PAT June, 2019; 15 (1): 53-62 ISSN: 0794-5213
Online copy available at www.patnsukjournal.net/currentissue
Publication of Nasarawa State University, Keffi

Effect of Poultry Manure and Cowpea Clipping on Popcorn and Soil quality in a popcorn / cowpea intercrop at Samaru in the Northern Guinea Savanna of Nigeria.

[1]G.L. Luka and [2]J. Aliyu
[1]Department of Agronomy, Faculty of Agriculture, Institute for Agricultural Research, Ahmadu Bello University, Samaru, Zaria. glluka@abu.edu.ng
[2]Department of Soil Science, Faculty of Agriculture, Institute for Agricultural Research, Ahmadu Bello University, Samaru, Zaria

Abstract
Field trials were conducted at the Institute for Agricultural Research (IAR) farm at Samaru during 2013 and 2014 rainy seasons to determine the effect of the poultry manure and cowpea clipping on popcorn and soil quality. Treatments were poultry manure application rates (0, 2, 4 and 6 t ha^{-1}), cowpea varieties (SAMPEA 6 and Kanannado), time of cowpea introduction (sowing at the same time with popcorn and 4 weeks after) and clipping practices (clipped and not clipped) factorially combined and laid out in a split plot design replicated three times. Poultry manure was incorporated in the center of the ridge. Cowpea was clipped 6 inches from the soil surface at 6WAS (flower initiation) using secateurs. Soil sample was analysed and data were collected on plant height, leaf area index, shoot dry weight, crop growth rate and grain yield. Datawere subjected to analysis of variance using the general linear model procedure of the statistical analysis system package. Treatment means were separated using Duncan Multiple Range Test. Based on the result of this study, of 2 t ha^{-1} of poultry manure can be used to cultivate popcorn where the cowpea in the intercrop is clipped and incorporated into the soil as green manure.
***Key words**: Manure, Cowpea clipping, Fertility, Organic matter, Soil degradation*

Introduction

Nigeria is the largest maize (corn) producing country in Africa, producing about 8million tons per annum (Rachael, 2018). There are about 50 species of maize differing in grain color, texture, shapes and sizes. Popcorn (*Zea mays var. everta*) is one of the types and it is the most primitive of the surviving race of corn used basically as a snack (Deepa *et al*., 2016).
Poor management of agricultural soils has resulted in soil degradation (decrease in soil condition) some of which is expressed as decline in fertility, erosion, salinization, loss of soil biodiversity, deterioration of the soils structural condition etc. (Johannes, 2013). In the bid to increase yields, the use of mineral fertilizers is employed but the effect that mineral fertilizers have on crop yields remains low because degraded soils have minimal amounts of organic matter. Low amounts of organic matter results in these soils having a low capacity to bind dissolved nutrients into the soil and make them available to plants (Johannes, 2013). The use of manure raises the humus content in the soil and improves the soil's nutrient storage capacity and nutrient availability to plants. The trial was carried out to determine the effect of poultry manure and cowpea clipping on the growth and yield of popcorn and on the soil quality of the experimental site.

Materials and Methods

The trials were carried out at the Institute for Agricultural Research (IAR) farm at Samaru (11°11'N, 07°38'E and 686m above sea level) during the 2013 and 2014 rainy seasons.The same fields / plots were used in the second year of the study. Random samples of soil were taken at depth 0-30cm from the experimental sites and analyzed for physical and chemical properties before trial commenced and after harvest (Table 1).Treatments were: poultry manure rates (0, 2, 4 and 6 t ha^{-1}), cowpea varieties (SAMPEA 6 and Kanannado), time of cowpea introduction (early i.e. sowing at the same time with popcorn and late i.e. at 4 weeks after sowing popcorn) and clipping practices (clipped and not clipped). These were factorially combined and laid out in a split plot design replicated three times.

Poultry manure was incorporated by opening the centre of the ridge and burying the manure. It was allowed for 2 weeks to further decompose before seeds were sown. Cowpea was clipped by cutting of the shoot at 6 inches from the soil surface before leaf senescence (Odion and Singh 2005). Clipping was done at 6 weeks after sowing (WAS) (flower initiation stage) by using secateurs according to the treatments.The clipped cowpea shoot was then incorporated as green manure by remoulding (earthening up) of the ridges.

