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Full Length Research Paper

Chicken manure-enhanced soil fertility and productivity: Effects of application rates

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The utilization of chicken manure as an organic fertilizer is essential in improving soil productivity and crop production. We carried out the study to assess the effects of chicken manure on soil chemical properties and the response of application rate on the yield of spinach (S*pinacia oleracea*) as well as the uptake of nitrogen and phosphorus nutrients. To quantify these effects, we added chicken manure to samples of Calcisols, Arenosols and Luvisols at application rates: 5, 10, 20 and 40% chicken manure. The addition of chicken manure irrespective of application rate did not change the acidity or pH of Calcisol, suggesting its hypo-buffering capacity. While the results reveal increases of EC with increasing rate, at rate above 40%, the ECs were above the critical salinity level of 4 mS/cm indicating potential threat to soil productivity. The exchangeable bases increased with application rate, suggesting the positive effects of chicken manure in enhancing soil fertility. Similarly significant increase of nitrogen and phosphorus were observed following the addition of chicken manure. Initially the spinach yield increases up to optimum rate of 0.06, 0.07 and 0.16 g/plant for Luvisol, Arenosol and Calcisol, respectively and subsequently drops after critical threshold values; 15, 5 and 1% for Calcisol, Arenosol and Luvisol, respectively. Interestingly above the rate of 40%, the yield was almost zero for all soils, suggesting the ineffectiveness of chicken manure in enhancing soil productivity.

Key words: Chicken manure, soil chemical properties, soil types, spinach (S*pinacia oleracea*).

INTRODUCTION

The increasingly demand of chicken meat has prompted more poultry farming with consequent effects on increased utilization of organic wastes (e.g. chicken manure) as fertilizers. Organic wastes contain varying amounts of water, mineral nutrients, organic matter (Edwards and Daniel, 1992; Brady and Weil, 1996). While the use of organic wastes as manure has been in practice for centuries world-wide (Straub, 1977) and in the recent times (Omiti et al., 1999; Clay et al., 2002; Gambara et al., 2002; López-Masquera et al., 2008), there still exists a need to assess the potential impacts of chicken manure on soil chemical properties and crop yield and in particular evaluating the critical application levels. Moreover, the need and utilization of chicken manure has overtaken the use of other animal manure (e.g. pig manure, kraal manure) because of its high content of nitrogen, phosphorus and potassium (Warman, 1986; Schjegel, 1992). Escalating prices of inorganic fertilizers due to the increase in the fuel prices has also prompted the use of chicken manure (Place et al., 2003; Duncan, 2005). Similarly, organic wastes are also being advocated for by different environmental organizations world-wide to preserve the sustainability of agricultural systems. Recent studies have shown a host of nutrient management practices undertaken by smallholder African farmers (Place et al., 2002). While the relative adoption rates between organic and mineral nutrients vary by location, the incidence of organic practices is often more than the use of mineral fertilizers.

Furthermore, chicken manure is preferred amongst other animal wastes because of its high concentration of macro-nutrients (Warman, 1986; Duncan, 2005). For example, Chescheir et al. (1986) found increase in nitrogen levels from 40 - 60% and 17 - 38% with respect to control for Norfolk sandy soils and Cecil sandy loam soils, respectively following application of manure. In addition, application of chicken manure to soil enhances concentration of water soluble salts in soil. Plants absorb

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plant nutrients in the form of soluble salts, but excessive accumulation of soluble salts (or soil salinity) suppresses plant growth. Stephenson et al. (1990) reported the EC of chicken manure of about 11 dS/m in silt loam soils too high for salinity sensitive crops. The pH of dry chicken manure pellets was found to be 7.9, with most of the nutrients available in this environment (López-Masquera et al., 2008) while a decrease in the soil pH (< 6.5) affects the availability of nutrients to plants (Warman, 1986).

For example, loses of grassland soils 23 - 35% of their total available bases (Ca, Mg, K, and Na) in England through acidification by animal manure were observed (Horswill et al., 2007). Wong et al. (1983) found that the acidity due to chicken manure addition severely affects root growth and seed germination. Moreover, if applied correctly chicken manure acts as a good soil amendment and/or fertilizer (e.g. provides N, P and K) and can also increase the soil and leaf N, P, K Ca, and Mg concentrations (Duncan, 2005; Agbede et al., 2008). These soil chemical properties provide information on the chemical reactions, processes controlling availability of nutrients and ways of replenishing them in soils (Prasad and Power, 1997). Thus, the study aims to assess the effects of chicken manure on soil chemical properties including exchangeable bases (Na, K, Mg, Ca); soil pH, electrical conductivity (EC) and as well as soil nutrients (such as N,P, K) for three different types of soils. The response of application rate to the yield of spinach (S*pinacia oleracea*) was also evaluated in a greenhouse study. To quantify these effects, various application rates were used in the greenhouse potted soils experiments.

