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ENHANCING THE FERTILIZER VALUE OF CATTLE MANURE USING ORGANIC RESOURCES FOR SOIL FERTILITY IMPROVEMENT: A REVIEW

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ABSTARCT

The poor quality of cow dung in Ghana resulting from the opportunistic feeding mode of cattle impedes its adoption due to high quantities needed for application. This calls for nutrient optimization of cattle manure with inexpensive locally available sources of organic inputs that could enhance its quality. Though large volumes of crop residues and other agro-wastes are produced on-farm, they are underutilized and mostly a nuisance. Major food crops take approximately, 44 %, 42 % and 56 % of the total nitrogen (N), phosphorus (P) and potassium (K), respectively and are found in crop residues. There is therefore the need to develop appropriate technologies for utilizing agro-wastes by transforming them into useful “resources” with potentially available plant macro and micronutrients. Common agro-wastes in Ghana include cocoa pod husk (CPH), palm kernel cake (PKC), cattle manure (CM) and poultry manure. Hence, this review sought to explore the use of crop residues and agro-minerals to improve the quality of manure and consequently its fertilizer value for soil fertility improvement and increased crop yield. The review presented an assessment of resource potentials of some crop residues and local agro-mineral as a means of enhancing the quality of CM. Using published data, the review has identified that PKC, rock phosphate (RP) and CPH have high potential for improving the N, P and K contents of CM, respectively. In conclusion, it recommends the need to extensively explore the potential of other commonly available organic resource materials for their efficacy to improve the fertilizer value of cattle manure.

Keywords: Compost, crop residues, rock phosphate, cocoa pod husk, palm kernel cake.

INTRODUCTION

Low soil fertility has been identified as the major biophysical cause for the declining rate of crop production in most sub-Saharan African (SSA) countries, including Ghana (Sanchez, 2002). Therefore, in order to satisfy the demands of the rising human population and enhance food security, replenishment of the degraded agricultural soils is imperative as the exacerbated decline in soil fertility with its consequent suboptimal crop yields has been a major crop production constraint in diverse agro-ecologies over the years. Intensive agriculture cannot be sustained unless through soil nutrient application to replace those depleted by crop production (Grant et al., 2002; Morris et al., 2007). Inorganic and organic fertilizers are the most common sources of nutrients to crops.

In this era of climate change, the sole use of inorganic fertilizers is not environmentally sustainable because of their inability to solely improve the soil's biological and physical properties. The high prices of inorganic fertilizers have also resulted in intensified studies into locally available, low-cost, ecologically sound, and inexpensive sources of nutrients like organic manures (Adejobi et al., 2013). The commonly used organic

manures in Ghana are poultry and cattle manures. Cattle manure has a relatively low nutrient content (1.20 % N, 0.07 % P, 0.09 % K, 0.25 % Ca and 0.08 % Mg) as compared to poultry manure (2.20 % N, 0.77 % P, 0.91 % K, 1.70 % Ca and 0.42 % Mg) (FAO, 2005). The poor quality of cattle manure, for example, significantly impedes its adoption for application (Vanlauwe and Giller, 2006) resulting in high quantities needed for application. This calls for optimization of cattle manure using inexpensive, locally available organic inputs that could enhance its quality. Most studies have attempted improving the N content of manure using crop residues (Ewusi-Mensah, 2009; Kolade et al., 2006) and P using agro-minerals (Mahimairaja et al., 1995) by composting. However, studies to improve N, P and K simultaneously in manure is limited.

Composting cattle manure with locally available materials such as cocoa pod husk (CPH), palm kernel cake (PKC) and rock phosphate (RP) agro-mineral would enhance the fertilizer value of manure and subsequently decrease the quantity needed for application. Cocoa pod husk can serve as a rich source of K ranging between 3.35 to 3.87 % (Adamtey, 2005; Hamzat and Adeola, 2011). Similarly, PKC from agro-processing industries is a rich source of nitrogen (2.88 %) (Kolade et al., 2006) and rock phosphate has a relatively high P content (28 – 30 %).

The objective of this review therefore was to explore the use of these nutrient enriched resources for improving the quality of manure, and thus its fertilizer value for soil fertility improvement and consequently increased crop yield. This review therefore highlights recent advances on soil fertility trends in SSA, especially Ghana and presents an assessment of the resource potentials of some crop residues and a local agro-mineral as a means of enhancing the quality of cattle manure.

MATERIALS AND METHODS

This study reviewed scientific literature on soil fertility status in SSA (Henaio and Baanante, 2006), especially Ghana (Hill, 2014; Jayne et al., 2015), ways of improving soil fertility (Grant et al., 2002; Morris et al., 2007; Omotayo and Chukwuka, 2009), potential of agricultural farm residues and agro-minerals as a nutrient source (Adamu et al., 2014; Maheshwari, 2014; Essel et al., 2021), quality improvement of manures (Singh and Amberger, 1991; Sanginga and Woomer, 2009; Fening et al., 2010; Opoku, 2011) and compost enrichment (Singh and Amberger, 1991; Sanginga and Woomer, 2009; Akbari et al., 2010). In the past two decades (2000 to 2020), literature about “manure quality”, “fertilizer value”, “compost” and its effects on soil fertility has considerably increased, thus indicating a strong interest by researchers in this topic from different points of view. Scopus (Elsevier) literature database (<https://www.scopus.com>) was used for data retrieval in this review, as it covers a wider scope of high-quality, peer-reviewed articles across multiple disciplines. The data was retrieved on June 30, 2020 using the search query: (TITLE-ABS-KEY ("manure quality" OR "fertilizer value" OR "compost" AND "soil fertility") AND PUBYEAR > 1999 AND (LIMIT-TO (SUBJAREA,"AGRI") OR LIMIT-TO (SUBJAREA, "ENVI))). This search produced a total of 1015 documents as presented in Figure 1; with India dominating with 154 and Ghana having 10 reported publications.