Soil sample was analysed for particle size distribution using the hydrometer method (Gee and Or, 2002), soil pH was measured in water and (1:2.5 w/v) using glass electrode pH meter (Agbenin, 1995), organic carbon was determined by the dichromate wet oxidation method of Walkley and Black (Nelson and Sommer, 1986) total nitrogen was determined by the kjeldahl method (Bremner and Mulvaney, 1982), available phosphorus was determined using Bray 1 method (Bray and Kurtz, 1945), exchangeable bases were extracted using HCl as described by Agbenin (1995), Exchangeable potassium and sodium were read using a photometer while exchangeable calcium and magnesium concentration were determined using the atomic absorption spectrophotometer and cation exchange capacity was determined using ammonium acetate method (Thomas, 1982).

Data were collected on plant height, leaf area index, shoot dry weight, crop growth rate (CGR) and grain yield. These were subjected to analysis of variance as described by Snedecor and Cochran (1967), using the general linear model (GLM) procedure of the statistical analysis system (SAS) package (SAS, 1990) version 9.1. The treatment means were separated using Duncan Multiple Range Test (Duncan, 1955).

Results and Discussion

The physical and chemical properties of the soils at the experimental site in 2013 and 2014 cropping seasons are presented on table 1. The soil was clay loam and pH in H_2O was slightly acidic while pH in $CaCl_2$ was moderately acidic in both years. The pH was observed to decrease in the second year of the trial. This could be because the manures (poultry and green manures) applied have released organic acids which in turn reduced soil pH by releasing hydrogen ions. Patil *et al.* (2003) also reported decrease in soil pH with increase in farm yard manure rates which he attributed to organic acid production during its decomposition. The organic carbon and the total nitrogen (N) were low in the first year but increased in the second year. The increase could be attributed to the mineralization of the manures applied. A research by Baskar (2003) showed that direct incorporation of the organic matter into the soil and also the subsequent decomposition of these materials resulted in the higher organic carbon content of the soil. The exchangeable cations showed moderate amount of calcium (Ca) in the soil and the value was the same in both years. This corroborates the finding of Qian *et al.* (2005) who reported that extractable Ca in the soils remained unchanged or tended to decrease after repeated application of swine manure.The magnesium (Mg) content in the soil was medium although increased in the second year. Increase in Mg content could be attributed to the incorporation of the manures. Reports show that magnesium may be found in manure and are beneficial to the soil especially if deficiency exist (Josh and John, 2015). Potassium (K) content was high in 2013 and medium in 2014. Decrease in K content of the soil in the second year could be attributed to plant uptake. Higher uptake could be because of better root penetration leading to better absorption due to greater availability of and improved soil condition as result of the manures applied (Meena *et al*., 2010). The exchangeable sodium (Na) content was higher in 2013 but decreased in 2014. Decrease in soil sodium could be due to the magnesium and calcium contained in the manure applied which might have produced a liming effect when added to the soil (Josh and John, 2015). Medium cation exchange capacity (CEC) was recorded in both years although a decline was recorded in 2014.This could be due to the decrease in soil pH with the manure application. Similar finding was made by Julia *et al*. 1993 where manure application did not contribute significantly to the cation exchange capacity (CEC) of the soil.

Table 1: Physical and Chemical Properties of the soil of the experimental site during 2013 and 2014 rainy seasons at 0-30cm depth.

	2013 before harvest	2014 after harvest
Particle Size Distribution (g/kg)		
Sand	370	366
Silt	358	360
Clay	272	274
Textural class	Clay loam	Clay loam
Chemical properties		
pH in H_2O	6.30	6.06
pH in 0.01M $CaCl_2$	5.90	5.76
Organic carbon(g/kg)	0.50	1.25
Total N (g/kg)	0.063	0.15
Available P(mg kg^{-1})	3.50	6.85
Exchangeable bases (cmolkg^{-1})		
Ca	3.40	3.40
Mg	0.55	0.71
K	0.42	0.11
Na	0.57	0.18
CEC	5.34	4.32

Soil samples analyzed in the analytical laboratory, Agronomy Department Ahmadu Bello University Samaru Zaria

Analysis of the poultry manure (Table 2) showed that the total nitrogen (N) and available potassium (K) content of the poultry manure used in the trial during 2014 rainy season were higher than that in 2013. The available phosphorus (P) content was higher in 2013 than the one used in 2014. The addition of the poultry manure improved the soil as it helps in soil amendment (improves bulk density, aggregation, organic matter, water infiltration and retention), in addition to provision of nutrients to crops (Warren *et al*., 2006; Agbede *et al.,* 2013; 2014; Atakora *et al.,* 2014; Agbede *et al.,*2017).