MATERIALS AND METHODS

Study site description

The greenhouse pot experiment soil samples were collected from the Glen valley farms lying between Latitudes (24º35'23.56"S and 24º37'01.14"S) and Longitudes (25º58'43.29"E and 25º58'16.74"E) near the city of Gaborone, Botswana. Vegetables including spinach, carrot, okra and rape are being grown by private farms who sell the produce to the city of Gaborone. Soils occur on a gentle slope of between 0.3 and 2%, gradually decreasing from the Southwest to the Northeast ranging between elevations of 978 - 960 m above mean sea level. The soils are predominantly sandy loam to sand occurring in an alluvial-cum-colluvial landscape, with patches of vertisolic clayey materials alternating with areas of more sandy and, even, gravelly deposits. The soils are classified as Luvic Calcisol and Ferralic Arenosol and Vertic Luvisol (FAO, 1988) with the following textural classes; sandy clay loam, loamy sand and clay, respectively. The study area is semi-arid, characterized by annual rainfall amounts between 400 and 500 mm and the annual average temperature of about 20.6℃. The mean annual relative humidity is about 56.3%, with monthly averages between 40% in September to 60% in April months of the rainfall season.

Chicken manure, soil sampling and sample preparations

The manure (of at least two months old) of the chicken layers was collected from one of the chicken production farms near the city of Gaborone, Botswana in December 2008. The manure was sun dried (0.03% moisture content) to allow it to heal, that is, kill any germs available and/or insects which could later hinder the growth of spinach crop. Soil samples were collected from each of the classified soil types from a fallow area, in order to avoid influence of other fertilizers on the outcome of this study. Samples were collected randomly at a depth of 0 - 30 cm which constitutes the rooting zone of the spinach crop. The soil was mixed with the chicken manure on a weight per weight (w/w) ratio according to the methods by Wong et al. (2001), at the rate of: 95:5 (that is, 95% soil, 5% manure); 90:10; 80:20 and 60:40. After homogenization, each sample was transferred into plant pots in 3 replicates for each application rate for the greenhouse pot experiment. The spinach crop was grown in the potted mixed samples and watered to field capacity until the end of growth period.

Soil analysis

Samples were analysed for soil pH, EC, exchangeable bases and nutrients using samples from the soil (control) and soil–manure mixtures. The pH was measured potentiometrically both in water and 1M Potassium chloride (KCl) suspension (van Reeuwijk, 1993). Using a HANNA 210 Microprocessor pH meter, three pH readings were taken in the supernatant of each sample suspension. The mean was recorded as sample pH. The electrical conductivity (EC) was determined from the saturation paste extract. A THERMO Orion model 162A conductivity cell was used to measure the EC of all samples. The exchangeable bases (K, Na, Mg, and Ca) were determined in the CH_3COONH_4 leachate obtained from the determination of CEC. After leaching for 12 h, each leachate was collected in separate 100-ml volumetric flasks and made up to the volume with CH_3COONH_4. K and Na were determined using the principle of flame emission with cesium suppressant solution. Whereas, the Mg and Ca were measured using Atomic Absorption Spectrometry (AAS) with lanthanum suppressant solution. A Varian spectra AA 220 model instrument was used in the determination of these bases.

The samples were also analysed for P and N nutrients. Phosphorus index in the samples were determined using the classic method of Olsen-P (Olsen et al., 1954) extraction as described in Van Reeuwijk (1993) and USDA (1995). The intensity of the blue colour developed (which is directly proportional to the amount of phosphorus) was measured with a SCHIMADZU UV 1601 UV- visible spectrophotometer at a wavelength of 882 nm. The value from each sample was used to calculate its P content in mg/kg. Available nitrogen in all soil samples was extracted with 2 M KCl by shaking for an hour on reciprocating shaker (Csuros, 1997). Each sample was filtered and a 10 ml aliquot of the filtrate transferred with a pipette into a distillation flask. About 0.2 g of heavy Magnesium oxide (MgO) ignited between 600 - 700℃ in a muffle furnace was added to each sample to make the extracts alkaline in order to enhance the determination of NH_4^+- N. Each mixture was distilled using a Gerhardt Vapodest 30 distilling unit into an Erlenmeyer flask containing 5 ml boric acid indicator solution until about 30 ml in each flask was collected. After distillation was stopped, NH_4^+- N was determined in the distillate by titrating with standardized 0.002 N Sulphuric acid (Okalebo et al., 1993). Into the same distillation flask 0.2 g of Devarda's Alloy was added to reduce NO_3^--N to NH_4^+, which was easily measured by steam distillation. Distillation was continued into another Erlenmeyer flask with 5 ml of fresh Boric acid indicator. This was again titrated with 0.002 N Sulphuric acid to determine the amount of NO_3^--N in the sample.

