International Journal of Plant & Soil Science
9(2): 1-7, 2016; Article no.IJPSS.19691
ISSN: 2320-7035

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Evaluation of Soil Aggregate Stability under Long Term Land Management System

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Authors' contributions

This work was carried out in collaboration between all authors. All authors read and approved the final manuscript.

Article Information

DOI: 10.9734/IJPSS/2016/19691
Editor(s):
(1) L.S. Ayeni, Adeyemi College of Education, Ondo State, Nigeria.
(2) Junhong Bai, School of Environment, Beijing Normal University, Beijing, China.
Reviewers:
(1) Bassey Udom, University of Port Harcourt, Nigeria.
(2) Anonymous, South Dakota State University, USA.
(3) Yi Zhang, Tsinghua University, China.
(4) Nyatuame Mexoese, Ho Polytechnic, Ho, Ghana.
Complete Peer review History: http://sciencedomain.org/review-history/11964

Original Research Article

Received 23rd June 2015
Accepted 2nd October 2015
Published 24th October 2015

ABSTRACT

The influence of land management on soil structural stability of National Animal Production Research Institute (NAPRI) farm Shika Zaria in Northern ecological zone of Nigeria was studied. Soil samples were collected from depth of 0-15 cm in fields under three perennial pasture fields not subjected to tillage for over 20 years since establishment using an adjacent continuously cultivated field as reference which has also been under cultivation for over 20 years. The long-term field experiment had four treatments: Three perennial pasture Digit grass "*Digitaria smutsii''*, Signal grass *"Bracheria decumbens''*, Gamba grass *"Andropogon gayanus''* fields and a continuously cultivated field with 12 samples collected from each plot. The highest dry aggregate stability means 47.40, 42.20, and 38.60 were observed under the perennial grasses land management in the 2-5mm aggregate class. The highest water stable aggregate stability means was also observed under the three perennial pastures following the same trend B.D>A.G>D.S 36.02, 35.18, and 33.68 as observed dry aggregate stability mean values in the 2-5 mm aggregate class range. The land management system under the *Bracheria decumbens* has 2.07, 0.99 as the highest values for dry mean weight diameter, wet geometric mean diameter, while 0.57 and 1.00 were respectively

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observed as the highest value for wet mean weight diameter and dry geometric mean diameter under the *Digitaria smutsii* land management system. Fields under the pasture grasses are higher in organic matter and total nitrogen. The highest C/N ratio value of 1:7.9 was also observed under the pasture grasses fields. The data obtained from the experiment showed that land management under pasture grasses increases the organic matter content, total nitrogen content and consequently increases the structural stability of the soil on long-term basis.

Keywords: Soil; land; mean weight diameter.

1. INTRODUCTION

Land use and management practices often have significant effects on soil properties, especially on soil organic carbon (SOC) dynamics, aggregation and aggregate stability, which are important indicators of soil physical quality [1]. Erodibility as a dynamic property of a soil depends on the stability of soil aggregates and the percentage of coarse primary particles that are resistant to erosion. The formation and maintenance of stable aggregates is the essential feature of the soil tilth, a qualitative term used to describe highly desirable physical condition in which soil is optimally loose, friable and contains a porous assemblage of stable aggregates. This in turn permits free percolation of water and air, enhance the ease of cultivation as well as germination, and emergence of seedlings and growth of roots through the soil pores.

Evaluating the impact of agricultural practices on agroecosystems functions is essential to determine the sustainability of management systems [2], which cover the productivity, economic, social, and environmental components of land use systems [3]. However, decision making for sustainable land management could be improved by tools that provide integration and synthesis of soil research results, management priorities, and environmental concerns [4].

Soil quality is considered a key element used to evaluate sustainable land management in agroecosystems [5] through identification of soil quality indicators [6]. Soil quality, encompasses both soil's productive and environmental capabilities [7], has two parts: An intrinsic part covering a soil's inherent-capacity for crop growth and a dynamic part influenced by the soil management. Soil structure is a crucial soil physical property used to infer soil quality [8]. The degradation of soil structure should be balanced and or exceeded by regeneration in order to have a sustainable soil management [9]. Conservation agriculture (CA), defined as minimal soil disturbance and permanent soil cover (live mulch) combined with crop rotations, was found to be more sustainable cultivation system for the future than those conventionally practiced cultivation system, because conservation agriculture can recover soil functioning through improving water infiltration, reducing erosion, increasing soil organic matter content, and improving soil surface aggregates [10].