The analysis of the clipped cowpea foliage (Table 3) showed high organic carbon (OC), calcium (Ca) and carbon nitrogen (C: N) ratio at 0 t ha^{-1} of poultry manure (control). High phosphorous (P), potassium (K), and magnesium (Mg) were recorded at 2 t ha^{-1} and nitrogen (N) at 4 t ha^{-1} of poultry manure. The Kanannado contained higher K and Ca at 0 t ha^{-1}, N and Mg at 2 t ha^{-1}, P at 4 t ha^{-1}, organic carbon and carbon nitrogen ratio at 6 t ha^{-1}. Nutrients in the incorporated foliage can only be available to the plants when decomposition takes place, and decomposition of organic matter is greatly influenced by C: N ratio. In this research, C: N of SAMPEA 6 decreased with increasing poultry manure rates indicating that the rate of decomposition of cowpea foliage was high thus supplying more nutrients into the soil taken up by plants. Reports show that decomposition and nitrogen release generally occur faster for organic materials with narrowed C: N (Lomander *et al.,* 1998). C: N ratio however was observed to increase with increased poultry manure for the Kanannado variety. This means that rate of decomposition is reduced because when C:N is large, the amount of nitrogen available for growth of the decomposition microorganisms will be limited and any mineralized nitrogen will tend to be depleted as it is used up by the organisms for their growth (Giller and Wilson, 1991).

Table 2: N, P and K contents of poultry manure used during the experiment in 2013 and 2014 rainy seasons.

Nutrients	2013	2014
Total N (%)	1.70	1.74
Available P (mgkg^{-1})	1.59	1.32
Available K (Meq/100g)	0.63	0.89

Poultry manure analyzed in the analytical laboratory, Department of Agronomy, Ahmadu Bello University, Zaria.

Table 3:Mean nutrient composition of the cowpea varieties incorporated as green manure at Samaru during the years of experiment

	Percentage (%)				Mg kg^{-1}		
Treatments	Nitrogen	Phosphorus	Potassium	Organic Carbon	Calcium	Magnesium	C: N (%)
SAMPEA 6							
0 t ha^{-1} Pm	1.40	0.370	1.53	44.89	2111.10	6734.50	32.06
2 t ha^{-1} Pm	2.10	0.455	2.50	33.58	1979.10	7808.44	15.99
4 t ha^{-1} Pm	4.73	0.436	1.96	42.46	2106.30	4789.55	8.98
6 t ha^{-1} Pm	3.71	0.394	1.42	37.11	1784.50	6347.42	10.00
Kanannado							
0 t ha^{-1} Pm	4.10	0.443	1.71	52.34	2165.40	3846.33	12.77
2 t ha^{-1} Pm	4.87	0.374	1.56	47.52	1987.30	4983.72	9.760
4 t ha^{-1} Pm	2.63	0.483	1.28	45.88	2066.62	13572.21	17.44
6 t ha^{-1} Pm	1.75	0.284	1.18	55.20	2022.60	1368.46	31.54

Poultry manure analyzed in the analytical laboratory, Department of Soil Science, Ahmadu Bello University, Zaria. Pm = Poultry manure

The height of popcorn (Figure 1) in 2013 increased with increase in poultry manure applied up to 6 t ha^{-1} at 8WAS whether the cowpea was clipped or unclipped. At 12WAS, when the cowpea in the mixture was clipped, the tallest popcorn plants were recorded at the control while when cowpea was unclipped, the tallest popcorn plants were recorded at 6 t ha^{-1} of poultry manure.In 2014 at 8 and 12WAS, plant height increased with application of poultry manure up to 4 t ha^{-1} where cowpea in the mixture was clipped beyond which decreases in height were recorded Similar trend was recorded at 8WAS where cowpea was unclipped but beyond 4 tha^{-1} of poultry manure the increase in height was not significant. At 12WAS, when the cowpea in the mixture was unclipped, 2 t ha^{-1} poultry manure applied resulted in the tallest popcorn plants beyond which decreases in height were recorded.

