Properties and functions of organic materials in poor agricultural soil condition

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ABSTRACT

A field experiment was conducted under different soil strata in poor agricultural soil condition. Each soil stratum was treated separately with different organic material for soil fertility management. These organic materials are cow dung, sheep dung, goat dung, donkey dung, rice husks, millet husks, *Acacia albida*, *Acacia nilotica*, wood ash, house refuses, and combination of all 'ani-cro-ber'. In the first assessment, soil structure, texture, colour, consistency, bulk density were determined in the field, while in the second assessment N, P, K, Na, Ca, OC, OM and pH were determined under specific laboratory analysis. It is believed that the use of organic materials in soil management is a good way to improve and maintain soil quality and soil fertility rehabilitation in poor agricultural soil condition.

INTRODUCTION

One of the key goal of sound soil management is to create a healthy soil environment which may retain balance nutrient status (Omotayo and Chukwuka, 2009) by protecting the surface soil cover from unacceptable changes such that its fertility will maintained over time. Generally speaking, little information on properties and functions of most used organic materials for soil quality management in areas such as the Sudan Savannah (SS) of Kebbi State, Nigeria can be found up to the writing of this work. While organic materials protect soil against runoff, mass movement of fine soil particles and surface soil damages. Organic materials are the storehouse of all essential soil and plant nutrient in soil and they are important components of soil fertility, which are associated with a variety of other important soil physical, chemical and biological characteristics (McDonald, 2010). Therefore, to improve the standard balance of the morphological and genetic properties of the deteriorated agricultural surface and subsurface soils in the SS, it is necessary to be able to address and understand the properties and functions of organic material in single and in combination under poor agricultural soil conditions in the SS. However, in the process of addressing and understanding the properties and role of organic materials in soil, the complete management exercise was undertaken according to four principal stages. However, the main objective of this study was assessment of physical, chemical, physico-chemical properties and functions of organic material under soil quality and soil fertility management in the SS. The study would profitably lead to more sustainable and permanent soil management, soil quality and soil fertility rehabilitations for high crop yield in agriculture.

MATERIAL AND MEHOD

Integrated soil management exercise (ISME)

Integrated soil management exercise (ISME) was carried out in the dryland area of the SS. The study site, is 5 km away from the town city of Argungu located within latitude 12°44'24"N and longitude 4°31'12"E. The common agricultural activity is mono-cropping. The land is aridic and hot (30–45^{o}C). The topography of the site is flat (visible at 1–10 m), blonged to soil group Aridisols according to FAO classification system (FAO, 2006). The surface soil of the site is physically characterised by sheet erosion appeared to be poor soil textural quality by visual soil assessment in the field. Generally the ISME carried out in the study site has four principal stages as described below.

First principal stage: Physical and physico-chemical assessment

At the beginning of this exercise, 11 samples of different organic materials were collected using tile spade shovel (animal, wood and house refuse sources) and by hand picking (crop and leaf source). All the samples were stalked separately in a clean experimental plastic rubber (Figure 1). The collection of these samples was partly made from house-hold cattle reared sites (animal source) and partly from cropping and forest-vegetation areas (crop and leaf sources). Experimentally, 500 ml of water was added to each sample after one day of collection and 1.1 kg of each was used to determine the physical and physico-chemical properties. In addition, 0.1 kg from each of the 11 samples were bulked together to have a unique representative sample (ani-cro-ber). The assessment was completed in a 3 week period 25/12/2010 to 01/01/2011 (1^{st} week), 02/01/2011 to 09/01/2011 (2^{nd} week), and 16/01/2011 to 24/01/2011 (3^{rd} week). The guidelines in USDA-NRCS (2002) were used as a complete guide under this assessment.

Figure 1: Different sources of organic materials used under first assessments: (a) cow dung, (b) donkey dung, (c) sheep dung, (d) goat dung, (e) millet husk, (f) ani-cro-ber, (g) rice husk, (h) *Acacia nilotica*, (i) *Acacia albida*, (j) wood ash, (k) house refuse and (l) wood husk

Second principal stage: Chemical analyses

All the samples were chemically analysed at Soil Research Institute, Kumasi, Ghana according to the general procedures described by Nelson and Sommers (1982) and that of Bray and Kurtz (1945) for the determination of total organic carbon, organic matter, nitrogen and exchangeable bases.