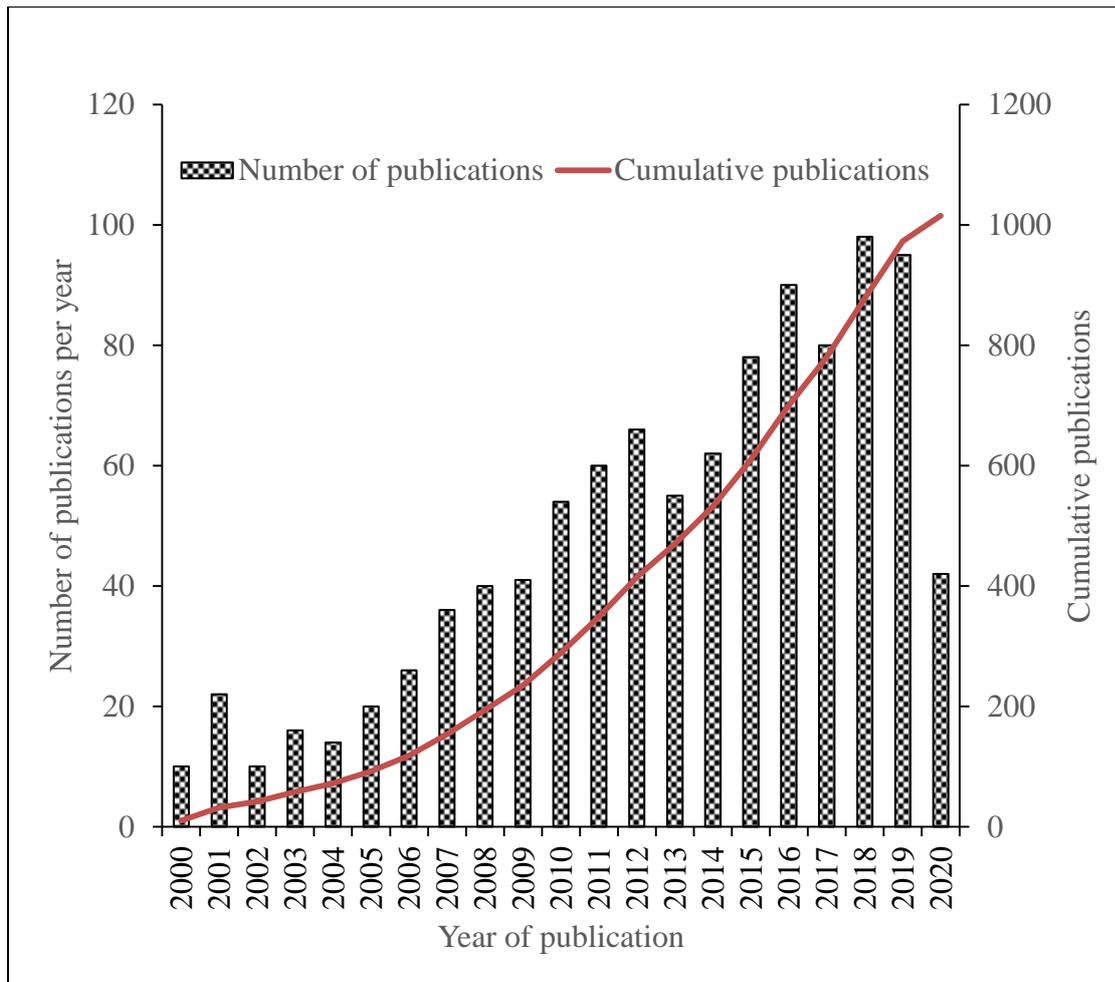


Figure 1: Results of the search performed on Scopus in June, 2020 sorted by inputting “manure quality”, “fertilizer value”, “compost” and “soil fertility” in the article title, abstract and keyword fields, and in the subject area “Agricultural and Biological Sciences” and “Environmental Science”.

REVIEW

i. Overview of Soil Fertility Status in Ghana

Due to several physical or chemical limitations; high bulk density, low organic carbon content, nutrient deficiency, acidity, etc., most soils in their inherent capacity are unable to provide adequate/required nutrients for the growth of crops, resulting in reduced crop yields. Hartemink (2006) reported that, soil fertility decline is an implication of soil quality decline. Reports have been made by several scientists about the poor fertility status of most soils in SSA (Henao and Baanante, 2006; Chukwuka and Omotayo, 2009). It was reported by Sanchez (2002), that depletion of soil fertility in smallholder farmers’ fields was the major biophysical cause of the declining crop production in most SSA countries. This has resulted in low crop yields and per capita food production in SSA (Henao and Baanante, 2006). Low soil fertility costs farmers over US\$ 4 billion annually in reduced yields (Wortmann and Sones, 2017).

Ghana, like many other countries in Africa, has been facing an escalating soil fertility crisis over decades with predicted losses of 35, 4 and 20 kg/ha of N, P and K annually (Jayne et al., 2015). This has been affirmed by Hill (2014), who reported that significant soil multi-nutrient (N, P and K) deficiencies have been found throughout Ghana. This has often resulted

through drivers such as nutrient mining by crops, leaching of soil nutrients and inappropriate management practices resulting from lack of fallow periods, deforestation and land degradation (Morris et al., 2007). Also, when nutrient outflows through crop harvest and crop residue removal from farms are greater than nutrient inflows by fertilizer application, the soil nutrient stock will decline and consequently contribute to soil fertility depletion (Henaio and Baanante, 1999). Nevertheless, several years of research have not been able to completely reverse this trend in declining soil fertility status. Jayne et al. (2015) made an observation of the average fertility status of soils in the six agro-ecological zones (AEZ) of Ghana. According to the aforementioned authors' report, the soil pH, organic C, total N, available P and exchangeable K of soils in the Semi-deciduous forest AEZ was in the range 5.5 – 6.2, 1.59 – 4.80 %, 0.15 – 0.42 %, 0.36 – 5.22 mg/kg and 0.16 – 0.22 cmol(+)/kg, respectively (Table 1). The soils were moderately acidic with very low nutrients.

Table 1: Average soil fertility status of the agro - ecological zones in Ghana.

Agro-ecological zone	Soil pH	Organic C (%)	Total N (%)	Available P (mg/kg)	Exch. K (cmol(+)/kg)
Rainforest	3.8 – 5.5	1.52 – 4.24	0.12 – 0.38	0.12 – 5.42	0.16 – 0.39
Transitional zone	5.1 – 6.4	0.59 – 0.99	0.04 – 0.16	0.30 – 4.68	0.15 – 0.19
Semi-Deciduous Forest	5.5 – 6.2	1.59 – 4.80	0.15 – 0.42	0.36 – 5.22	0.16 – 0.22
Coastal Savanna	5.6 – 6.4	0.61 – 1.24	0.05 – 1.16	0.28 – 4.10	0.12 - 0.15
Guinea Savanna	6.2 – 6.6	0.51 – 0.99	0.05 – 0.12	0.18 – 3.60	0.12 – 0.14
Sudan Savanna	6.4 – 6.7	0.48 – 0.98	0.06 – 0.14	0.06 – 1.80	0.09 – 0.11

Exch K: Exchangeable potassium; Adapted Jayne et al., (2015)

The need to build resilience towards a climate-smart agriculture has resulted in paradigm shifts in several aspects of farming such as a shift from individual crop nutrient requirements to optimum use of nutrient sources, and also a shift from the first year's nutrient application effects to a long-term residual effect. Due to the generally low fertility status of the soils, Grant et al., (2002) and Morris et al., (2007) suggested that intensive agriculture cannot be sustained unless inorganic or organic or both nutrient sources are applied to the soil to replace the ones removed through increased crop production.

ii. Use of Inorganic Fertilizers

The importance of inorganic fertilizer in crop production is well documented globally as a major supplier of plant nutrients. Inorganic fertilizer was a significant element of the technological trinity comprising fertilizer, improved seed and irrigation that led to the Green Revolution in Latin America and Asia (Dittoh et al., 2012).

In developing countries outside Africa, 50 to 70 % of crop yield increases have been attributed to unprecedented inorganic fertilizer use (Issaka et al., 2016). In Ghana, however, approximately 10 % of smallholder farmers with less than one hectare of farmland use inorganic fertilizers (Ghana Fertilizer Assessment, 2012). Though, the global mean of inorganic fertilizer application is 101 kg/ha (Camara and Heinemann, 2006), SSA applies 9 kg/ha and Ghana applies about 8 kg/ha (FAO, 2005).

The low application rate has been probably attributed to its high cost, which is usually beyond the purchasing power of the smallholder farmer (Tetteh et al., 2008). The extensive and improper use of inorganic fertilizers increase micronutrient deficiency and nutrient imbalance; reduce microbial population and deteriorates soil quality (Kannan et al., 2013) resulting in crop productivity decline (Tovihoudji et al., 2017).

iii. Use of Organic Fertilizers

Kannan et al., (2013) opined that, the adverse effects of inorganic fertilizer use were due to its exclusive and improper use coupled with the non-application of organic nutrient sources. Due to the high inorganic fertilizer cost and its associated soil acidity problems as a result of leaching of the nutrients, there is therefore an urgent need for an ecologically sound and efficient soil management technology with consideration from organic sources. Issaka et al., (2016) observed that, Ghana's organic farming sector is relatively underdeveloped, representing 0.2 percent of the total agricultural land. However, it must be noted that, although the sole use of organic fertilizers cannot provide adequate nutrients to sustain crop yields, they will continue to be a critical source of nutrients for smallholder farmers (Palm et al., 2001).

The most commonly used organic nutrient sources in SSA are animal manure, green manure, crop residues, leguminous cover crops, household wastes and mulches (Omotayo and Chukwuka, 2009). Organic fertilizers in the form of manures and compost are important complements to inorganic fertilizer use (Fairhurst, 2012; Jayne et al., 2015). Their use for soil fertility improvement has been an age-old practice (Omotayo and Chukwuka, 2009). This is backed by a report by Issaka et al. (2012) that the economies of most developing countries dictate that resources must be used to their fullest potential, leading to a culture of reuse, repair and recycling. Some reports have also indicated that, organic fertilizers increase the buffering capacity of soils. They can also improve the moisture retention capacity of soils, leading to increased germination percentage and vigorous plant growth (Spaccini et al., 2002). Furthermore, organic fertilizers regulate the soil physicochemical properties, have the ability to supply micronutrients which are not contained in inorganic fertilizers, ameliorate soil acidity constraints and replenish soil organic matter (Fairhurst, 2012).