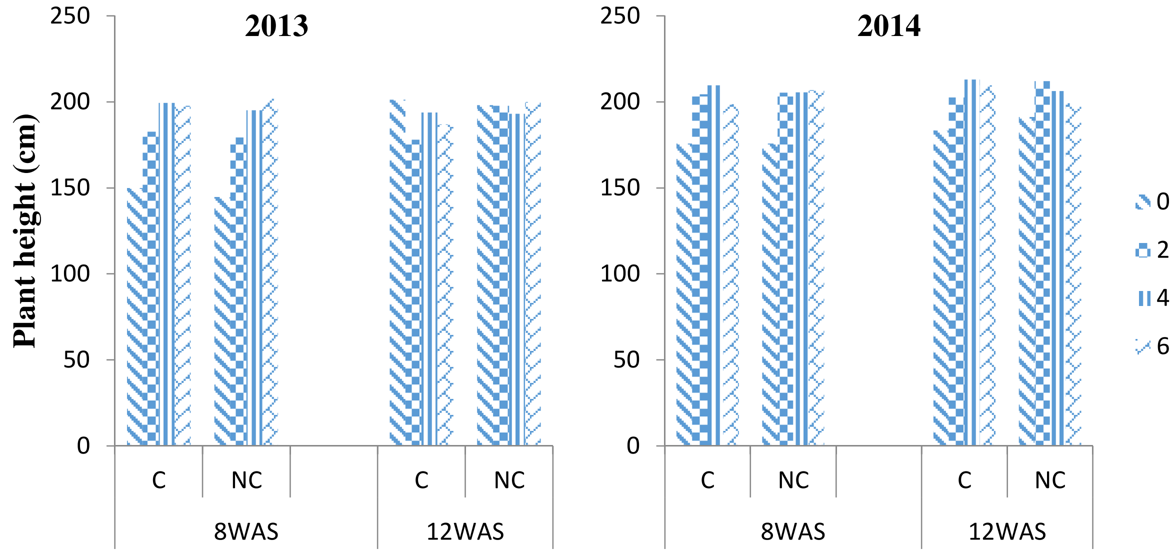

Figure 1: Height (cm) of popcorn at 8 and 12 weeks after sowing (WAS) during 2013 and 2014 rainy season as affected by poultry manure and cowpea clipping at Samaru. C= clipped, NC = Not clipped

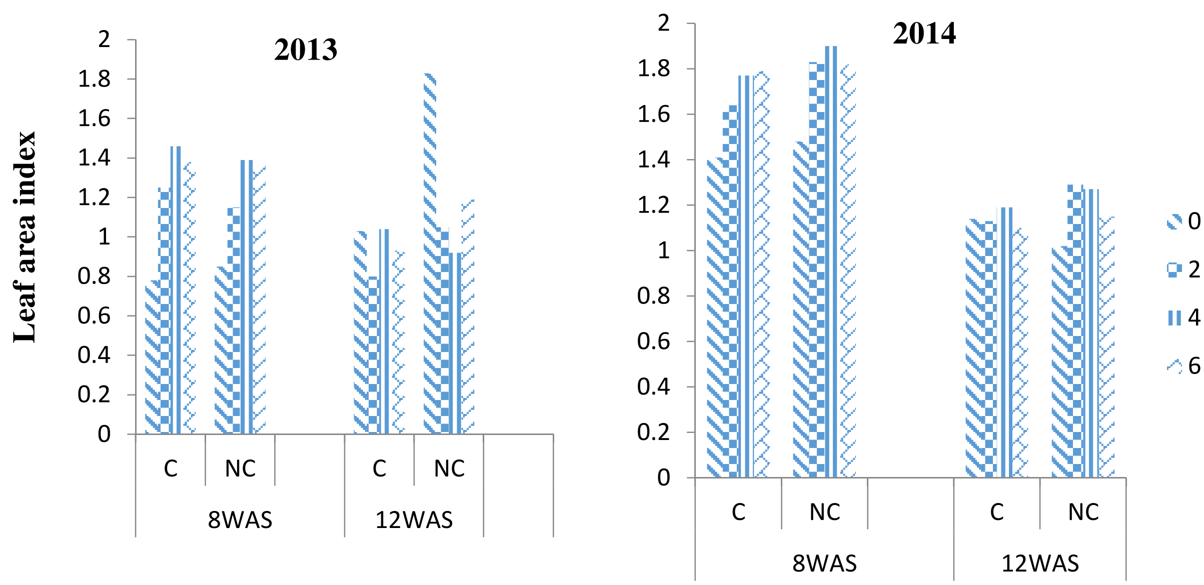

Figure 2: Effect of poultry manure and cowpea clipping on leaf area index of popcorn at 8 and 12 weeks after sowing during 2013 and 2014 rainy season at Samaru. C= clipped, NC = Not clipped

The leaf area index (LAI) of popcorn (Figure 2) increased with application of poultry manure in both years whether the cowpea was clipped or unclipped. In 2013, at 8WAS, LAI increased with increased rates of poultry manure application up to 4 t ha^{-1} when cowpea was clipped or not clipped. Further increase to 6 t ha^{-1} resulted in decreased LAI. At 12WAS, popcorn at the control (0 t ha^{-1}) significantly had the highest LAI when the cowpea in the mixture was unclipped while the least was recorded at 2 t ha^{-1} of poultry manure when cowpea was clipped.