Third principal stage: Experimental field soil quality management test

A stratified random sampling was used in this experiment (Upton, 1987). The field site was divided into a number of strata (groups), each stratum consists of the same soil and climate conditions, the same agricultural and management activities under dryland farming system. Twelve different soil strata were designed and each has five representative soil units. These strata were provided with specific field codes as: S-cow01, S-sheep02, S-goat03, S-donkey04, S-rice-husk05, S-millet-husk06, S-albida07, S-nilotica08, S-wood-ash09, S-wood-husk10, S-house-refuse11, and S-ani-cro-ber12. However, all the strata were treated separately with different organic sample under soil quality management exercises (SQME). Soil holes were dug (40 cm length x 30 cm depth) in each soil unit. Organic samples were supplied to these holes and about 1000 ml of water was poured twice every day (morning and evening) for one week. This is to enhance the proper decomposition of organic materials in soil. The experiment lasted for a period of three weeks consecutively. After the three weeks, soil physical properties (texture, structure, colour, consistency and bulk density) were examined. Finally, a random soil sample within each stratum was collected for chemical analyses. Similarly, nitrogen, phosphorus, potassium, calcium, and magnesium were analysed.

Fourth principal stage: statistical analysis of the chemical data

Cluster analysis was primarily used to classify and group the chemical components of different organic materials as well as different soil strata 'individually' treated with the same organic materials. The purpose of using this analysis was to determine the number of groups under the different organic materials, which are best combination for soil management exercise under poor soil condition in the SS. Addinsoft (2012) version 14.3.1.0 statistical software package, was used.

RESULTS

The results of the assessment of the properties and functions of 12 different organic materials in soil are presented in Tables 1, 2, 3, 4 and 5.

Table 1: Physical properties of twelve different organic materials after one week of test

Organic material	**Colour**		**Consistency**	**Structure**	**Texture**
	Sample	**Water**			
Cow	Black	Dark	Soft-hard	Blocky (plate)	Cemetery
Sheep	Black	Ashy-black	Slight-hard	Sub-angular	Gravely
Goat	Dark	Darker	Slight-hard	Sub-angular	Gravely
Donkey	Black	Urea-dark	Soft	Blocky (round)	Cemented
Rice husks	Dark brown	Light-ash	Loose	Single-grain	Fine-husks
Millet husks	Light	Yellowish	Loose	Granular	Coarser
Acacia albida	Light brown	Light-grey	Loose	Massive-leafy	Fine-leafy
Acacia nilotica	Green	Light-green	Loose	Massive-leafy	Fine-leafy
Wood ash	Light grey	Lighter	Flowery	Massive	Ashy
Wood husk	Dark pink	Dark-pink	Loose	Granular	Woody
House refuse	Black-dark	Blacker	Clotted	Decomposed	Clay-loam
Ani-cro-ber	Dark-black	Darker	Hard	Granular	Cemented

Table 1 shows the physical properties of 12 organic samples under physical assessment. The result shows that, the animal dung samples: cow, donkey, goat and sheep have common physical properties. The colours appearance of these 4 animal samples are black and dark, the structures are blocky and sub-angular, the textures are cemented and gravely and consistencies are soft and slightly hard. Similarly, it appeared that the house refuse and ani-cro-ber samples have the same physical properties, characterised by dark and black colour, clotted and hard consistency, decomposed and granular structure as well as cement textural nature. Leaf samples are types of organic materials, which show some similarities in term of texture (fine), consistency (loose) and colour (light green), but differed significantly in term of structure: *A. nilotica* has massive structure whereas *A. albida* has single-grain. For millet husk, texture is coarser, structure is granular, consistency is loose and colour is yellowish. However, wood ash and wood husk are two types of organic wood materials but differed significantly. Wood ash is characterised by light-grey colour, loose consistency, massive structure and texture is ashy whereas wood husk is characterised by dark-pink colour, loose consistency and granular and woody structure and texture respectively. A preliminary chemical analysis of these 12 organic samples is given in Table 2.

Table 2 indicates that the nitrogen content for all the animal dungs is above 2%, however, a reasonable variation was observed in term of phosphorus, potassium, calcium, and magnesium. Ani-cro-ber has the highest nitrogen content (3.07%) and wood-husk has very low content (0.98%). There is high potassium content in A. nilotica (2.01%), A. albida (1.87%) and ani-cro-ber (1.82%). With the exception of ani-cro-ber (1.04%), all the organic materials have low phosphorus contain (below 1%). Calcium is high in ani-cro-ber (17.9%), wood ash (17.6%), and wood husk (16.3%); but very low in sheep dung (0.13%), cow dung (0.16%), millet husk (0.20%), goat dung (0.21%), and donkey dung (0.29%). Also, calcium is high in ani-cro-ber (5.39%), wood husk (4.11%), wood-ash (3.23%), and millet husk (2.88%).