Determination of spinach yield and N and P content of leaves

Each plant pot in the greenhouse experiment was kept moist until

Table 1. Characteristics of chicken manure and basic soil properties of selected soil types.

Soil type	pH (H_2O)	EC (mS/cm)	Exchangeable bases (cmol/kg) Na	K	Mg	Ca	Nutrients (mg/kg soil) N	P
Luvic Calcisol	7.38	0.44	0.21	0.08	0.39	5.81	350	17.6
Ferralic Arenosol	6.59	0.06	0.25	0.11	0.06	1.47	771	44.5
Vertic Luvisol	5.80	0.19	0.17	0.04	0.14	2.44	665	52.8
Chicken manure	7.29	19.74	0.84	1.51	0.63	9.79	5,954	10,490

Table 2. Mean pH values of the different soil types and manure.

Sample	pH (H_2O)	pH (KCl)	ΔpH
Luvic Calcisol	7.38	6.81	-0.57
Ferralic Arenosol	6.59	6.02	-0.57
Vertic Luvisol	5.80	5.22	-0.58
Chicken manure	7.29	7.36	0.07

ΔpH = pH (KCl) - pH (H_2O).

the spinach (S. *oleracea*) seedlings were planted. Germination was activated in the seeds on a damp or moist tissue paper and placed in the oven for about 30 h at an optimum temperature of 21°C to ensure uniform germination. The seeds that showed early signs of germination were directly seeded into the plant pots. About 8 seeds were sown in each pot until emergence and growth. The seedlings were thinned when they were about 5 cm tall while the most viable seedlings left after thinning were evenly spaced. Samples were watered to field capacity three times a week until the end of the growth period (63 days). About three (3) relatively healthy shoots were allowed to grow to maturity in each pot and subsequently harvested to determine the spinach yield in terms of its dry biomass and the N and P content of leaves. The harvested leaves were oven dried at 80°C for 48 h to measure the dry biomass of the leaves and the N and P nutrient content of leaves determined using micro-kjeldahl digestion method.

Statistical analysis

The Kendall correlation coefficient was used to analyse and the relationship between the application rate of chicken manure and the yield components. The t-test analysis (α = 5%) was used to find the difference of the treatment means in relation to the control (Mead, 1996).

RESULTS AND DISCUSSION

Characterization of chicken manure and soil samples used

The mean values of the 3 replicates of the measured parameters were computed and presented in various forms of graphs and tables. The analytical data of soils and chicken manure before the experiment presented in Table 1 shows that, generally the soils are characterized by relatively low EC, N and P, with chicken manure having exceptional higher contents of exchangeable Ca, N and P and EC. Statistical analysis showed that there was significant difference ($p < 0.05$) between the soil type parameters.

There is significantly and relatively higher concentrations of Ca observed in all soil types and chicken manure compare to other exchangeable bases. Similar claims were reported for the chicken manure in other studies (Schlegel, 1992; Duruigbo et al., 2007). The higher concentration of exchangeable Ca in Luvic Calcisols is associated with the nature of the parent material which is predominately calcite minerals. The high EC in chicken manure is attributable to higher salt levels of N and P nutrients which are proportionally high (Table 1). Soil EC is the indication of the salinity status of the soil and is influenced by both natural and anthropogenic factors. The three different soils could be described as salt free because of low EC values.

Similarly, the results indicate that the pH of chicken manure together with Luvic Calcisol are slightly alkaline, whereas, the Ferralic Arenosol and Vertic Luvisols are slightly acidic to neutral and in general agreement with classified soils. The acidity of the soils was in decreasing order Vertic Luvisol > Ferralic Arenosol > Luvic Calcisol (Tables 1 and 2). To further evaluate the effects of cationic adsorption capacities of soils, we computed ΔpH index, that is, from the experimental measured pHs in water (pH- H_2O) and potassium chloride (pH-KCl) (Table 2). The index is given as: ΔpH= pH (KCl) - pH (H_2O) (Table 2).

The pH values for all soil samples were higher in the H_2O suspension than in KCl suspension as expected (Table 2). The values were in the same order as for pH: the Vertic Luvisol > Ferralic Arenosol > Luvic Calcisol

Table 3. Particle size distribution of soils.

Soil classification	%fractions of particles				Textural class
	Sand	CSi	FSi	Clay	
Luvic Calcisol	49.06	2.53	11.59	36.82	sandy clay loam
Ferralic Arenosol	63.02	2.66	29.01	5.31	loamy sand
Vertic Luvisol	43.82	2.71	10.84	42.63	Clay

Sand (0.05 - 2 mm); CSi-coarse silt (0.02 - 0.05 mm); FSi-Fine silt (0.02 - 0.002 mm); Clay (< 0.002 mm).