In 2014, LAI at 8WAS were significantly higher than at 12WAS the popcorn. At 8WAS, it was observed that when cowpea was clipped, LAI of popcorn increased with increase in poultry manure rates applied up to 6 t ha^{-1}. When the cowpea was however unclipped, significant increase was recorded from 0 – 4 t ha^{-1} of poultry manure but further increase to 6 t ha^{-1} decreased LAI of popcorn. At 12WAS, when the cowpea in the mixture was clipped, the highest LAI of popcorn was recorded at 4 t ha^{-1} but when unclipped, application of 2 t ha^{-1} of poultry manure resulted the highest LAI of popcorn while the least was recorded at the control.

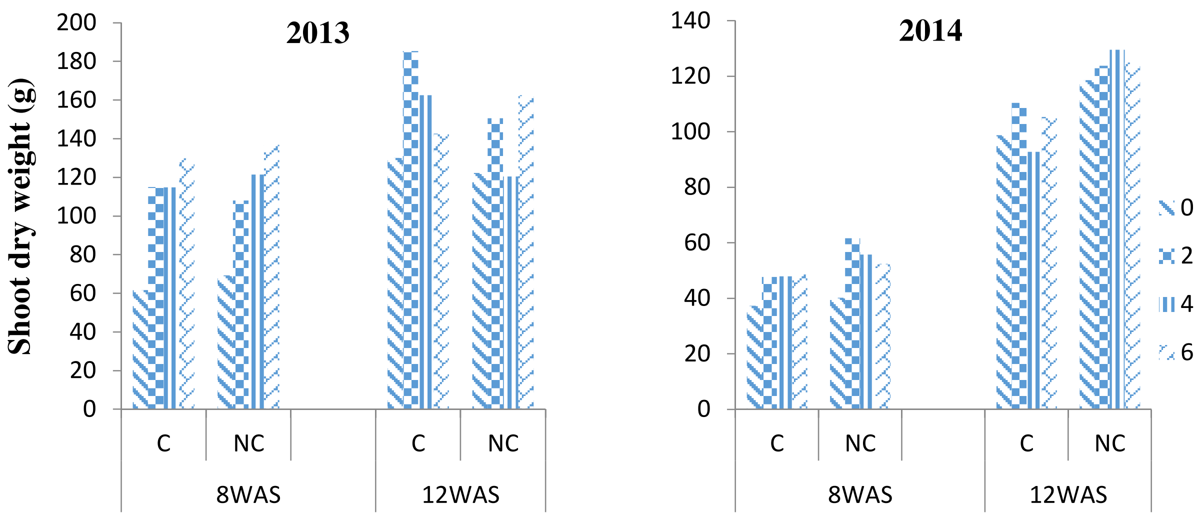

Figure 3: Shoot dry weight of popcorn at 8 and 12WAS as influenced by poultry manure and cowpea clipping during the 2013 and 2014 rainy season. C= clipped, NC = Not clipped

The shoot dry weight of popcorn (Figure 3) in the intercrop was increased with application of poultry manure and clipping of cowpea. In 2013, at 8WAS, shoot dry weight increased with poultry manure application up to 6 t ha^{-1} whether the cowpea in the mixture was clipped or unclipped. But at 12WAS, heaviest dry shoots of popcorn were recorded at 2 t ha^{-1} of poultry manure irrespective of cowpea clipping.

Popcorn dry shoot weights recorded in 2014 were observed to be higher at 12WAS than at 8WAS. Popcorn dry shoots were heaviest at 8WAS with application of 2 t ha^{-1} of poultry manure when the cowpea in the mixture was unclipped. At 12WAS, clipping of cowpea significantly increased shoot dry weight of popcorn with application of 2 t ha^{-1} of poultry manure resulting in the heaviest shoots.When cowpea was unclipped, shoot dry weight of popcorn increased with application of poultry manure up to 4 t ha^{-1} but further increase to 6 t ha^{-1} depressed shoot dry weight.