Table 2: Chemical properties of twelve different organic material samples

Sample Name	%Nitrogen	%Phosphorus	%Potassium	%Calcium	%Magnesium
Cow	2.06	0.42	0.29	0.16	0.38
Sheep	2.92	0.68	0.41	0.13	0.68
Goat	2.56	0.70	0.38	0.21	0.63
Donkey	2.06	0.23	0.34	0.29	0.32
Rice husk	1.87	0.56	1.03	2.11	0.55
Millet husk	1.72	0.66	0.54	0.20	2.88
Acacia albida	1.19	0.37	1.87	1.02	0.91
Acacia nilotica	1.08	0.60	2.01	1.11	1.89
Wood ash	1.34	0.73	1.19	17.6	3.23
Wood husk	0.98	0.81	1.27	16.3	4.11
House refuse	2.21	0.48	0.11	1.60	0.57
Ani-cro-ber	3.07	1.04	1.82	17.9	5.39

In addition, the result of physico-chemical assessment related to soil quality and soil fertility functions is given in Table 3. It appeared that some of these organic materials have gaseous and sulphurous compounds and some does not have. These gaseous and sulphurous compounds are found presence in all animal samples, ani-cro-ber and house-refuse. However, high reactions in term of these physic-chemical properties were noted strongly in cow dung, donkey dung and ani-cro-ber, but the reaction is very low in sheep and goat dung.

Table 3: Physico-chemical properties of twelve organic materials after three weeks of test

Organic materials	**Colour**		**Gaseous compound**	**Sulphurous compound**
	Sample	**Water**		
Cow	Dark-black	Darker-creamy	High bubble of O_2	H_2S
Sheep	Dark-black	Black	Low bubble of O_2	H_2S
Goat	Dark-black	Black	-	H_2S
Donkey	Dark-black	Dark-black	High bubble of O_2	H_2S
Rice husks	Dark-brown	Brown	-	-
Millet husks	Light-black	Light-black	Bubble of O_2	-
Acacia albida	Black-grey	Grey-brown	-	-
Acacia nilotica	Dark-green	Army-green	-	-
Wood ash	Lighter	-	-	-
Wood husk	Dark-brown	-	-	H_2S
House refused	Dark-black	-	Bubble of O_2	-
Ani-cro-ber	Darker, blacker	-	Bubble of O_2	H_2S

In contrast, differences were observed after all the 12 samples were tested in soil for soil quality and soil fertility functions. The results of this test are given in Table 4 and 5.

Table 4: Physical properties of different soil holes after three weeks of soil-field-test

Soil strata	Texture (%)				Structure	Colour	Consistency	Bulk d
	Sand	Silt	Clay	OM			(Dry class)	(g/cm)
S-cow01	57	18	10	15	Angular	Dark	Hard	1.61
S-sheep02	59	17	10	14	Sub-angular	Black	Slight-hard	1.59
S-goat03	58	18	10	14	Sub-angular	Black	Slight-hard	1.60
S-donkey04	56	18	10	15	Prismatic	Dark	Mod-hard	1.60
S-rice-husk05	60	17	10	13	Granular	Brown	Friable	1.46
S-millet-husk06	59	18	10	13	Single-grain	Brown	Very-friable	1.46
S-albida07	60	17	10	13	Granular	Grey	Rigid	1.47
S-nilotica08	61	17	10	12	Granular	Green	Rigid	1.46
S-wood-ash09	62	17	10	11	Platy	Lighter	Loose	1.48
S-wood-husk10	66	18	09	09	Single-grain	Brown	Gravely	1.43
S-house-refuse11	56	19	10	15	Columnar	Dark	Very-hard	1.62
S-ani-cro-ber12	54	19	09	18	Prismatic	Darker	Harder	1.64