Despite the numerous merits of organic fertilizers, their effective use in nutrient management is constrained by certain factors. These include the large labour force needed for processing and transporting organic materials in bulk and also the large quantities required to provide adequate nutrients needed by plants for successful crop production due to their relatively low nutrient concentrations and poor quality (Palm et al., 1997; Fatondji et al., 2009). They are also sometimes associated with slow mineralization of nutrients (Lukman et al., 2016) causing loss of synchrony between nutrient release and crop demand (Gondwe and Nkonde, 2017). In an earlier study, Snapp et al. (1998) reported that most crop residues and animal manures are of low quality, due to their N contents falling below the critical value of 1.8 – 2.0 %, and causing temporal N immobilization when applied to soils. Therefore, the sole use of crop residues or animal manures without optimizing their nutrient contents is an imperfect form of nutrient cycling due to their inability to solely close the nutrient loop (Tovihoudji et al., 2017). However, the use of high quality, fast decomposing organic resources such as *Crotalaria*, *Tithonia* and *Sesbania* spp. slows down the build-up of organic matter in soils due to the rapid decomposition rates and results in leaching out of nutrients from the soil (Omotayo and Chukwuka, 2009). Furthermore, Jama et al., (2000) reported that, there are more organic resources with relatively high nutrient concentrations, but little is known about their potential for use as a nutrient source to improve soil fertility and crop yields.

iv. Potential of Agricultural Farm Residues and Agro-Minerals as a Nutrient Source

Crop residues is agriculture's largest harvest (Smil, 1999). According to Adamu et al., (2014), agricultural residues constitute straws, stem, leaves, roots, stovers, haulms, processed waste such as rice husks, oil cakes, etc, that remain after crop harvest. Large

volumes of Ghana's crop residues and wastes produced on-farm are underutilized and mostly constitute a nuisance. This assertion is confirmed by a farm survey by Ogunrinde (2006) who observed that approximately 70 percent of crop residues produced by farmers in the Ashanti region of Ghana served no alternative agricultural use. Despite the alarming rate of declining soil fertility, an assessment by Rhodes (1995) on the major nutrients removed by food crops in the tropics such as sorghum, rice, millet, maize, cassava and yam revealed that approximately 44 % of the total N, 42 % of the total P and 56 % of the total K taken up by the major food crops are found in crop residues. There is therefore the need to develop appropriate strategies for re-using agricultural farm residues by transforming the "wastes" into useful "resource" materials.

The use of agricultural resource waste and residues is increasingly gaining importance among smallholder farmers. The use of agricultural resource waste and residues would be of immense benefit to the smallholder farmer because aside it being readily available, it is extremely sustainable and environmentally friendly in restoring and maintaining soil fertility and productivity (Agbeniyi et al., 2011). These residues are noted for their potentially available plant macro and micronutrients. However, for safe application to plants, there is the need to compost them (Adamtey, 2005; Issaka et al., 2012). Even though in Ghana, there are many sources of agricultural residues and wastes with the potential of being used as sources of organic fertilizer, this review will focus on cocoa pod husk, palm kernel cake, cattle manure and rock phosphate.

v. *Cocoa Pod Husk*

Cocoa pod husk is a major agro-industrial residue in Ghana, obtained from the fruit of cocoa (*Theobroma cacao* L.) and a very important commodity due to the economic value of cocoa beans. Nfor et al. (n.d.), in valorizing the by-products of cocoa in Cameroon reported that, cocoa beans constitute 10 % of the fresh weight of the cocoa fruit. This means that only 10 % of the cocoa fruit is commercialized while 90 % by weight is discarded as cocoa waste. For instance, an estimated 6,800,000 tons of CPH are generated annually from farms in the Ashanti, Brong-Ahafo and Western regions of Ghana (Ofori-Frimpong et al., 2003; Moyin-Jesu, 2004; Odedina et al., 2007; Mensah-Brako, 2011). According to reports by Alemawor et al. (2009), CPH constitutes over 70 % (w/w) of the whole matured cocoa fruit, but is currently under-utilized. This means during every cocoa harvesting season, a colossal amount of CPH become available but are discarded as "waste". These have environmental implications as CPH serves as a host for *Phytophthora* spp., the major causal agent for black pod disease in cocoa and a major threat to the cocoa industry and Ghana's economy (Ofosu-Budu et al., 2015). Cocoa pod husk contains approximately 1.47 % N, 0.19 % P and 3.35 % K (Adamtey, 2005). In Nigeria, Hamzat and Adeola (2011) also revealed that CPH contained 0.10 % P, 3.87 % K, 10.4 % moisture and 89.6 % dry matter. Hence, there is the need to exploit the potassium in CPH for soil amelioration.

vi. *Palm Kernel Cake*

Palm kernel cake is one of the major co-products obtained from the residues of the monocotyledonous oil palm (*Elaeis guineensis* Jacq.) (Mohamed et al., 2012). According to Rupani et al., (2010), 70 % of the fresh fruit bunches in the oil palm industry are generated as waste, with palm kernel cake accounting for 3 percent.

Palm kernel cake is the less fibrous solid waste produced following the extraction and refining of palm kernel oil from the endosperm of oil palm fruits. According to a report by Alimon (2004), PKC has high mineral composition, with 0.46 – 0.71 % P, K (0.76 – 0.93 %), Ca (0.21 – 0.34 %) and Mg (0.16 - 0.33 %). Also, Maheshwari (2014) reported that,

PKC contains 2.42 % N, 0.22 % P, 1.08 % K, 1.6 % Ca and 0.5 % Mg. These nutrients which are often allowed to go waste, can therefore be used in soil amendment programmes.

Contrary to the high nitrogen content of 2.42 %, reported by Maheshwari (2014), Kolade et al., (2006), found that palm kernel cake is generally deficient in nitrogen and therefore in order to compost it, there is the need to supplement it with nitrogen-rich materials usually from animal wastes. Kolade et al., (2006) therefore composted palm kernel wastes using goat manure and poultry manure and as nitrogen supplements and realized the sole application of the palm kernel waste compost resulted in greater number of leaves, stem girth and plant height of amaranthus comparable to that of organo-mineral fertilizer. Prior to composting, the aforementioned authors recorded 58.92 % moisture content, 96.21 % C, 2.88 % N, 0.60 % P and 0.19 % K for PKC. Nutrients in organic resources are variable and as such, Adamtey (2005) also reported values of 1.63 % N, 0.70 % P and 0.06 % K in PKC. The use of PKC will therefore be an innovative approach of positively enhancing the fertilizer value of manure. This is because oilcakes are generally known to contain higher nutrient concentrations especially nitrogen (5.20 % N and 0.77 % P) than manure (0.50 % N and 0.06 % P) (Opoku, 2011).

vii. Cattle Manure

The beneficial effect of manure on soil fertility is well documented (Snapp et al., 1998). The use of animal manure is a technology for enhancing SOM on smallholder farms, having a high propensity of raising crop yield in the short term and soil fertility in the medium term. The ease of adoption of animal manure use is high due to the low competition for arable land and the labour required (Snapp et al., 1998).

There are several kinds of animal manures used by farmers in Ghana, however, poultry manure and cattle manure are the two most common types. Out of these two manures, cattle manure has a relatively low nutrient content (1.20 % N, 0.07 % P, 0.09 % K, 0.25 % Ca and 0.08 % Mg) as compared to poultry manure (2.20 % N, 0.77 % P, 0.91 % K, 1.70 % Ca and 0.42 % Mg) (FAO, 2005). Despite the relatively low nutrient content of cattle manure, a report by SRID and Veterinary Services Directorate (2015) indicated that the trend of cattle production has been increasing steadily over the years, that is, from 1,438,000 in 2009 to 1,657,000 in 2014. Ofosu-Budu et al., (2015) reported that the estimated total wet and dry cattle manure produced in Ghana in 2008 were 22.8 million and 2.9 million tonnes, respectively.

Cattle manure is an affordable and valuable organic resource, as it contains some quantities of macro and micronutrients necessary for crop growth (Akila and Ramasubramanian, 2015). However, overproduction of this waste has resulted in inappropriate disposal methods such as the indiscriminate and inappropriately application to agricultural lands (Lazcano et al., 2008). This therefore signifies the importance of applying manure to crops and therefore the need to improve its value for crop production. This is necessary because the application of cattle manure to farmland is an economically and environmentally sustainable mechanism for increasing crop production, as it produces about one-third less the greenhouse gases emitted into the atmosphere. It is also an excellent soil amendment that is capable of increasing the quality of soils.

viii. Rock Phosphate

Rock phosphate (RP) is a tri-calcium phosphate compound (agro-mineral); $[\text{Ca}_3(\text{PO}_4)_2]_3 \cdot \text{CaCO}_3$ which is insoluble in water (Sharif et al., 2011) and whose P is not readily available to plants (Brady 1980; Das 2005). According to Khan and Sharif (2012), it is the main raw material used in the manufacture of chemical phosphatic fertilizers, for

example, single superphosphate and triple superphosphate, by mostly treating the rock phosphate with sulphuric acid (H_2SO_4).