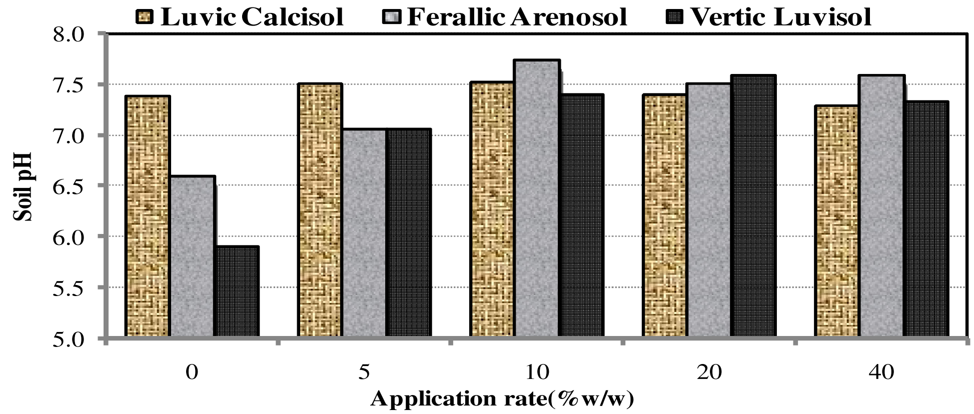

Figure 1. pH variation with application rates of samples for different soil types: Luvic Calcisol, Ferralic Arenosol and Vertic Luvisol (significant at $p < 0.05$).

(Tables 1 and 2). The negative values of ΔpH suggests that soils were all carrying a negative charge associated with the relatively appreciable amounts of clay (Table 3), with Vertic Luvisol carrying slightly more than the other two soil types. Based on the results, Vertic Luvisol is likely to have a higher capacity to sorp cations than the other soil types (Brady and Weil, 1996). This is because generally vertic soils have swelling–type clays and are associated with the larger adsorptive capacity as reflected by the higher clay content (42.63%) (Table 3). In contrast Luvic Calcisols has higher concentration of exchangeable bases probably due to the calcite minerals and of higher content of clays (Table 3). The results also indicate that the classified soil types generally have appreciable amounts of clay to significantly retain most of the exchangeable bases and the nutrients (Table 1). The textural ranges from sandy clay loam to clay with relatively less content of silt.

Effect of chicken manure on chemical properties and soil fertility

The effects of application rate on soil pH and EC

The addition of chicken manure, irrespective of the application rate did not change the pH or acidity of the Luvic Calcisol (Figure 1) suggesting its hypo-buffering capacity. However, substantial pH increase or response with increasing application rate of manure was observed in the case of Ferralic Arenosol and Vertic Luvisol, although a noticeable drop in pH was observed for the Vertic Luvisol at the rate of 40 w/w%. The highest pH recorded was 7.72 for Ferralic Arenosol at 10% application rate and the least being 7.01 for Vertic Luvisol at 5% (Figure 1). Generally, the pH for the soil- chicken manure mixtures were found to be neutral to slightly alkaline, which agreed with the results by López-Masquera et al. (2008) on the pH of dry chicken manure pellets. In contrast, Horswill et al. *(*2007) reported that the acidity of the chicken manure would decrease by 0.2 - 0.4 points if the manure is used for longer periods (8 - 10 years). Wong et al. (1983) found that the acidity due to chicken manure addition severely affected the root growth and seed germination of *Brassica parachinensis* (flowering Chinese cabbage), but in this case the pH is neutral therefore, any problem with the growth was not attributed to the acidity of the soil due to chicken manure addition.

When the Kendall correlation coefficient was applied ($r = 6$) it was that, there was a positive correlation between pH and addition of chicken manure, and that there is a statistical significance ($p < 0.05$) using the t-test analysis.

Generally, there was a significant increase in soil pH for statistical significance ($p < 0.05$) using the t-test analysis. Generally, there was a significant increase in soil pH for

Table 4. EC for various samples in different soil types.