Table 4 shows the physical properties of 12 organic samples in soil under soil quality management exercises. The percentages of textural classes: sand, silt, clay and organic matter are presented accordingly. Angular, sub-angular, prismatic, granular, single grain, platy, and columnar are deferent types of soil structure observed under different soil strata. The consistencies are hard for stratum 01, slightly hard for strata 02 and 03, moderately hard for stratum 04, friable and very-friable for strata 05 and 06 as well as rigid for strata 07 and 08. Wood ash and wood husk are two organic materials characterised by loose and gravely consistencies under strata 09 and 10. Strata 11 and 12 have same consistency, colour, and bulk density (1.60–1.65 g/cm). Also, strata 05, 06, 07, 08, 09 and 10 have bulk density between 1.40 to 1.50 g/m. The dark, black and darker are soil colours under strata 01, 02, 03, 04, 11 and 12. Strata 05, 06 and 10 are attributed to brown soil colour appearance whereas strata 07, 08 and 09 are attributed to grey, green and lighter colours respectively. The chemical analysis of these 12 different soil strata is given in Table 5. Soil strata 12, 11 and 01 have high organic matter nitrogen content by ranks than soil strata 05, 06, 02, 04, 08, 03, 09 and 10 accordingly. However, the total exchangeable base saturation is high in soil strata 12, 10, 09, 07 and 06 than in soil strata 05, 03, 01, 04, 02 and 11 accordingly.

Table 5: Chemical properties of 12 different soil holes after 3 weeks of test

Soil strata	% OC	% OM	%N	Ava. P	Ava. K	Ex. Ca	Ex. Mg	Ex. K	Ex. Na	pH	TEB
S–01	1.72	1.93	0.16	38.1	128.3	4.73	2.55	1.56	1.01	6.1	9.85
S–02	1.01	1.22	0.15	33.9	140.6	6.55	1.11	1.04	0.99	6.5	9.69
S–03	1.07	1.07	0.11	26.2	153.9	3.99	4.20	1.09	0.82	7.2	10.1
S–04	1.00	1.16	0.21	15.7	126.6	5.31	2.12	1.63	0.79	5.5	9.85
S–05	1.98	1.50	0.09	19.5	147.4	6.74	2.83	1.23	1.00	5.8	11.8
S–06	2.04	1.23	0.10	41.3	171.5	6.77	3.11	1.43	0.89	5.8	12.2
S–07	1.05	1.08	0.10	38.6	182.8	7.34	3.85	2.01	1.00	5.1	14.2
S–08	1.00	1.11	0.09	47.2	182.1	5.86	4.00	2.01	0.93	4.9	12.8
S–09	1.58	1.00	0.08	50.4	197.7	9.71	4.41	3.79	0.69	5.2	18.6
S–10	2.11	0.82	0.04	50.8	179.5	8.33	6.11	4.01	1.05	4.4	19.5
S–11	1.83	2.01	0.20	36.7	138.0	4.99	2.06	1.09	0.97	7.0	9.11
S–12	1.70	2.08	0.58	41.4	164.9	6.62	5.21	3.51	0.86	6.5	16.2

Also, a preliminary cluster analysis of all the organic samples given in Table 5 has provided a better understanding of the close relationship of each individual organic material with another in term of their chemical composition as shown in dendrogram (Figure 2). This analysis has grouped the available chemical data of twelve different organic materials into three clusters – 1, 2 and 3. This grouping of the organic materials into three cluster-codes was performed according to the order of their chemical content of individual compound tested as presented in Table 5. The cow-dung, sheep-dung, goat-dung, donky-dung, rice-husk and house-refuse are grouped under class 1, whereas millet-husk, *Acacia albida* and *Acacia nilotica* are grouped under class 2 while wood-ash, wood-husk and ani-cro-ba are grouped under class 3 (Figure 2). This grouping has further suggested that all the organic materials under each respective class have the same chemical characteristics and are likely to have the same function under soil management point of view. On the other hand, a representative of organic material (e.g. cluster-code 1) from each group can be used in combination with another organic material from other group (e.g. cluster-code 3) as a formulation under best sustainable management practice for high crop yield.