Research has proven that composting animal manure and crop residues with rock phosphate enhances the dissolution of rock phosphate (Singh and Amberger, 1991). It is therefore widely practiced as a low-input technology to improve the fertilizer value of organic manure (Mahimairaja et al., 1995). For instance, Rashid et al. (2004) observed that the enrichment of manures with P by composting rock phosphate with organic materials, produced several beneficial organic acids during composting. Some of these acids are acetic, citric, fumaric, gluconic, oxalic and succinic acids. The afore-mentioned authors also alluded that the acids were either from chemical reactions or soil microbial activities. The high calcium concentration of rock phosphate (24 – 33 %) gives it an added advantage of increasing soil pH and cation exchange capacity, with its resultant increases in crop yield (Zin et al., 2005).

ix. Enhancing the Fertilizer Value of Agricultural Residues and Wastes

Cattle manure is noted for its low N contents as compared to other sources of farm manure (Ewusi-Mensah, 2009; Fening et al., 2010). According to Palm et al., (1997), manures with less than 2.5 % N are of low quality. The quality of manure therefore refers to its ability to improve soil properties and crop yield (Kimani and Lekasi, 2004; Opoku, 2011). In view of this, several researchers have sought for ways of improving the quality of manures. Different management categories of handling organic resources have been suggested by Palm et al., (1997; 2001) as presented in Figure 2.

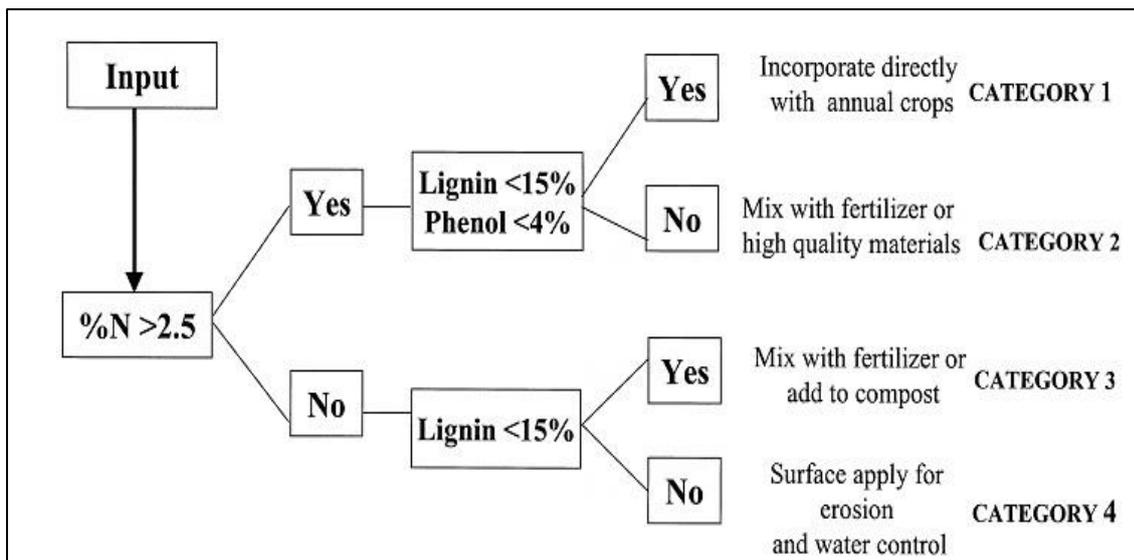
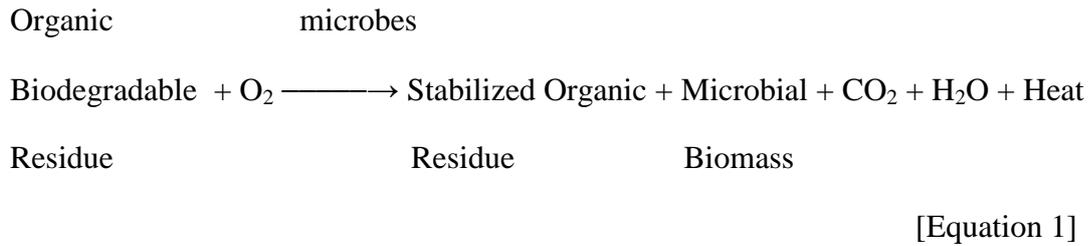


Figure 2: A decision tree guiding the use of organic resources in agriculture. (Source: Palm et al., 2001)

Composting is an environmentally friendly way of increasing food productivity (Akila and Ramasubramanian, 2015). According to Hoyos et al., (2002) as indicated in equation 1, composting is a biochemical process which involves the biological degradation of organic materials, producing organic and inorganic by-products and heat energy.



Composting is an environmental remediation process and aids in closing the natural loop by returning lost nutrients back to the soil. It is a sustainable waste management option. Co-composting manure and other organic resource materials with complementary characteristics have been suggested as an effective way of improving the quality of manure (Opoku, 2011). Sanginga and Woomeer (2009) termed this as fortified composting as it involves the co-composting of inorganic fertilizers, agro-minerals, manures and crop residues to produce a high-quality organic fertilizer. Due to the high nutrient concentrations of oilcakes, Roy et al., (2006) suggested composting of manure with oilcakes as an innovative way of improving its quality. Kolade et al., (2006) and Opoku (2011) also observed positive results by co-composting oilcakes with manure. Other ways by which the value of manure have been improved are co-composting the manure with inorganic fertilizers (Dalzell et al., 1987; Sanginga and Woomeer, 2009; Maheshwari et al., 2014), agro-minerals (Dalzell et al., 1987; Singh and Amberger, 1991; Sanginga and Woomeer, 2009) and crop residues (Mahimairaja et al., 1995; Ewusi-Mensah, 2009; Fening et al., 2010). Some of the nutrient characteristics obtained from several studies as a result of improving the fertilizer value of manure are summarized in Table 2. One notable study to improve the quality of cattle manure was conducted by Essel et al., (2021). From the authors, the addition of palm kernel cake, cocoa pod husk and rock phosphate to cattle manure increased the nitrogen, phosphorus and potassium contents of cattle manure by 73 %, 145 % and 50 %, respectively. The study by Essel et al., (2021) also revealed that such organic material combination to cattle manure also increased maize grain yields.

x. *Effects Of Compost Application on Soil Quality*

There have been numerous definitions of soil quality since Warkentin and Fletcher (1977) introduced the term. However, the most comprehensive definition of soil quality to date was published by the Soil Science Society of America's Ad Hoc Committee on Soil Quality (S-581) as "the capacity of a specific kind of soil to function, within natural or managed ecosystem boundaries, to sustain plant and animal productivity, maintain or enhance water and air quality, and support human health and habitation" (Karlen et al., 1997).

Soil quality indicators are used to evaluate the functional state of soils; however, it is sometimes difficult to quantify (Fuentes et al., 2009). It involves an integration of interpretable qualitative and quantitative soil biological, physical and chemical properties that correlate well with ecosystem processes and are responsive to management and climate (Doran and Parkin, 1996). The use of organic amendments such as organic manures and composts are noted to contribute significant proportion of nutrients to the soil when applied at the proper rate and appropriate time to synchronize with nutrient release and leave a lasting effect on the soil after the year of amendment application. Several authors have reported the ameliorating effects of organic amendments and compost on soil quality (eg. Okalebo et al., 2004; Liza et al., 2014). These have been reviewed in the subsequent sections.

Table 2: Chemical characteristics of some organic resource materials with their resultant compost.