Rapid population growth in Nigeria requires additional farmlands for food production. One way to expand the cropland is by cutting down the forests and converting pasturelands to the croplands. This results in destruction of natural ecosystems and reduction of the current or future capacity of soil productivity. In Nigeria, land use change is one of the major factors causing soil degradation [11]. The problem is further aggravated by the intensive cultivation on fragile soil types, which are characterized by low activity clay, low organic matter, low water holding capacity, weak aggregation, high bulk density and poor buffering capacity [12]. Adoption of any management practice that would improve the quality of such soils is imperative in guaranteeing good environmental conditions and high productivity.

2. MATERIALS AND METHODS

2.1 Soil Sampling

The study area is located in National Animal Production Research Institute (NAPRI) farm at Shika Zaria (Latitude 11°00'S and 11°12'N and Longitude 007°33'E) in the Northern Guinea Savanna ecological zone of Nigeria. The mean annual rainfall of the area is 1150 mm usually from May to September ending and a mean daily temperature of 24°C.

Four land use system closely located to each other were selected for this study. The first three were cropped with three different species of perennial grasses namely: Digit grass "*Digitaria smutsii* (DS)'', Signal grass "*Bracheria decumbens* (BD)'', and Gamba grass "*Andropogon gayanus* (AG)'' without tillage (No-tillage) for over fifty years, while the fourth land use system was continuously cultivated (CC) land cropped with maize and cowpea as sole or combined for 20 years. Twelve auger soil samples were collected from each of the four plots at the depth 0-15 cm. The samples were air-dried and prepared for analyses. Water stable aggregate fractions, dry aggregate size fractions, total organic carbon, and total nitrogen were determined using standard methods. Number Cruncher Statistical System "NCSS'' computer package was used to analyze the data and the means were compared using Tukey-Kramer Multiple-Comparison Test. Significance differences were reported for 5% probability level.

2.2 Laboratory Analysis

2.2.1 Dry sieving

Dry aggregate size distribution was determined after air drying by mechanical sieving into different size fractions as described by [13]. The same number and size of sieves (2 mm, 1 mm, 0.5 mm, 0.25 mm, 0.05 and <0.05 mm) were used throughout. The weight of aggregate sizes collected from each sieve size were taken and recorded.

2.2.2 Wet sieving

The wet sieving method of Kemper and Rosenau [14] with a set of sieves of 2, 1, 0.5, 0.25, 0.05 and <0.05 mm diameter was used. The mean weight diameterboth of wet and dry sieved samples was calculated by the relationship:

$$MWD = \sum_{i=1}^{n} \bar{X}_i W_i$$

MWD = Mean weight diameter (mm)

W_i = Proportion of each size class with respect to the total sample

$\bar{X}_i$ = Mean diameter of the class

2.3 Total Organic Carbon

The soil organic carbon was determined by the Walkley-Black wet oxidation method.

2.4 Total Nitrogen

Total nitrogen was analyzed by micro Kjeldahl digestion method [15].

3. RESULTS AND DISCUSSION

3.1 Aggregate Size Distribution

The distribution of dry aggregate size class under various land management systems. The dry aggregate size obtained in the 2-5 mm, 1-2 mm and 0.5-1 mm aggregate class range are significantly higher under the three pasture grasses compared with the values obtained under continuous cultivation. This may be attributed to the high root biomass, high microbial activities, and high organic carbon content in the soil under the perennial grasses. On the other hand the values obtained for the 0.25-0.5, 0.05-0.25 and < 0.05 mm aggregate size classes are significantly higher under continuous cultivation compared to the values obtained under the three perennial grasses except that CC and BD maintained statistical par on <0.05 mm-sized aggregate. This may be attributed to the collapse of larger aggregates into smaller sized aggregate caused by continuous conventional tillage [16-18] which results from low root biomass, reduced microbial activities, and low organic carbon content in the soil. Franzluebber and Arshad [19] found that macroaggregates (> 0.25 mm) and mean weight diameter were greater under zero tillage (harrowing following harvest) than under conventional tillage (one fall tillage with a cultivator followed by two cultivation in the spring prior to seeding) in coarse-textures soils.