Application rate (w/w %)	EC (mS/cm)		
	Luvic Calcisol	Ferralic Arenosol	Vertic Luvisol
0	0.44	0.06	0.19
5	0.11	2.15	1.13
10	0.12	4.35	3.09
20	1.46	5.42	5.11
40	4.60	8.72	13.40

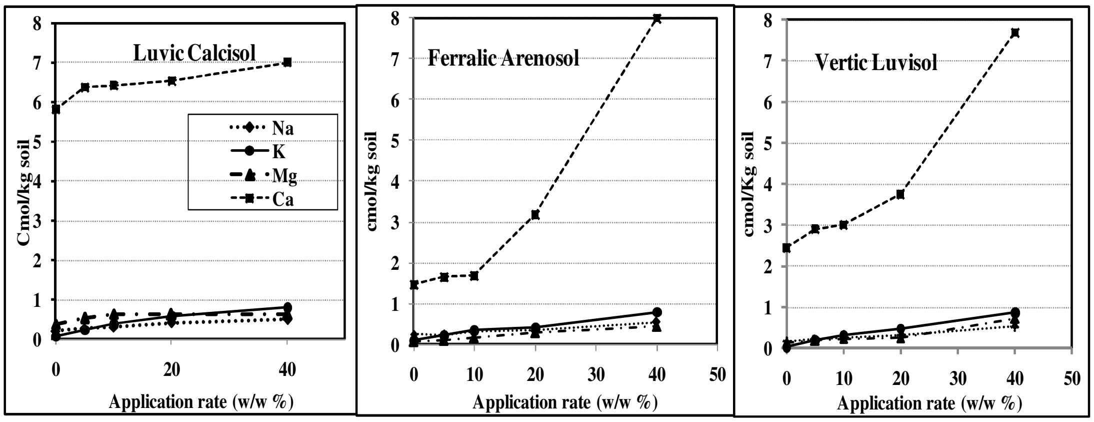

Figure 2. Exchangeable base cations with application of manure on selected soil types (signicant at p< 0.05).

all the soil types with increase in application rate of chicken manure. This increase in soil pH with increased chicken manure were also reported in other studies (Pitman and Singh, 1993). The mechanism responsible for this increase in soil pH was due to ion exchange reactions which occur when terminal OH^- of Al or Fe^{2+} hydroxyl oxides are replaced by organic anions which are decomposed products of the manure such as malate, citrate and tartrate (Eshoo and Bell, 1992; Pocknee and Summer, 1997; Hue and Amiens, 1989). The ability of chicken manure to increase soil pH was also attributable to the presence of basic cations in the chicken manure released upon microbial decarboxylation (Natsher and Schwetnmann, 1991).

In terms of salinity at 0 w/w%, Luvic Calcisol soil had the highest value of EC (0.439 mS/cm), followed by Vertic Luvisol and lastly Ferralic Arenosol in decreasing order (Table 4). It is evident that the EC increased with the application rate in all soil types (Table 4). The highest recorded was for Vertic Luvisol at 40% (13.42 mS/cm) and the lowest for Luvic Calcisol (4.60 mS/cm) at 40% rate. The build-up of the salts is attributable to increases of the chicken manure suggesting that the chicken manure negatively affects the salinity of the soil. However, in all cases (that is, at application rate of < 40% manure), the EC is lower than the critical value of 4 mS/cm and therefore suggesting no potential threat the productivity of the soils to crop growth.

Values obtained for soil-manure mixtures shows that the electrical conductivity increased significantly ($p < 0.05$) with the application rate (Table 4). The Kendall correlation coefficient ($r = 6$) also showed a positive correlation between the EC and application rate of chicken manure. Natsher and Schwetnmann (1991) attributed increase in EC to the salts in the chicken manure which are released during microbial decarboxylation and this is in agreement with studies (Davis et al., 2006).

The effects of application rate on cation capacity of soils

With the addition of chicken manure, the amount of exchangeable bases increased with the increasing application rate to for all the soil types. The trend of cations was similar for all the soil types and increases in the following order; Ca> K> Na> Mg (Figure 2). The amount of exchangeable bases were very low (< 1 cmol/kg soil) in all soil types except exchangeable Ca (7 - 8 cmol/kg soil) which was higher for all rates of the mixed samples. More dramatic increases in exchangeable Ca were observed in Ferallic Arenosol and Vertic Luvisol (almost 2 - 8 cmol/kg) while Luvic Calcisol shows a modest increase from 6 - 7 cmol/kg (Figure 2). Therefore the exchange capacity of the soils is attributed to the Ca from