Organic resource/ compost	waste/ waste/	Total N (%)	Total P (%)	Total K (%)	C:N ratio	Reference	
Palm kernel cake (PKC)		2.88	0.60	0.19	33	Kolade et al. (2006)	
Goat manure (GM)		3.62	0.51	0.18	21		
Poultry manure (PM)		2.83	3.29	0.16	28		
PKC + PM (3:1) compost		3.52	0.19	0.28	23		
PKC + GM (3:1) compost		4.63	0.20	0.15	17		
Cattle manure (CM)		0.72	0.26	0.39	28	Ewusi– Mensah(2009)	
(S+MS):CM (1:1) compost		1.46	0.31	1.26	23		
(S+MS): CM (2:1) compost		1.10	0.28	0.68	30		
<i>Chromolaena odorata</i>		2.46	0.42	2.56	15	Quansah et al. (2001); Fening et al. (2005)	
Cattle manure		0.72	0.26	0.39	28		
(CO+S+MS):CM(1:1compost)		1.46	0.31	1.26	23	Fening et al. (2010)	
(CO+S+MS):CM(2:1compost)		1.10	0.28	0.68	30	Fening et al. (2010)	
FYM		2.01	1.87	1.70	ND	Qureshi et al. (2014)	
Pressmud		1.70	2.04	0.80	ND		
Poultry manure		1.87	1.35	2.05	ND		
Green manure		2.05	0.99	2.45	ND		
Rock phosphate		ND	0.13	ND	ND		
Compost		2.50	2.89	1.93	18		
Poultry manure (PM)		2.45	2.05	0.39	5		Kayode et al. (2015)
Neem leaf (NL)		2.16	0.23	2.38	6		
Cocoa pod husk (CPH)		1.49	0.17	3.76	15		
CPH + PM (3: 1 compost)		2.06	0.82	1.28	ND		
CPH + NL (3: 1 compost)		1.99	0.65	1.04	ND		
CPH+PM+NL(3:1:1 compost)		2.33	1.17	1.46	ND		

PKC: Palm kernel cake, S: Stylosanthes guinensis (biomass); MS: Maize stover; CM: Cattle manure; CO: Chromolaena odorata; PM: Poultry manure; GM: Goat manure; NL: Neem leaf; CPH: Cocoa pod husk, ND: Not determined

xi. Physical Soil Properties

Organic amendments usually have significant effects on soil physical properties in the long term. They can positively influence the moisture contents in the top and sub-soil layers (Venugopalan and Tarhalkar, 2003). Similarly, continuous cultivation of crops on the same land results in a reduction of soil organic carbon and soil physical properties (Jat et al., 2015). Also, long-term addition of organic matter to the soil is known to improve soil porosity, while decreasing the bulk density of soils (Maltas et al., 2018). Low soil bulk density is of great importance in agriculture as it creates favourable conditions for the proper growth of crops. Bulk density commonly defined as the mass per unit volume of soil (Chaudhari et al., 2013) is a very important physical soil property. The bulk density of the soil is mostly determined by the management practices and can either cause a hindrance to root penetration or more porous conditions for root growth. According to Landon (2014), there is a very high tendency for bulk density to increase with depth, as the effects of cultivation and organic matter content increase. The ideal bulk density for sandy and sandy

loam soils range between 1.20 and 1.6 Mg/m³, whereas the bulk density of compacted soils exceeds 2 Mg/m³ (Landon, 2014).

xii. Chemical Soil Properties

The application of organic amendments has been reported to have significant impact on soil chemical properties by several authors. Dhull et al., (2004) reported an increase in soil C, N, P and microbial biomass carbon after the application of organic amendments. The application of compost to soils is a means of improving soil fertility and enhancing soil carbon sequestration (Ganunga et al., 1998). It acts as a long-term reserve and a slow-release source of soil nutrients (N, P, K) (Sullivan et al., 2002) while promoting stable soil aggregates with residual fertilizing effects for subsequent crops (Kolade et al., 2006). Organic amendments have the potential of increasing soil organic C, N and P (Venugopalan and Tarhalkar, 2003).

Soil pH is a major determinant of soil nutrient availability. Soils with very acidic pH usually have adverse effects on crop growth as it depresses the activities of beneficial microbes. Soil with low pH also have a low available P content and hence have a high tendency of causing P fixation. The application of composts to soils can increase or decrease soil pH (Crecchio et al., 2001). However, this depends on the pH of the compost applied as well as the initial pH of the soil before planting. The application of organic manures to soil leads to the production of organic anions during decomposition which consequently causes an increase in soil pH due to the removal of associated protons in the soil (Whalen et al., 2000). Fischer and Glaser (2012) reported that the application of organic amendments is expected to improve soil pH, however, in a few cases, a decrement in soil pH was observed after compost application.

Soil organic matter (SOM) is also an important source of nutrient elements, particularly nitrogen. Omotayo and Chukwuka (2009) reported that, the application of organic amendments to soils can lead to increased SOM content over the long term. This is due to the slow formation of SOM (Jat et al., 2015). Comparing the residual nutrients left in the soil after the application of manure to compost, Eghball (2002) reported that composts have a greater potential of sequestering carbon than manures. This was evident in the over 36 % of applied compost being left in the soil after a four-year period as compared to the 25 % of the applied manure remaining after the four years.

xiii. Biological Soil Properties

The effects of organic amendments on biological soil properties are mostly determined by measuring the microbial biomass content of soil (Logah, 2009; Also, 2014). According to Logah (2009), microbial biomass is very instrumental in assessing the degradation of SOM, leading to a consequent release of nutrients for crop growth. Soil microbial biomass is a living component of SOM, serving as a transformative agent for added and native organic matter and acts as a labile reservoir for plant available N, P and S (Jenkinson and Ladd, 1981; Logah, 2009). Its importance as a vital source and sink of plant nutrients makes it one of the main determinants of soil fertility (Logah et al., 2010). Microbial biomass constitutes fungi, bacteria and other microbiota (Goyal et al., 1992) and plays an important function in soil biochemical processes which contributes to soil health and quality improvement (Belay et al., 2002). Although, microbial biomass contributes substantial nutrients in the soil, soil microbial biomass carbon (C_{mic}) constitutes 1 – 3 % of the total soil carbon whereas microbial biomass nitrogen (N_{mic}) constitutes up to 5 % of the total soil N (Jenkinson and Ladd, 1981).

Soil microbial biomass is generally influenced by soil physico-chemical properties (Amaral and Abelho, 2016) as well as variations in soil moisture, temperature, organic matter and nutrient supply (Logah, 2009; Logah et al., 2010). Reports by Shannon et al., (2002) and Logah (2009) indicate that carbon-rich residues, serving as a source of energy for microbial growth under organic amendments results in higher soil microbial biomass carbon as compared to conventionally managed plots. In another research, Logah et al. (2010) observed a higher Cmic in the 2007 major season of a three-season field experiment. The aforementioned authors ascribed the increase in Cmic to the cumulative impact of the amendments and crop residues left on the field after previous seasonal harvests. The residual effect of the residues and amendments contributed to an extra energy source, which caused microbial build-up even in plots where no amendment was applied in subsequent seasons. In a more recent study by Issoufa et al., (2018) in Niger, Cmic increased with increasing rates of compost application, which was attributable to the accumulation of organic matter with its consequent stimulation of the growth of indigenous soil microbiota.

In the case of microbial biomass phosphorus (Pmic), several researches have reported a higher and significant influence of integrated nutrient application on microbial biomass phosphorus compared to sole nutrient application and control treatments with no amendments (Logah et al., 2010; Also, 2014; Issoufa et al., 2018). For instance, Logah et al., (2010) recorded a Pmic range of -39.62 to 120.23 mg P/kg soil) in the 2007 major cropping season of a 3-year field experiment on a Ferric Acrisol in Ghana.

CONCLUSION AND RECOMMENDATION

The review summarized the nutrient composition of common agricultural residues in farmers' fields and their potential to improve the low quality of cattle manure. The review highlighted that, Ghana, like many other countries in Africa, has been facing an escalating soil fertility crisis over decades with predicted losses of 35 kg/ha, 4 kg/ha and 20 kg/ha N, P and K annually. Thus, in order to feed the ever-increasing human population, there is the need to replenish soil fertility. One of the environmentally sustainable ways that was recommended to improve soil fertility, was to explore the use of crop residues for improving the quality of cattle manure. It was observed that most of the agricultural residues produced on-farm are underutilized despite the fact that they have potentially available plant macro and micronutrients. The beneficial effects of manure on soil fertility are well documented, however, among the two most common types of organic manures (poultry manure and cattle manure) used by farmers in Ghana, cattle manure is noted for its relatively low nutrient content. Diverse approaches for enhancing the fertilizer value of manure have been suggested; such as composting with inorganic fertilizers, agro-minerals and crop residues. Since agriculture is known to be the backbone of most developing economies, this review recommends the need to extensively explore the potential of other commonly available organic resource materials for their efficacy to improve the fertilizer value of cattle manure. This will be an environmentally sustainable way of improving soil fertility, increase crop yields and consequently enhance food security.