3.2 Water Stable Aggregates

The distribution of water stable aggregate size class under various land management system. The proportion of 2 mm-5 mm, 1 mm-2 mm and 0.5 mm-1 mm water stable aggregate (WSA) size classes were significantly higher under the three pasture grasses compared with the values obtained under continuous cultivation. This also may be attributed to the high root biomass, high microbial activities, and high organic carbon content in the soil under the perennial grasses. On the other hand the values obtained for the 0.25 mm-0.5 mm, 0.05 mm-0.25 mm and < 0.05 mm aggregate classes are significantly higher under continuous cultivation compared to the values obtained under the three perennial grasses land management. This is attributed to the reduction in the size of soil aggregate formed under continuous cultivation which results from low root biomass, reduced microbial activities, and low organic carbon content in the soil.

More pronounced negative effects of continuous cultivation are found in macro-aggregate size classes (>0.25 mm). Tisdall and Oades [20] and Gupta and Germida [21] stated that fungal biomass is a key factor in the formation of macroaggregates and emphasized the sensitivity of macro-aggregate size classes and their nutrient and microbial content (1.00 to 0.25 mm) to long term cultivation, while micro-aggregate size classes are stabilized by organic matter. However, our findings also show a significant (p=0.05) impact of long term cultivation on the micro-aggregate size classes (<0.25 mm).

3.3 Aggregate Stability Indices

Significantly higher values of wet and dry mean weight diameter (MWD) and geometric mean diameter (GMD) were observed under the three pasture grasses than in continuous cultivation land management (Table 3.0). This is attributed to high root biomass, microbial activities and organic carbon content of the soil and this implies that the soil under the perennial pasture grasses land use presents greater macro-aggregate stability, higher water permeability and is more effective in mitigating wind and water erosion [22] than the other land uses. Detachability index (Di) show a significantly higher value under continuous cultivation compared with the three perennial grasses. This is as a result of decrease in size of the aggregates, low organic carbon content and reduced microbial activities in the soil. The low values of MWDw under CC land use relative to the land use under perennial pasture grasses showed that continuous mechanical soil disturbance weakens macro-aggregate stability [23] thus resulting to detachment of smaller aggregates and particles from macroaggregates. This also points to the fact that greater proportion of large WSA shift to small macro-and microaggregates with cultivation which induces significant reduction in MWD. Since soil stability decreases as the MWD decreases, the result obtained in this study indicate that macro-aggregate stability against wind erosion decreased in the order: BD>AG>DS>CC, while macro-aggregate stability against water erosion decreased in order: DS>BD>AG>CC.

3.4 Total Organic Carbon, Total Nitrogen and C:N Ratio

Total organic carbon (TOC), total nitrogen (TN) and C:N ratio (see below Table 4) did not show significant difference between the perennial pasture grasses fields, but the values were significantly higher than that of CC. Lack of differences between the perennial pasture grasses in TOC, TN and C:N ratio may reflect long-term stability of the fields.

Table 1. Percentage weight of dry sieving aggregate fractions under various land management systems

Treatment	2-5	1-2	0.5-1	0.25-0.5	0.05-0.25	<0.05
			mm			
AG	42.2b	19.8a	13.4ab	10.8b	12.0b	1.7b
BD	47.4a	17.4a	12.5ab	10.1b	9.6b	3.1ab
CC	11.5c	8.5b	11.9b	19.8a	45.4a	2.9b
DS	38.6b	20.3a	15.0a	12.5b	9.1b	4.4a

AD= Andropogon gayanus, BD= Bracaria decumbens, CC= continuous cultivation, DS= digitaria smuthsii. means followed by the same alphabets are not significantly different at p= 0.5 probability