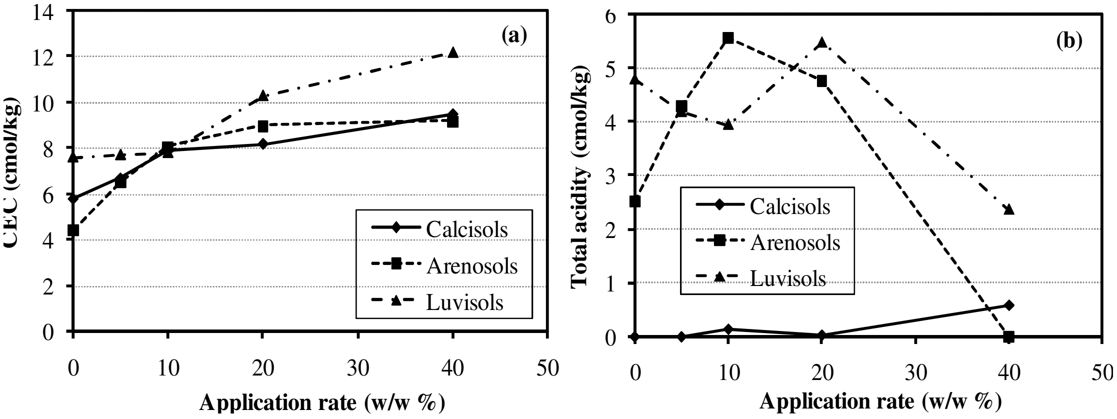

Figure 3. Effect of chicken manure application rate for different soils on (a) CEC and (b) Total acidity (significant at $p < 0.05$).

the addition of the chicken manure. This could also explain why the pH of the soils is relatively high.

Figure 3a shows increases in CEC and total acidity of soils with application rate due to the humus contained in the chicken manure. Generally, the CEC increases with application rate in all soil types. In contrast the total acidity initially increases and subsequently decreases with application rate with the exception of Calcisol and Luvisols probably due to their hypo-buffering capacities. These profound changes clearly indicate the importance of chicken manure in modifying the exchange capacities of soils and the total acidity of soils (Figures 3a and b). A wide variation of CEC with application rates was somehow consistent with variations in exchangeable bases (Figure 2). At application rate of 40%, the maximum CEC (12.2 cmol/kg) was recorded for Vertic Luvisols while Ferralic Arenosol and Luvic Calcisols was 9.4 cmol/kg suggesting large adsorptive capacity of Luvisols to adsorb cations than other soil types. Whilst there is significant increase of CEC with application rate, the results also shows an initial increase and subsequent decrease of the total acidity with application rate with the exception of Calcisol (Figure 3b). This has an implication on the availability of acidic ions (e.g. H^+, Fe, or Al^{3+}) and consequently the pH of the soil, toxicity and crop yield.

Kendall correlation coefficient(r = 6) showed a positive relationship between the CEC and the addition of chicken manure. Statistical analysis showed that the increase of CEC due to the addition of chicken manure was significant ($p < 0.05$) and consistent with other studies (Alabadan et al., 2009; Duruigbo et al., 2007; Davis et al., 2006; Eshoo and Bell, 1992; Pocknee and Summer, 1997; Hue and Amiens, 1989).

The effect of application rate on the available P and N nutrients

With no application of chicken manure, the P concentration of the different samples varied with soil type, Vertic Luvisol having the highest value (52.79 mg/kg) and Luvic Calcisol with the lowest (17.55 mg/kg) (Table 1). With addition of chicken manure, the results indicated increased available P with application rate for all soils types. This because concentration of P in soils is influenced by, besides the mineralogical composition of the parent material, anthropogenic sources like addition of fertilizers and organic manure to improve soil fertility (Brady and Weil 1996; Duncan 2005; Agbede et al., 2008). There were significant increases of available P with increasing application rate due to the addition of the chicken manure in all soil types. However, the amount of P was higher in Vertic Luvisol at about 8 g/kg soil followed by Luvic Calcisol (~8 g/kg) and lowest in Ferralic Arenosol (~4 g/kg) at the application rate (Figure 4).

Similarly, available N while increasing with the application rate appeared lower than available P and this suggest more P release than N in humified chicken manure. Despite this, available N was somewhat higher in Luvic Calcisol and Vertic Luvisols (~2.2 g/kg soil) and Ferralic Arenosol (~1.75 g/kg) at the maximum application rate of 40% (Figure 4). However, with no manure (0% rate), the amount of available N differed from the trend above with Ferralic Arenosol having the highest value (~0.77 g/kg) and Luvic Calcisol the lowest (~0.35 g/kg). In all cases the results shows substantial gains for the available N and P with the addition of chicken manure.