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CONFLICT OF INTEREST

The authors declare that they have no conflict of interest.

REFERENCES

- Adamtey N (2005) Evaluation of agricultural and agro- industrial residues for composting for agricultural use in Ghana (A case study in the Kwaebibirem District). MPhil Thesis, University of Ghana, Legon. 171 pp.
- Adamu UK, Alimu J, Adam IA, Sani SA (2014) Evaluation of nutrient composition of some cereals and legumes crops residues as compost materials. *Bayero J Pure Appl Sci.*, 7 (2): 52 – 54.
- Adejobi KB, Fameye AO, Akenbi OSO, Adeosun SA, Nduka AB, Adeniyi DO (2013) Potentials of cocoa pod husk ash as fertilizer and liming materials on nutrient uptake and growth performance of cocoa. *RJAEM.*, 2(9): 243 - 251.
- Agbeniyi SO, Oluyole KA, Ogunlade MO (2011) Impact of cocoa pod husk fertilizer on cocoa production in Nigeria. *World J Agric Sci.*, 7 (2): 113-116.
- Akbari KN, Vora VD, Sutaria GS, Hirpara DS, Padmani DR (2010) Enrichment of compost by bio inoculants and natural mineral amendments. *Asian J Soil Sci.*, 5(1): 100-102.
- Akila D, Ramasubramanian V (2015) Studies on the nutrients status from two different wastes by using *Eisenia foetidae*. *Indian J Sci.*, 15(45): 42 - 49.
- Alemawor F, Dzagbebia VP, Oddoye EOK, Oldham JH (2009) Effect of *Pleurotus ostreatus* fermentation on cocoa pod husk composition: Influence of fermentation period and Mn²⁺ supplementation on the fermentation process. *Afr J Biotechnol.*, 8(9):1950-1958.
- Alimon AR (2004) The nutritive value of palm kernel cake for animal feed. *Palm Oil Developments. Malaysian Palm Oil Board*, 40:12 – 14.
- Also MI (2014) Mineral Nitrogen and Microbial Biomass dynamics under millet glume compost application in Semi-Arid Niger. Masters thesis, KNUST. 107pp.
- Amaral F, Abelho M (2016) Effects of agricultural practices on soil and microbial biomass carbon, nitrogen and phosphorus content: a preliminary case study. *Web Ecol.*, 16(1): 3-5.
- Belay A, Claassens A, Wehner FC (2002) Effect of direct nitrogen and potassium and residual phosphorus fertilizers on soil chemical properties, microbial components and maize yield under long-term crop rotation. *Biol Fertil Soils.*, 35(6): 420-427.
- Brady NC (1980) *The Nature and Properties of Soils*. 8th ed. Macmillan publishers Co., Inc. New York. 639 pp.
- Camara O, Heinemann ED (2006) Overview of fertilizer situation in Africa. Background paper prepared for the African Fertilizer Summit. Abuja, Nigeria.
- Chaudhari PR, Ahire DV, Ahire VD, Chkravarty M, Maity S (2013) Soil bulk density as related to soil texture, organic matter content and available total nutrients of Coimbatore soil. *IJSRP.*, 3(2): 1 - 8.
- Chukwuka KS, Omotayo OE (2009) Soil fertility restoration potentials of *Tithonia* green manure and water hyacinth compost on a nutrient depleted soil in South Western Nigeria using *Zea mays* L. as test crop. *Res J Soil Biol.*, 1(1): 20 - 30.
- Crecchio C, Curci M, Mininni R, Ricciuti P, Ruggiero P (2001) Short-term effects of municipal solid waste compost amendments on soil carbon and nitrogen content, some enzyme activities and genetic diversity. *Biol Fertil Soils.*, 34(5): 311 - 318.
- Dalzell HW, Dalzell HE, Biddlestone AJ, Gray KR, Thurai Rajan K (1987) *Soil management: compost production and use in tropical and subtropical environments* (No. 56). Food and Agriculture Org., 186pp.

- Das KD (2005) *Introductory Soil Science*. 4th ed. Kalyani Publishers, New Dehli, India.
- Dhull S, Goyal S, Kapoor K, Mundra M (2004) Microbial biomass carbon and microbial activities of soils receiving chemical fertilizers and organic amendments. *Arch Agron Soil Sci.*, 50(6): 641 - 647. , <https://doi.org/10.1080/08927010400011294>
- Dittoh S, Omotosho O, Belemvire A, Akuriba M, Haider K (2012) Improving the effectiveness, efficiency and sustainability of fertilizer use in sub-Saharan Africa. Briefing paper Number 3, 2012; GDN Agricultural Policy Series.
- Doran JW, Parkin TB (1996) Quantitative indicators of soil quality: a minimum data set. *Methods for assessing soil quality*.
- Eghball B (2002) Soil properties as influenced by phosphorus-and nitrogen-based manure and compost applications. *Agron J*, 94(1): 128 - 135.
- Essel B, Abaidoo RC, Opoku A, Ewusi-Mensah N (2021) Efficacy of selected crop residues and rock phosphate in improving the quality of cattle manure. *Commun Soil Sci Plant Anal* 52 (5): 511 - 521. DOI:10.1080/00103624.2020.1862151.
- Ewusi-Mensah N (2009) Optimizing manure quality for increased food production on smallholder farms in the Upper East Region of Ghana. PhD Thesis, Kwame Nkrumah University of Science and Technology, Kumasi, Ghana. 205pp.
- Fairhurst T (ed.) (2012) *Handbook for integrated soil fertility management*. Africa Soil Health Consortium. 156pp.
- FAO (2005) *Fertilizer use by crop in Ghana*. Land and Plant Nutrition Management Service, Land and Water Development Division, Food and Agriculture Organization of the United Nations, Rome. 39pp.
- Fatondji D, Martius C, Zougmore R, Vlek PL, Biolders CL, Koala S (2009) Decomposition of organic amendment and nutrient release under the zai technique in the Sahel. *Nutr Cycl Agroecosyst.*, 85(3): 225 - 239.
- Fening JO, Adjei-Gyapong T, Yeboah E, Ampontuah EO, Quansah G, Danso SKA (2005) Soil fertility status and potential organic inputs for improving smallholder crop production in the interior savanna zone of Ghana. *J Sustain Agric.*, 25(4): 69 - 92.
- Fening JO, Ewusi-Mensah N, Safo EY (2010) Improving the fertilizer value of cattle manure for sustaining small holder crop production in Ghana. *J Agron.*, 9(3): 92 - 101.
- Fischer D, Glaser B (2012) Synergisms between compost and biochar for sustainable soil amelioration. In *Management of organic waste*. InTech.
- Fuentes M, Govaerts B, De León F, Hidalgo C, Dendooven L, Sayre KD, Etchevers J (2009) Fourteen years of applying zero and conventional tillage, crop rotation and residue management systems and its effect on physical and chemical soil quality. *Europ J Agronomy.*, 30(3): 228 - 237.
- Ganunga R, Yerokun O, Kumwenda JDT (1998) *Tithonia diversifolia*: an organic source of nitrogen and phosphorus for maize in Malawi. In Angstone M (2015) Assessment of smallholder farmers' perceptions and degree of adoption of *Tithonia diversifolia* compost in addressing declining soil fertility in Ming'ongo Extension Planning Areas, Lilongwe, Malawi. *J Soil Sci Environ Manage.*, 6(3):58 - 67.
- Ghana Fertilizer Assessment (2012) IFDC in support of The African Fertilizer and Agribusiness Partnership. 40pp.
- Gondwe B, Nkonde D (2017) Optimizing Fertilizer Use within the Context of Integrated Soil Fertility Management in Zambia. In: *Fertilizer Use Optimization in Sub-Saharan Africa*. Wortmann CS, Sones K (eds) CAB International, Nairobi, Kenya, pp. 210 - 219.
- Goyal S, Mishra MM, Hooda IS, Singh R (1992) Organic matter-microbial biomass relationships in field experiments under tropical conditions: effects of inorganic fertilization and organic amendments. *Soil Biol Biochem.*, 24(11): 1081 - 1084.