The crop growth rate (CGR) of popcorn (Figure 4) at 8WAS in 2013 increased with application of poultry manure up to 6 t ha^{-1} whether the cowpea in the mixture was clipped or not clipped. This trend was also recorded at 12WAS when the cowpea in the mixture was unclipped. But when cowpea in the mixture was clipped, application of 2 t ha^{-1} of poultry manure resulted in the highest CGR of popcorn.

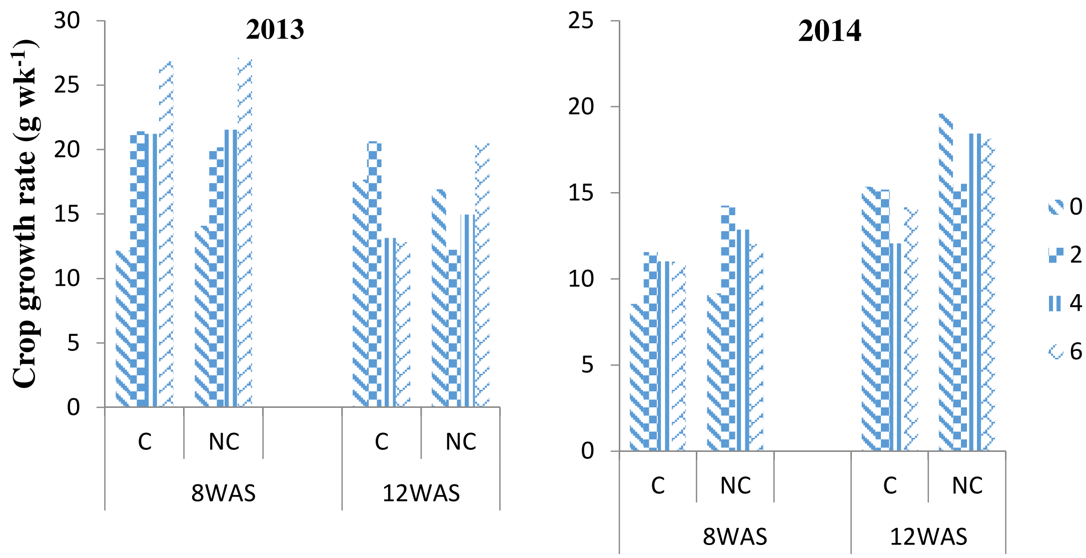

Figure 4: Effect of poultry manure and cowpea clipping on crop growth rate of popcorn at 8 and 12WAS during the 2013 and 2014 rainy season. C= clipped, NC = Not clipped

CGR in 2014 at 8WAS showed that application of 2 t ha^{-1} of poultry manure resulted in popcorn plants with the highest CGR than the other poultry manure rates whether the cowpea in the mixture was clipped or unclipped. At 12WAS, the control (0 t ha^{-1}) recorded plants with the highest CGR. The grain yield of popcorn (Figure 5) in both years increased with increase in rates of poultry manure applied. In 2013, it was observed that grain yield increased with each increase in rate of poultry manure applied whether the cowpea in the mixture was clipped or unclipped.

In 2014, the increases in grain yield were not significantly different at higher poultry manure rates except at the control where the least was recorded irrespective of clipping or not clipping of the cowpea.

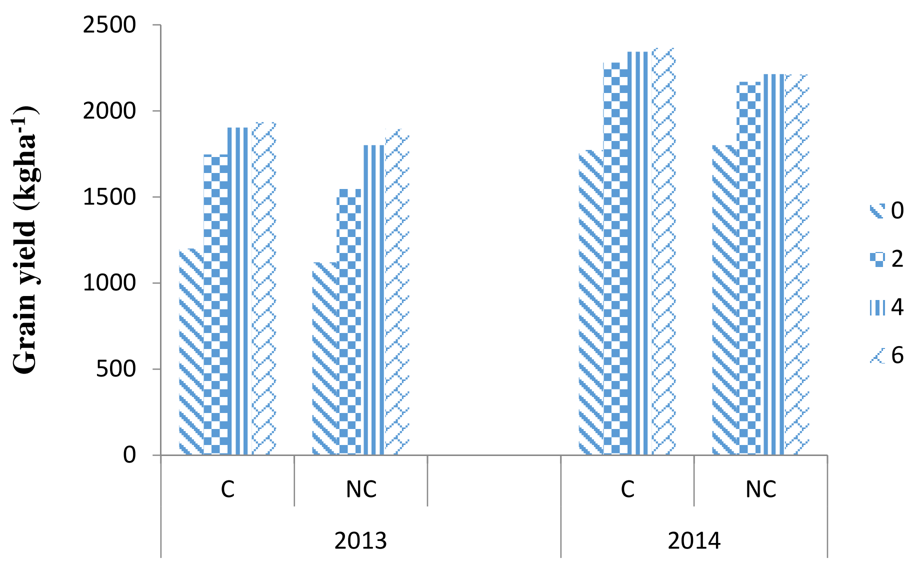

Figure 5: Effect of poultry manure and cowpea clipping on grain yield of popcorn at Samaru during 2013 and 2014 rainy season. C= clipped, NC = Not clipped