Statistical analysis showed that the increase of P and N concentration due to chicken manure addition was significant ($p < 0.05$). This is in agreement with other studies (Kingery et al., 1993; Adeniyan and Ojeniyi, 2005; Adenawoola and Adejoro, 2005; Davis et al., 2006), where P was significantly increased by chicken manure application. Agbede et al. (2008) observed that the amount of P almost doubled when the chicken manure was added, increasing from 8.4 - 12.5 mg/kg soil, 8.20 - 14.4 mg/kg soil and 9.6 - 16.4 mg/kg soil. The nitrogen content is higher than the P and this is because of the

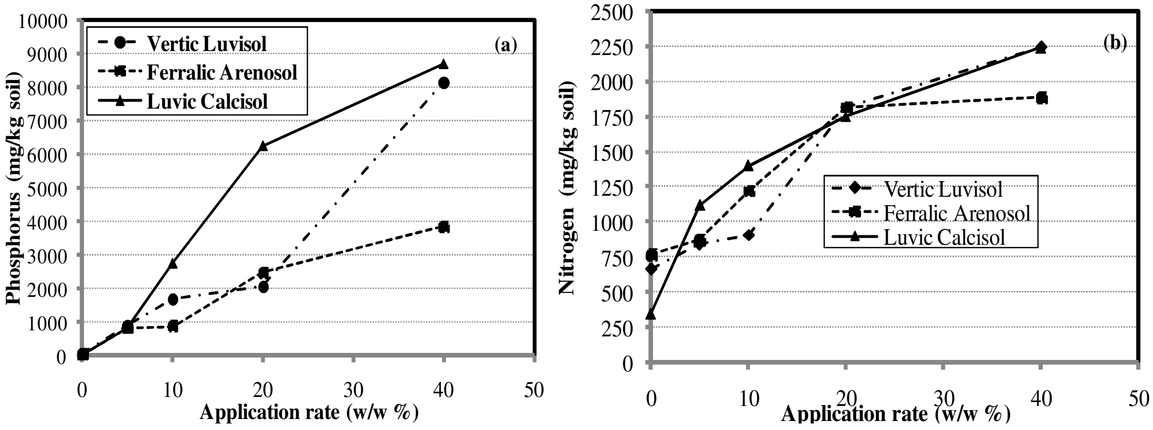

Figure 4. Available nutrient concentrations in selected soils types at different application rates: (a) Phosphorus and (b) Nitrogen (significant at p< 0.05).

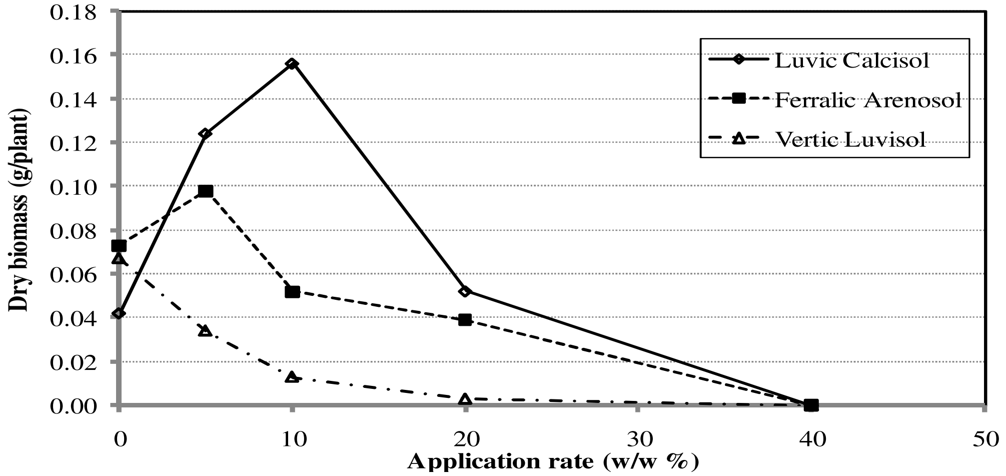

Figure 5. Effect of application rate of chicken manure on the dry biomass of spinach in selected soil types (significant at p < 0.05).

nitrogenous compounds, for example ammonia found in the chicken manure which is released during decomposition.

Effects of manure on the yield and uptake of N and P on spinach leaves

To assess the impact of manure on the spinach (S. *oleracea*) crop yield, we harvested the leaves at maturity and weighed them to determine the dry biomass (Figure 5). The results show the initial increases and subsequent decreases of the dry biomass of spinach (S. *oleracea*) with application rate. The area was significantly increased ($p < 0.05$) by addition of chicken manure except for Vertic Luvisols, where the yield was significantly decreased by chicken manure addition. The Kendall correlation coefficient ($r = 6$) was positive for Luvic Calcisols and Ferralic Arenosols while negative for Vertic Luvisols ($r = -5$). The increase in yield observed is consistent with the studies (Jamil et al., 2004; Davis et al., 2006; Ouda and Mahadeen, 2008). Because of these intricacies the critical threshold values for each soil type was established. The critical threshold value here is referred to as the application rate value point that produces the opti-mum yield with the following values observed; 1, 5 and 15% rate for Vertic Luvisol, Ferralic Arenosol and Luvic Calcisol, respectively. These threshold values correspond to the optimum spinach yield of 0.06, 0.07 and 0.16 g/plant for Vertic Luvisol, Ferralic Arenosol and Luvic Calcisol, respectively. However, interestingly at the chicken manure application rate of 40%, the spinach yield was almost zero for all the soil types (Figure 5) suggesting the negative impact of chicken manure on