- Grant CA, Peterson GA, Campbell CA (2002) Nutrient considerations for diversified cropping systems in the northern Great Plains. *Agron J.*, 94(2): 186 - 198.
- Hamzat RA, Adeola O (2011) Chemical evaluation of co-products of cocoa and kola as livestock feeding stuffs. *J Anim Sci Adv.*, 1(1): 61 - 68
- Hartemink AE (2006) Soil fertility decline: definitions and assessment. *Encyclopedia of Soil Science*, 2: 1618 - 1621.
- Henao J, Baanante C (2006) Agricultural production and soil nutrient mining in Africa: Implications for resource conservation and policy development. 13pp.
- Henao J, Baanante CA (1999) Estimating rates of nutrient depletion in soils of agricultural lands of Africa. Muscle Shoals: International Fertilizer Development Center.
- Hill A (2014) Maize response to fertilizer and fertilizer-use decisions for farmers in Ghana. MSc Thesis, University of Illinois at Urbana Champaign. 91pp.
- Hoyos SG, Juárez JV, Ramonet CA, López JG, Rios AA, Uribe EG (2002) Aerobic thermophilic composting of waste sludge from gelatin-grenetine industry. *Resour Conserv Recyc.l*, 34(3): 161 - 173.
- Issaka RN, Buri MM, Tobita S, Nakamura S, Owusu-Adjei E (2012) Indigenous fertilizing materials to enhance soil productivity in Ghana. In *Soil Fertility Improvement and Integrated Nutrient Management-A Global Perspective*. InTech., pp:119 – 134.
- Issaka YB, Antwi M, Tawia G (2016) A comparative analysis of productivity among organic and non-organic farms in the West Mamprusi District of Ghana. *Agriculture.*, 6(2): 13 – 23.
- Issoufa BB, Ibrahim A, Abaidoo RC, Ewusi-Mensah N (2018) Combined use of millet glume-derived compost and mineral fertilizer enhances soil microbial biomass and pearl millet yields in a low-input millet cropping system in Niger. *Arch Agron Soil Sci.*, 1 - 13.
- Jama B, Palm CA, Buresh RJ, Niang A, Gachengo C, Nziguheba G, Amadalo B (2000) *Tithonia diversifolia* as a green manure for soil fertility improvement in western Kenya: A review. *Agrofor Syst.*, 49: 201 – 221.
- Jat LK, Singh YV, Meena SK, Meena SK, Parihar M, Jatav HS, Meena RK, Meena VS (2015) Does integrated nutrient management enhances agricultural productivity? *J Pure Appl Microbiol.*, 9(2): 1211 - 1221.
- Jayne TS, Kolavalli S, Debrah K, Ariga J, Brunache P, Kabaghe C, Rodriguez WN, Baah KO, Bationo AA, Husing EJ, Lambrecht I (2015) Towards a Sustainable Soil Fertility Strategy in Ghana. Report submitted to the Ministry of Food and Agriculture Government of Ghana, Accra, Ghana. 30pp.
- Jenkinson DS, Ladd JN (1981) Microbial biomass in soil: measurement and turnover. In: Anderson JM, Ingram JSI (eds) (1998) *Tropical Soil Biology and Fertility. A handbook of methods*. Pp: 68 – 70.
- Kannan P, Manikandan K, Ponmani S (2013) Non-edible oilcake: a novel approach for soil health management. 9pp.
- Karlen DL, Mausbach MJ, Doran JW, Cline RG, Harris RF, Schuman GE (1997) Soil quality: a concept, definition, and framework for evaluation (a guest editorial). *Soil Sci Soc Am J.*, 61(1): 4 - 10.
- Kayode CO, Oluwa OA, Adekunle AF, Ogunleti DO, Ezekiel-Adewoyin DT (2015) Nutrient Release Pattern of Cocoa Pod Husk Based Composts in an Incubation Study. *Int J Plant Soil Sci.*, 4(6): 513 – 520.
- Khan MU, Sharif M (2012) Solubility enhancement of phosphorus from rock phosphate through compositing with poultry litter. *Sarhad J Agric.*, 28(3):415 - 420.

- Kimani SK, Lekasi JK (2004) Managing Manures Throughout their Production Cycle Enhances their Usefulness as Fertilisers: A. Managing nutrient cycles to sustain soil fertility in sub-Saharan Africa., 187 – 197.
- Kolade OO, Coker AO, Sridhar MKC, Adeoye GO (2006) Palm kernel waste management through composting and crop production. *J Environ Health Res.*, 5(2): 81 - 86.
- Landon JR (2014) Booker tropical soil manual: a handbook for soil survey and agricultural land evaluation in the tropics and subtropics. Routledge. 530pp.
- Lazcano C, Gómez-Brandón M, Domínguez J (2008) Comparison of the effectiveness of composting and vermicomposting for the biological stabilization of cattle manure. *Chemosphere.*, 72(7): 1013 - 1019.
- Liza MMJ, Islam MR, Jahiruddin M, Hasan MM, Alam MA, Shamsuzzaman SM, Samsuri AW (2014) Residual effects of organic manures with different levels of chemical fertilizers on rice. *Life Sci J.*, 11(12): 6 - 12.
- Logah V (2009) Soil fertility and microbial biomass carbon, nitrogen and phosphorus dynamics under different amendments and cropping systems in Ghana (Doctoral dissertation), KNUST., 200pp.
- Logah V, Safo EY, Quansah C, Danso I (2010) Soil microbial biomass carbon, nitrogen and phosphorus dynamics under different amendments and cropping systems in the semi-deciduous forest zone of Ghana. *West Afr J Appl Ecol.*, 17(1):121 - 133.
- Lukman SA, Audu M, Dikko AU, Ahmed HG, Sauwa MM, Haliru M, Noma SS, Yusif SA, Salisu A, Hayatu NG (2016) Effects of NPK and cow dung on the performance of rice (*Oryza sativa*) in the Sudan Savanna agro-ecological zone of Nigeria. *Asian Res J Agric.*, 1(4): 1 - 9.
- Maheshwari DK (Ed.) (2014) Composting for sustainable agriculture (Vol. 3). Springer. 289pp.
- Maheshwari DK, Dheeman S, Agarwal M (2014) Decomposition of organic materials into high value compost for sustainable crop productivity. In *Composting for Sustainable Agriculture Sustainable Development and Biodiversity 3*, Springer, Cham., pp: 245 - 267.
- Mahimairaja S, Bolan NS, Hedley MJ (1995) Dissolution of phosphate rock during the composting of poultry manure: An incubation experiment. *Fertil Res.*, 40: 93-104.
- Maltas A, Kebli H, Oberholzer HR, Weisskopf P, Sinaj S (2018) The effects of organic and mineral fertilizers on carbon sequestration, soil properties, and crop yields from a long-term field experiment under a Swiss conventional farming system. *Land Degrad Dev.*, 29:926 – 938.
- Mensah-Brako B (2011) Effect of watering regime and cocoa pod husk on soil fertility and growth of hybrid cocoa seedlings in the semi - deciduous forest zone of Ghana. MSc Thesis, Kwame Nkrumah University of Science and Technology, Kumasi, Ghana. 123pp.
- Mohamed WZ, Alimon AR, Wong HK (2012) Utilization of oil palm coproducts as feeds for livestock in Malaysia. Pp: 243-302.
- Morris M, Kelly VA, Kopicki RJ, Byerlee D (2007) Fertilizer use in African agriculture: Lessons learned and good practice guidelines. The World Bank. 162 pp.
- Moyin-Jesu EI (2004) Comparative evaluation of different plant residues on the soil and leaf chemical composition, growth and seed yield of castor bean (*Ricinus communis*). *Pertanika Jour of Trop Agric Sci.*, 27(1):21 - 30.
- Nfor BK, Forton OT, Bemu TA, Verhaert PDEM (n.d.) Valorization of the byproducts of cocoa production – towards a more sustainable cocoa value chain in Cameroon. 5pp.