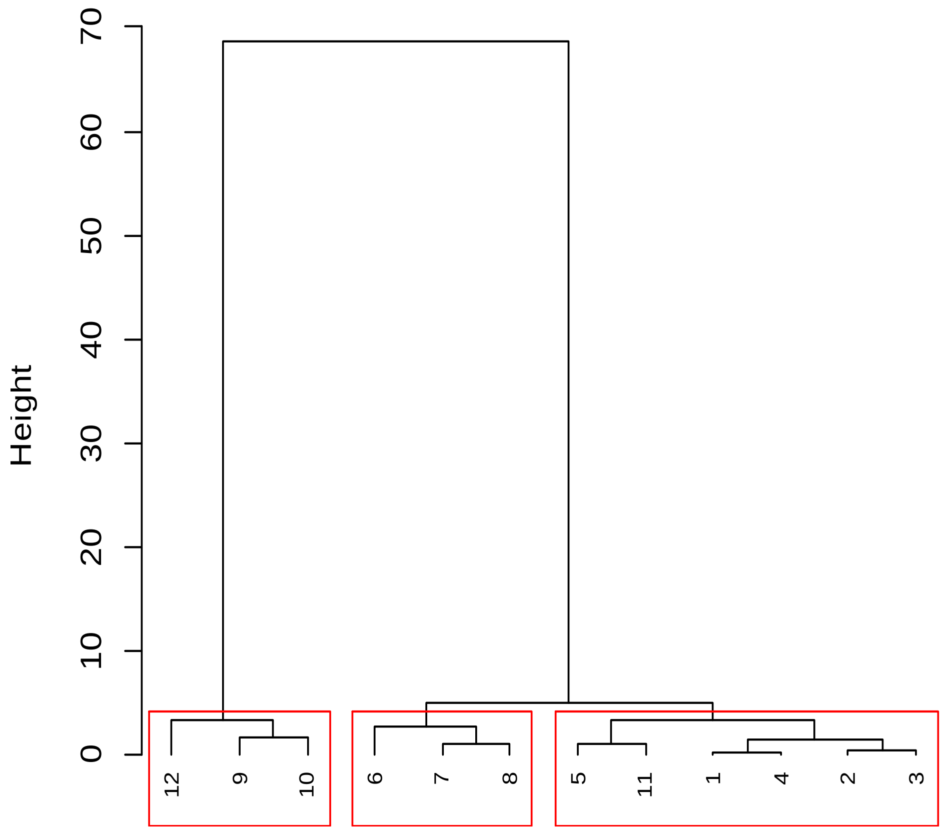

Figure 2: Cluster dendrogram of the organic material samples tested

DISCUSSION

The physical, chemical and physico-chemical properties of different organic materials were separately assessed (Tables: 1, 2 and 3). These organic materials were tested under soil quality and soil fertility management in the field (Tables: 4, 5). Physically, important soil particles transformation has been exist between soils texture, structure, consistency and colour under soil quality development whereas chemically, significant amount of essential nutrients were transferred into the soil for soil fertility function. This transformation of the physical and chemical properties over different organic materials has provided a healthy and functional soil condition for proper plant growth as (Basu *et al.*, 2007; Uzoma *et al.*, 2011). Increased addition of organic materials under soil fertility management, has led to increased nutrient concentration and transformation into soil solution (Powlson *et al.*, 2011). This increased nutrient concentration is caused by addition of the organic materials into the soil (Muriwira *et al.*, 2001) and depends entirely on the amount of chemical content in each individual material (Powlson *et al.*, 2011). The concentration of percentages organic matter and nitrogen and total exchangeable base saturation were 0.85 to 2.08%, 0.04 to 0.58% and 9.11 to 16.2 whereas the available phosphorus and potassium are 15.7 to 50.8 and 126.6 to 182.8 for all the soil strata respectively.

Although, the interpretation of this chemical data for soil fertility has been described as complex due to factors such as soil condition, spatial and temporal boundaries of the study, the type of data itself and how they have been analysed (Hartemink, 2006). However, taking into consideration the physical and biophysical relationships, which have been exist between organic materials, the soil of the study site and its properties (Tables 4, 5), the fertility of soil can be described according to the concentration of organic matter and movement of nitrogen, phosphorus, potassium and total base saturation in soil strata (Basu *et al.*, 2007; Caires *et al.*, 2011). This movement of chemical compounds in different soil strata are described in two stages of soil organic matter decomposition: mineralization and humification (FAO, 2005). The nature of these two stages of decomposition has made the added organic materials in each soil stratum actively to transform the soil colour, soil structure, soil texture, soil consistency and soil chemical concentration (Tables 4, 5). This has provided resilience against soil pH changes, improved soil organic matter as well as increased soil nutrient content (Pramanik *et al.*, 2010). For example, the instant decomposition was noted for soil strata 01, 04 and 12 throughout the experimental period. One of the probable reasons for the quick decomposition in these soil strata is the high concentration of proto-chemical, sulphurous and gaseous compounds in organic materials used (Table 3). Ideally, these organic chemical compounds are important in mineralisation and humification processes of soil organic matter decomposition (FAO, 2005).