The increases in height, LAI, shoot dry weight, CGR and grain yield recorded due to poultry manure application could be attributed to the fact that poultry manure contains essential nutrient elements that are associated with increased photosynthetic efficiency through increased photo – assimilate production and partitioning (Dauda *et al*., 2008, Agba *et al*., 2012). The increase in height of popcorn at the control 12WAS in 2013 when cowpea in the mixture was clipped could be because of the incorporated cowpea shoots which served as a source of green manure. Organic manures supply elements which promote vigorous growth, improve meristermatic and physiological activities in plants as well as improve the soil properties thereby resulting in the increases recorded (Agba *et al*., 2012). Higher LAI recorded at 8WAS than 12WAS in 2014 could be because, the crop was at the peak vegetative growth stage while at 12WAS the crop was the crop was at the reproductive growth stage and leaf senescence has set in. The significant LAI recorded at the control at 12WAS in 2013 could be attributed to competition between the crops in the mixture. The cowpea has a trailing ability thus the increase in growth of the popcorn to avoid being smothered by the cowpea. Decreases in height, LAI and shoot dry weight were however observed at higher poultry manure rates could be because, excess manure result in release of a lot of organic acids which resulted in decrease in soil pH and consequently making some essential elements unavailable for the plant. This could be seen on table one where decreases in soil pH were recorded in both years of the research. Positive responses due to poultry manure application and incorporation of cowpea shoots as green manure could be due to the low nitrogen and phosphorus status of the soil (Table 1). Additionally, increases recorded could be due to the increase in soil carbon content with manure application. The increase in soil carbon content (carbon sequestration) due to the addition of manures results in a win-win situation by improving crop growth and also helping to remove potential gases that result in global warming and climate change (Andre, 2018).

Conclusion

Based on the results obtained from this study, the application of 2 t ha^{-1} of poultry manure can be used to cultivate popcorn where the cowpea in the intercrop is clipped and incorporated into the soil as green manure. Soil organic carbon and total nitrogen content of the soil were improved as a result of the incorporation of poultry manure and cowpea clippings.

References

Agba O.A., Ubi B.E., Abam P.,Ogbechi J., Akeh M., Odey S. and Ogar N. (2012). Evaluation of agronomic Performance of Maize (*Zea mays* L.) under different rates of poultry manure application in an Ultisol of Obubra, Cross River State, Nigeria. International Journal of Agriculture and Forestry, 2(4):138-144

Agbede T.M., Adekiya A.O and Ogeh J.S. (2013). Effects of organic fertilizers on yam productivity and some soil properties of a nutrient depleted tropical alfisol. Archives of Agronomy and Soil Science 59 (4-6):803-822

Agbede T.M., Adekiya A.O and Ogeh J.S. (2014). Response of Soil Properties and Yam Yield to *Chromolaena odorata* (Asteraceae) and *Titinia diversifolia* (Asteraceae) Mulches. Archives of Agronomy and Soil Science 60(2):209-224

Agbede T.M., Adekiya A.O and Eifediyi E.K (2017). Impact of Poultry Manure and NPK Fertilizer on Soil Physical Properties and Growth and Yield of Carrot. *Journal of Horticultural Research. Volume 25 (1): 81-88*

Agbenin J.O. (1995). Laboratory manual for Soil Plant analysis. Department of soil science, Ahmadu Bello University, Zaria

Andre L. (2018). Healthy Soils for a Healthy Life – Increasing Soil Organic Matter Through Organic Agriculture.

Atakora K., Agyarko K., and Aseidu E.K. (2014). Influence of grasscutter, chicken manure and NPK fertilizer on the physical properties of Chromic Luvisol, growth and yield of Carrot (*Daucus carota*). International Journal of Plant and Soil Science 3(2): 197-204

Baskar K. (2003). Effect of integrated use of inorganic fertilizers and FYM or Greenleaf manure on uptake and nutrient use efficiency of rice-rice system on an Inceptisol. Journal of the Indian Society of Soil Science. 51:47-51.