- Odedina SO, Awodun M, Ojeniyi SO (2007) Effect of cocoa husk on the soil fertility, leaf mineral composition and growth of tomatoes. *Global Jour Environ Studies.*, 26(1):6-12.
- Ofori-Frimpong K, Afrifa AA, Osei-Bonsu K, Appiah MR (2003) Cocoa/coconut intercropping trial in Ghana: Effect of the cropping systems on soil nutrient dynamics. Paper presented at the 14th International Cocoa Research Conference, Accra Ghana.
- Ofosu-Budu KG, Hogarh JN, Adamtey N (2015) Recycling of agricultural and municipal solid wastes in Ghana: challenges, threats and opportunities. In Singh RP, Sarkar A (Eds.) (2015) *Waste management: challenges, threats and opportunities*. Nova Science Publishers Incorporated. 271 pp.
- Ogunrinde S (2006) *Permanent Crops Production (ACP)*. National Open University of Nigeria.
- Okalebo JR, Palm CA, Lekasi JK, Nandwa SM, Othieno CO, Waigwa M, Ndungu KW (2004) Use of organic and inorganic resources to increase maize yields in some Kenyan infertile soils: a five-year experience. *Managing Nutrient Cycles to Sustain Soil Fertility in Sub-Saharan Africa*, Academy of Science Publishers, Nairobi, Kenya. Pp: 359 - 372.
- Omotayo OE, Chukwuka KS (2009) Soil fertility restoration techniques in sub-Saharan Africa using organic resources. *Afr J Agric Res.*, 4(3): 144 - 150.
- Opoku A (2011) Sustainability of crop residues and manure management in smallholder cereal-legume-livestock systems in the Savannas of West Africa (Doctoral dissertation), KNUST. 216 pp.
- Palm CA, Myers RJ, Nandwa SM (1997) Combined use of organic and inorganic nutrient sources for soil fertility maintenance and replenishment. *Replenishing soil fertility in Africa, (replenishingsoi)*, 193 - 217.
- Palm CA, Gachengo CN, Delve RJ, Cadisch G, Giller KE (2001) Organic inputs for soil fertility management: Some rules and tools. *Agric Ecosyst Environ.*, 83: 27 - 42.
- Quansah C, Fening JO, Ampontuah EO, Afreh D, Amin A (2001) Potential of *Chromolaena odorata*, *Panicum maximum* and *Pueraria phaseoloides* as nutrient sources and organic matter amendments for soil fertility maintenance in Ghana. *Biol Agric Hortic: An International Journal for Sustainable Production Systems*, 19(2): 101 - 113.
- Qureshi SA, Rajput A, Memon M, Solangi MA (2014) Nutrient composition of rock phosphate enriched compost from various organic wastes. *J Sci Res.*, 2(3): 47 - 51.
- Rashid M, Khalil S, Ayub N, Alam S, Latif F (2004) Organic acids production and phosphate solubilization by phosphate solubilizing microorganisms (PSM) under in vitro condition. *Pak J Biol Sci.*, 7(2): 187 - 196.
- Reddy MS, Kumar S, Khosla B (2002) Biosolubilization of poorly soluble rock phosphates by *Aspergillus tubingensis* and *Aspergillus niger*. *Biores Technol.*, 84:187 - 189.
- Rhodes ER (1995) Nutrient depletion by food crops in Ghana and soil organic nitrogen management. *Agric Syst.*, 48(1): 101 - 118.
- Roy RN, Finck A, Blair GJ, Tandon HLS (2006) *Plant nutrition for food security. A guide for integrated nutrient management*. Food and Agriculture Organization of the United Nations. *FAO Fertilizer and Plant Nutrition Bulletin No. 16*. ISBN 92-5-105490-8. 368pp.
- Rupani PF, Singh RP, Ibrahim MH, Esa N (2010) Review of current palm oil mill effluent (POME) treatment methods: vermicomposting as a sustainable practice. *World Appl Sci J.*, 10(10): 1190 - 1201.
- Sanchez PA (2002) Soil fertility and hunger in Africa. *Science.*, 295: 2019 – 2020.

- Sanginga N, Woomer PL (Eds.) (2009) Integrated soil fertility management in Africa: principles, practices, and developmental process. CIAT. 270pp.
- Satoshi T, Satoshi N, Monrawee F, Fujio N (2014) Agricultural use of indigenous phosphate rocks in Sub-Saharan Africa. Japan International Research Center for Agricultural Sciences (JIRCAS). Pp 101 - 109.
- Scopus (Elsevier) database. Date Accessed: 30 June 2020.
- Shannon D, Sen AM, Johnson DB (2002) A comparative study of the microbiology of soils managed under organic and conventional regimes. *Soil Use Manag.*, 18: 274 - 283.
- Sharif M, Matiullah K, Tanvir B, Shah AH, Wahid F (2011) Response of fed dung composted with rock phosphate on yield and phosphorus and nitrogen uptake of maize crop. *Afri J Biotechnol.*, 10 (59):12595 - 12601.
- Singh CP, Amberger AA (1991) Solubilization and availability of phosphorus during decomposition of rock phosphate enriched straw and urine. *Biol Agric Hortic.*, 7(3): 261 - 269.
- Singh CP, Mishra MM, Kapoor KK (1982). Mobilization of insoluble phosphates by mesophilic fungi. *Rev Ecol Biol Soil.*, 19: 17 - 25.
- Smil V (1999) Crop residues: agriculture's largest harvest: crop residues incorporate more than half of the world's agricultural phytomass. *Bioscience.*, 49 (4): 299 – 308.
- Snapp SS, Mafongoya PL, Waddington S (1998) Organic matter technologies for integrated nutrient management in smallholder cropping systems of southern Africa. *Agric Ecosyst Environ.*, 71 (1-3): 185 – 200.
- Spaccini R, Piccolo A, Mbagwu JSC, Zena TA, Igwe CA (2002) Influence of addition of organic residues on carbohydrate content and structural stability of some highland soils in Ethiopia. *Soil Use Manage.*, 18:404-411.
- SRID and Veterinary Services Directorate (2015) In: Agriculture in Ghana: Facts and Figures (2015). Issued by Ministry of Food and Agriculture. Statistics, Research and Information Directorate., Pp: 32.
- Sullivan DM, Bary AI, Thomas DR, Fransen SC, Cogger CG (2002) Food waste compost effects on fertilizer nitrogen deficiency, available nitrogen and tall fescue yield. *Soil Sci Soc Am J.*, 66:154 - 161.
- Tetteh FM, Issaka RN, Ennin S, Buri MM (2008) Soil fertility initiative, Fertilizer update and recommendation trials. Soil Research Institute of Ghana. 33pp.
- Tovihoudji PG, Akponikpè PI, Adjogboto A, Djenontin JA, Agbossou EK, Biolders CL (2017) Combining hill-placed manure and mineral fertilizer enhances maize productivity and profitability in northern Benin. *Nutr Cycl Agroecosyst.*, 110(3): 375 - 393.
- Vanlauwe B, Giller KE (2006) Popular myths around soil fertility management in sub-Saharan Africa. *Agric Ecosyst Environ.*, 116(1-2): 34 - 46.
- Venugopalan MV, Tarhalkar PP (2003) Evaluation of organic recycling techniques in improving productivity of rainfed cotton (*Gossypium hirsutum* L.) on marginal soils. *Trop Agric (Trinidad).*, 80(3):163 – 167.
- Warkentin BP, Fletcher HF (1977) Soil quality for intensive agriculture. In Proceedings of the International Seminar on Soil Environment and Fertility Management in Intensive Agriculture.
- Whalen JK, Chang C, Clayton GW, Carefoot J P (2000) Cattle manure amendments can increase the pH of acid soils. *Soil Sci Soc Am J.*, 64(3): 962 - 966.
- Wortmann CS, Sones K (eds) (2017) Fertilizer Use Optimization in Sub-Saharan Africa. CAB International, Nairobi, Kenya. ISBN (e-book): 978 1 78639 205 3. 228pp.

Ayamba et al. (2021). Potential of Organic Resources for Soil Fertility Improvement.
J Biores Manag., 8(3): 89-107

Zin ZZ, Zulkifli H, Tarmizi AM, Hamadan AB, Khalid H, Raja ZRO (2005) Rock phosphate fertilizers recommended for young oil palm planted on inland soils. MPOB information series., ISSN 1511 - 7871.