Table 2. Percentage weight of wet sieving aggregate fractions under various land management systems

Treatment	2-5 mm	1-2 mm	0.5-1 mm	0.25-.5 mm	0.05-.25 mm	<0.05 mm
AG	35.1a	26.9a	14.0a	10.2000b	8.7667b	4.9
BD	36.0a	26.8a	16.7a	9.1792b	7.4417b	3.9c
CC	3.6b	6.9c	8.7b	16.4458a	26.8917a	37.5a
DS	33.7a	21.9b	16.4a	11.4667b	9.0708b	7.5b

AD= Andropogon gayanus, BD= Bracaria decumbens, CC= continuous cultivation, DS= digitaria smuthsii. means followed by the same alphabets are not significantly different at p= 0.5 probability

Table 3. Dry and wet mean weight diameter, dry and wet geometric mean diameter and detachability index under various land management systems

Treatment	dMWD	wMWD	wGMD	dGMD	Di
			mm		
	1.94b	0.55c	0.9429d	1.0008b	0.2862b
BD	2.07a	0.60b	0.9934b	1.0013a	0.2892b
CC	0.76d	0.50d	0.9922c	0.9950d	0.6791a
DS	1.83c	0.63a	0.9937a	1.0005c	0.3464b

AD= Andropogon gayanus, BD= Bracaria decumbens, CC= continuous cultivation, DS= digitaria smuthsii, dMWD= dry mean weight diameter, wMWD= wet mean weight diameter, wGMD= wet geometric mean diameter, dGMD= dry geometric mean diameter. Means followed by the same alphabets are not significantly different at p= 0.5 probability

Table 4. Total organic carbon and total nitrogen under various land management systems

Treatment	TOC(g/kg)	TN(g/kg)	C/N ratio
AG	9.5767a	1.2175a	1:7.9a
BD	9.5091a	1.2300a	1:7.7a
CC	6.8158b	1.1608b	1.5.9b
DS	9.2933a	1.2208a	1:7.6a

AD= Andropogon gayanus, BD= Bracaria decumbens, CC= continuous cultivation, DS= digitaria smuthsiitc= total carbon content, TN= total nitrogen content. means followed by the same alphabets are not significantly different at p= 0.5 probability

The higher total organic carbon under the perennial pasture grasses than under CC may be as a result of the differences in aggregation, high root biomass, litter return [24,25] and microbial activities. Šimansky et al. [26] also stated that the highest average TOC content is found under minimum tillage (9.5767 g/kg) compared with conventional tillage (6.8158 g/kg), which suggests that less or non-disturbance of soil favours accumulation of great amount of organic matter in the soil. The lower organic C and total N for the long-term conventionally tilled field was probably a result of high organic matter decomposition enhanced by disruption of aggregates [27]. Soil C:N ratio was significantly lower in the CC field, compared to the grasses probably due to the higher degree of humification and favour N mineralization.

Although nitrogen mineralization is expected to contribute an important part of the available N to plants under CC, the low N content reflects high leaching process due to continuous conventional tillage. However, the higher C:N ratios at the surface under no-tilled grasses fields compared to that of CT also indicated that even though substantial humification had taken place, the organic matter in the NT fields is still less humified and more carbon-enriched compared to the plots where CT has been applied.

4. CONCLUSION

Measurements of soil aggregate stability and distribution are strongly influenced by an interaction between soil sample pre-treatment, aggregate size class selected and sieving methodology.

Compared with continuous cultivation and recognizing the different forces of disintegration studied, the land management system (zero tillage) as practiced under the three perennial grasses fields improved soil structure by increasing soil organic matter, nitrogen content and increasing the proportion of larger aggregates and the stability of soil when subjected to changes in wetness as well as wind erosion.

ACKNOWLEDGEMENT

The authors thank Lawal Bashir, Professor J.D Olarewaju and Mr A.B Shobayo for stimulating us in reviewing this important topic.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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Peer-review history:
The peer review history for this paper can be accessed here:
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