Bray H. R. and Kurtz, L. T. (1945). Determination of organic and available forms of phosphorus in soils. Journal of Soil Science. 9: 39-46.

Bremner J. M. and Mulvaney, C. S. (1982). Nitrogen-Total. In: Methods of Soil Analysis, Part 2. Chemical and Microbiological Properties, Page, A.L., R.H. Miller and D.R. Keeney (Eds.). ASA and SSSA, Madison, WI., USA., pp: 595-624.

Dauda S.N., Ajayi F.A., and Dor E.N., (2008). Growth and yield of watermelon (*Citrullus lunatus*) as affected by poultry manure application. Journal of Agriculture and Social Science. 4(3),121-124

Deepa J., Archana B., Arpita S. and Onima V.T. (2016). Package and Practices of Popcorn (*Zea maysvar. everta*). *Biotecharticles.com*

Duncan D.B. (1955). Multiple ranges and Multiple 'F'test, *Biometrics.* 11-42

Gee G.W. and Or, D. (2002). Particle size analysis. In: J.H. Dane and G.C. Topp (eds). Methods of soil analysis, part 4. physical methods. Soil Science Society of America. Book series. No. 5 America Society Agronomy and Soil Science Society of America Madison, W1, pp 255-293.

Giller K.E. and Wilson K.J. (1991). Nitrogen fixation in tropical cropping systems. U.K. CABI. International Wallingford.

Johannes Kotschi (2013). A soiled reputation. Adverse impacts of mineral fertilizers in tropical agriculture. Study commissioned by Heinrich Boll Stiftung. Association for Agriculture and Ecology (AGRECOL)Pp 37

Josh B.P and John L. (2015). Manure as a source of crop nutrients and soil amendment. Animal manure management. Articles.extension.org

Julia M. O'Hallorans, Miguel A. Muñoz and Octavio Colberg. (1993). Effect of chicken manure on chemical properties of a Mollisol and tomato production. Journal of Agriculture of the University of Puerto Rico. 77(3-4), Pp 181-191

Lomander A., Katterer T. and Andren O. (1998). Modelling the effects of temperature and moisture on CO_2 evolution from top and sub-soil using a multi-compartment approach. Soil Biology and Biochemistry. 39:2023-2030

Meena R.N., Singh, S.P and Singh, K. (2010). Effect of organic nitrogen nutrition on yield, quality, nutrient uptake and economics of rice (*Oryza sativa*)-table pea (P*isum sativum var hortense*)-onion (*Allium cepa*) cropping sequence. Indian Journal of Agricultural Sciences. 80(11): 1003-6.

Nelson D.W. and Sommer L.E.(1986) Total carbon organic carbon and organic matter. In A.L. Oage, R.H. Miller and D.R. Keeney (eds) Methods of soil analysis Page 2 Chemical and Mineralogical properties 2nd ed. Agronomy 9:539-579

Odion E.C and Singh B.B (2005). Production of dual purpose cowpea varieties at two clipping heights in the sudan savanna of Nigeria:1 fodder production in pure stand. Journal of Arid Agriculture, Vol. 15, 9-14

Patil P.V., Chalwade, P. B., Solanke, A. S and Kulkarni, V. K. (2003). Effect of fly ash and FYM on physico-chemical properties of Vertisols. Journal of Soils and Crops. 13(1): 59-64.

Qian P., SchoenauJ. J., King T., and Japp M. (2005). Effect of repeated manure application on potassium, calcium and magnesium in soil and cereal crops in Saskatchewan. Canadian Journal of Soil Science 397-403

Rachael Odusanya (2018). Maize production in Nigeria: is it profitable in 2018. *www.legit.ng*

Snedecor G.W. and Cochran W.G. (1967). Statistical Method 6th Edition. Iowa State University Press. Ames Iowa, U.S.A. 607pp.

Statistical Analysis System (SAS) Institute (1990). The SAS users guide, version 9.1.3. SAS Institute, Cary NC.

Thomas G.W. (1982) Exchangeable cations. In R.H. Miller and D.R. Keeney (eds) Methods of soil analysis Page 2 Chemical and Mineralogical properties 2nd ed. Agronomy 159-166

Warren J.G, Phillips S.B, Mullins G.L, Kealey D and Penn C.J (2006). Environmental and production consequences of using alum amended poultry litter as a nutrient source for corn. Journal of Environmental Quality 35:172-182