In mineralization process, organic materials undergoes biochemical breakdown by either soil temperature or soil organisms (Brady, 1990). Physically, this biochemical breakdown has transformed the soil into good soil textural quality class. While in humification process, the different size simple massive organic materials completely become part of soil body by rearranging the soil particles into angular, sub-angular, granular, prismatic and clothed simple grain structural particles (Table 4). This rearrangement of soil particles into different types of soil structure as a result of humification process was directly related to the function of polysaccharides (decomposed organic materials) to the presence of functional groups, which become negatively charged and interact with positively charged oxides, producing stable soil organic and inorganic micro (massive, simple grain, granular) and macro (angular, prismatic) soil structures (Oades, 1984; Oades *et al.*, 1989). In addition, one of the characteristics of mineralization and humification processes observed under each soil strata is the effect of the added organic materials on soil bulk density. The breakdown of un-decomposed organic materials into decomposed ones account for the bulk density variations under soil quality rehabilitation (Table 5). Generally, in soil medium the weakly decomposed organic materials are characterised by a lower bulk density than strongly decomposed organic materials (FAO, 2005). Thus, the low bulk density values recorded under the different soil strata could be related to weak decomposition while high values to strong decomposition (Table 5).

Similarly, individual soil texture (sand, silt, clay) tends to improves as decomposition of organic materials increased in soil strata (Table 4). This improvement of soil texture is likely associated with textural properties of different organic materials such as cement, gravely, coarser and fine (Table 1). Interestingly, the percentages organic matter and clay content were increased as opposed to most of the textural classes and organic matter content observed under similar soils in the SS. This improvement of percentages organic matter and clay content were reported as one of the major indications of soil quality and soil health development (Usman, 2012). Also, colour is another important property of organic materials assessed (Table 3). Most of the organic materials are characteristically black and darker while some are grey to light-green. These various colours have reflected the properties of soil by transforming the surface soil into more fertile appearance, a condition related to soil ability to attract and accommodate varieties of soil organisms for wide range of soil biodiversity (FAO, 2005).

It is therefore assumed that the transformation observed in the aspect of soil physical properties was due to added organic materials in soil. Because as organic materials slowly decomposed in soil, they colour the surface soil, maintain the soil strength, increase soil resilience (ability of soil to return to its initial state after disturbances), soil aggregation and aggregate stability (Tisdall and Oades, 1982; Wiesmeier *et al.*, 2012), thereby transforming soil texture into stable, suitable and good textural quality classes for wide range of crop production. Physically, the high aggregate stability and surface soil colour quality are high under the soil strata 01, 02, 03, 04 and 12 than in soil strata 05, 06, 07, 08, 09, 10 and 11. The organic materials which have transformed the soil strata characterised by high aggregate stability and surface colour quality concentrations were considered as the major building components of soil quality and soil function in agriculture (Kay and Angers, 1999; Viaud *et al.,* 2011).

Although, the general interpretation of soil quality under poor soil condition is sometime complex due to deep uptake of the fully decomposed materials particularly when exceeded the depth (15–60 cm) of plant root (Hartemink, 2006), however, following the guidelines and definitions of soil quality provided by Lal (1997), the physical properties observed under the different soil strata in the SS could be consider as important components of soil quality development, surface soil protection against erosion impact, particles mass movement and overall actual decreased in potential surface and subsurface soil productivity as noted in previous chapters.

CONCLUSION

The physical, chemical and physico-chemical properties of different organic materials were separately assessed and analysed. These different organic materials were used under soil quality and soil fertility rehabilitation. Data presented indicated that each individual organic material have unique physical, chemical and physico-chemical properties. Characteristically, all the organic materials contained proto-chemical, sulphurous, and gaseous compounds as well as nitrogen, phosphorus, potassium, calcium and magnesium. These properties have reflected various processes and interactions of physical, chemical and biophysical properties of soil under soil quality and soil fertility rehabilitations. The compounds have also interacted with each other in soil and their interaction improved soil texture, soil structure, soil consistency, soil colour and soil organic matter. Although, further assessments are still needed under each individual organic material, however, it is possible that the outcome of this study will help in the understanding the physical and chemical aspect of organic materials under soil quality and soil fertility management practices in agriculture. The use of organic materials in soil management will be a good way to improve and maintain soil quality and soil fertility rehabilitation under agricultural production.

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