) | 0.20 | 4.96 | 1.81 | 1.38 |

Treatments: see Table 3.

This indicates that the more the manure used in combination with the inorganic amendment, the greater the amount of nutrients released into the soil; these will eventually be taken up by the crop. The significantly higher leaf Zn concentrations in plants from the manured plots compared to those from all un-manured plots implies that Zn is released from the manure into the soil and taken up by the plant. Compared to the LPM10 plots, the significantly higher Mn concentrations obtained in plots with NPK highlight that the liming properties of $CaCO_3$ and PM reduce Mn toxicity in maize crop.

The yield and yield component results show the complementary role of organic and inorganic amendments (Table 7). Adeniyan and Ojeniyi (2005) reported that treatments containing combinations of PM and reduced levels of NPK 15-15-15 were associated with higher yields than when NPK fertilizer was applied alone. However, the good performance associated with 10 Mg $ha^{-1}$ PM when combined with other soil amendments implies that nutrients are better released when larger quantities of manure are used. The lower grain yields obtained in the LNPK and LPM5 treatments compared to NPK or PM5 alone may be as a result of a kind of antagonism between the L and other soil amendments. This negative effect was, however, eliminated with the use of 10 Mg $ha^{-1}$ PM, a consequence of its greater buffering capacity. This shows that the combination of 10 Mg $ha^{-1}$ PM with other soil amendments has a greater capacity for raising maize yields than the use of 5 PM Mg $ha^{-1}$ or NPK alone (although the results for the applications of the two rates of manure were not significantly different).

In conclusion, the combined application of PM, L and NPK 15-15-15 fertilizer was the most efficient in raising the soil total N, available P and exchangeable cation concentrations. The use of the high rate of PM with L tended to reduce potential Mn toxicity problems. The combination of the organic and inorganic amendments used in this study increased maize yields beyond that achieved by these amendments on their own. Over-liming could result in maize yield depression, though the application of 10 Mg $ha^{-1}$ PM could check this since it affords the soil greater buffering capacity. The combined application of PM, L and a reduced level of NPK fertilizer is recommended to farmers for improving the yield of maize crops, especially where the soils are acidic. Since animal manure has the double role of checking soil acidity and raising soil nutrient levels, and because it is cheap, it should be considered a viable alternative to chemical fertilizers and liming materials by resource-poor farmers in developing nations.

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