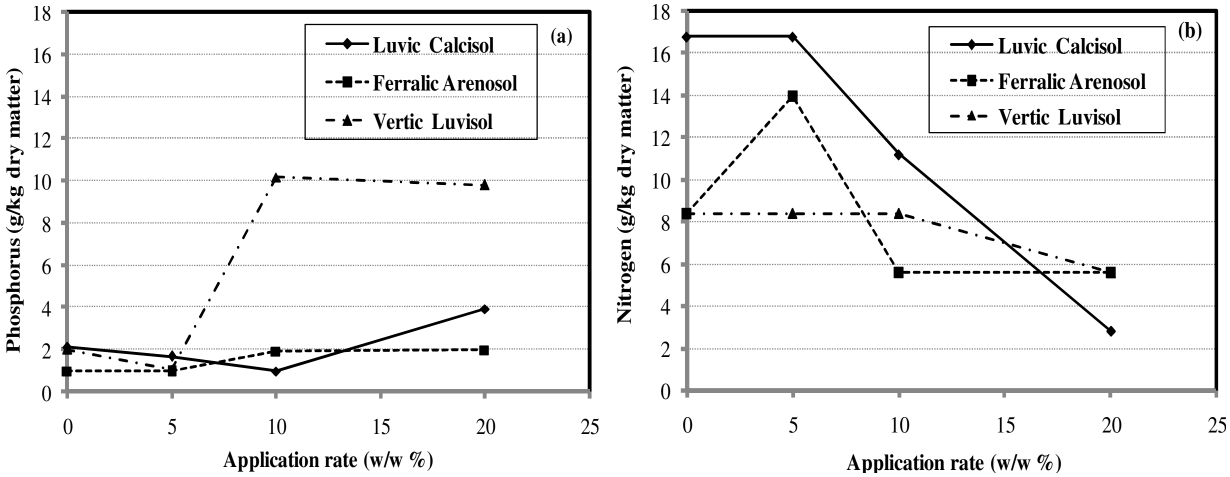

Figure 6. Effect of application rate on P and N content of spinach leaves for selected soil types; (a) Phosphorus and (b) Nitrogen (significant at $p < 0.05$).

spinach yield with increased application rate. Thus these critical threshold values might be of significance in modeling as they provide some insights into the dynamic changes of yield in response to application.

To quantify the effects of chicken manure on the uptake of N and P in leaves, we measured the P and N content of spinach (S. *oleracea*) leaves. Generally the results show substantial uptake of N than P in spinach leaves (Figure 6). Significant ($p < 0.05$) accumulation of P with increasing application rate was noticed in Vertic Luvisol (2 - 10 g/kg plant) while Luvic Calcisol and Ferralic Arenosol showed modest increase (2 - 3 and 1 - 2 g/kg/plant) respectively. Similarly, because of the intricate changes in N and P uptake on leaves with application, threshold values (particularly for the N accumulation on leaves) were established for each soil type. The threshold values were 5w/w% for Luvic Calcisol and Ferralic Arenosol with Vertic Luvisol having a threshold value at 10 w/w%. There was no significant accumulation of N and P for all soil types after the application rate of 20 w/w%.

SUMMARY AND CONCLUSION

The greenhouse experiment study was undertaken to assess the effect of chicken manure on soil chemical properties and yield of spinach. The study revealed that chicken manure is a potential source of plant nutrients and chemical conditioner. For instance, the EC together with exchangeable bases increased with application rate in all soil types, thus indicating positive effects on soils. Similarly, significant increases of N (up to 50%) and P (up to 80%) were observed following addition of chicken manure. While the pH at various application rates of the soil- chicken manure mixtures were found to be circum-neutral, significant increases of exchangeable Ca with manure were observed. The increased Ca contributed to the overall cation exchange capacity of all the soil types suggesting the improved nutrient retention and soil fertility with consequent effects on increased yield of spinach crop. Further, the study also provides insights to critical threshold values in response to the optimum yield of spinach and uptake of N and P on leaves (particularly at high application rate). The results indicate an increase of spinach yield (as measured in dry matter/plant) with poultry manure. For example, at rates exceeding 10 w/w%, the yield spinach decreased from 0.16 g/kg/plant to almost 0.0 g/kg/plant. The threshold values observed for different soil types for Luvic Calcisol, Ferralic Arenosol and Vertic Luvisol were 15, 5, 1 w/w%, respectively. Interestingly, at the application rate of 40 w/w%, the spinach yield was almost zero for all the soil types.

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