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Evaluation of Physicochemical Properties of Soil under Gum Arabic Tree (*Acacia senegal* L.) Wild Plantation in Sahel Zone of Jigawa State, Nigeria

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ABSTRACT: *Acacia senegal* (L), a nitrogen fixing tree and a drought resistant species with potentials to improve infertile soils was planted in Sahel zone of Jigawa State, Nigeria for the production of gum arabic. However, information on the soil physico-chemical properties under plantation in Nigeria is scanty, hence the objective of this paper was to evaluate the physicochemical properties of soil under gum arabic tree (*Acacia senegal* L) wild plantation in Sahel zone of Jigawa State, Nigeria. Soil samples were collected from four 30 x 30m plots in the plantation and another plot in open land (control). Three replicate soil samples were taken from 0-15 cm, 15-30 cm and 30-60 cm soil depths, analysed for micro and macronutrients using standard methods. Soil texture of the plantation is loamy sand but with slight textural differentiation under the open land. Mean soil bulk density ranged from 1.6 g/cm^3 in the plantation to 1.8g/cm^3 in the open woodland. The high values of soil bulk density might be ascribed to loss of organic matter as a result of soil erosion and animal grazing which are common occurrences. Results obtained indicated that the ECEC decreased as the soil depth increased and is low in values while the CEC of soils range from 5.57 to 5.97. The physicochemical properties of soils under the plantation were significantly different at $P < 0.05$ compared with the control an indication that *Acacia senegal* can gradually improves soil quality and productivity especially in Sahel zone of the northern part of Nigeria.

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Keywords: *Acacia senegal;* plantation; soil nutrients; physicochemical properties; soil properties

Trees perform a dynamic role of maintaining soil organic matter levels through the supply of litter and root residues, which in turn improve the fertility of the soil. Trees take up different amounts and different proportion of nutrients from a soil according to their species. However, the amounts taken depend on the soil conditions (Russell, 1973). Several studies have reported positive influence of trees on soil fertility and conservation (Kessler, 1992 and Bill, 2007). Soil fertility varies spatially from field to larger region scale, and is influenced by both land use and soil management practices (Sun, *et al.,* 2002). According to Brady and Weil (2002), as cited by Geeta *et al.* (2016), all soils have different properties and working with them requires understanding of these properties. The knowledge of the physical and chemical properties of soil helps in managing resources while working with a particular soil. *Acacia senegal* has special capacity to enrich poor soils, rehabilitate degraded land during fallow periods (Spore, 2001) using its root to break up hard clay soils, thus increasing aeration and drainage as a result, making essential nutrients more easily available and to mitigate desertification as well. Its use for associated food crops and its value for the production of gum arabic and good fuel wood even in areas with an extended dry season make it a very worthwhile species for large-scale exploitation as an agroforestry and a fuel wood species (NAS, 1979). However, there is inadequate information on the soil physicochemical properties under plantation in Nigeria, hence the objective of this paper was to evaluate the physicochemical properties of soil under gum arabic tree (*Acacia senegal* L) wild plantation in Sahel zone of Jigawa State, Nigeria.

MATERIALS AND METHODS

Study Area: Soil fertility study was carried out in Maifari Gum Arabic plantations in Maigatari Local Government Area of Jigawa State, Nigeria. The

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plantation covered an area of 20 hectares with an espacement of 6 x 6 m between and within the rows. The plantation lies between latitudes 12^0 48 and 18^0 20 N and longitudes 9^0 27 and 52^0 16 E with an elevation of about 350 m above sea level.

Experimental design and layout: The study investigated the effects of *Acacia senegal* on soil by comparing the soil properties of *Acacia senegal* plantation with that of a natural open woodland. The plantation was divided into plots of 30 m x 30 m with four plots randomly chosen with the adjacent natural open woodland of the same size selected as a control. In each plot, twenty-five quadrats of 6 m x 6 m were established and three quadrats were randomly chosen. The soil samples were collected from the depths of 0 - 15 cm, 15 - 30 cm and 30 - 60 cm. The study was conducted using a randomized complete block design.

Soil analysis: The soil samples were collected in polythene bags and air-dried in the laboratory for several days. Samples were gently crushed with porcelain pestle and mortar and sieved through a 2 mm sieve to remove coarse fragments. The fine soils separated were stored in polythene bags and taken to the Department of Soil Science, Ahmadu Bello University, Zaria, Nigeria for laboratory analyses.

Particle size distribution and bulk density were determined using the hydrometer method, while cores were oven-dried to constant weight at 105 ^{0}C for two days and expressed as mass of dry soil per unit volume of moist soil. The soil pH was determined both in water and 0.01M $CaCl_2$ solution using a soil solution ratio of 1:2.5 (International Institute for Tropical Agriculture, 1979; American Water Works Association, 1992). Cation exchange capacity (CEC) of the soil was determined with 1M NH_4OAC (1M ammonium acetate) buffered at pH 7.0 (Chapman, 1965, Rowell, 1994). Exchangeable Cation exchange capacity (ECEC) was calculated from the summation of exchangeable bases determined by 1M NH_40Ac extraction and the exchange acidity by 1M KCl extraction (Anderson Ingram 1998). Organic carbon was determined by chromic acid digestion method of Walkley Black (1934). Total N was determined using the micro-Kjeldahl digestion technique (Bremmer Mulvaney 1983), while available P was estimated colorimetrically by the molybdo-phosphoric- blue method using ascorbic acid as a reducing agent (Bray Kurtz, 1945). Field and laboratory data generated were subjected to analysis of variance (ANOVA). Differences in mean values were tested at 0.05 level of significance with Duncan's multiple range tests (DMRTs).

RESULTS AND DISCUSSION

Soil physical properties: The results of the physical and chemical properties of the soil under *Acacia senegal* plantation are presented in Tables 1, 2, 3 and 4. The general soil texture of the plantation is loamy sand. However, under the open land used as the control, the soil had a slight textural differentiation. The texture of the soil is sandy, especially at the top soil (0-15 depth). This may likely be as a result of selective removal of silt and clay particles by run-off water during accelerated water erosion in the rainy season as suggested by Harris (1998). Another reason may be the annual removal of fine soil particles by windstorms during the dry season, leaving the coarse and rough sand.

Table 1: Mean Soil Physical Properties at Different Depths under *Acacia senegal* Plantation

Plot	Depth (cm)	Sand g/kg)	Silt (g/kg)	Clay (g/kg)	Textural Class
1	0-15	853	100	47	Loamy sand
	15-30	860	80	60	Loamy sand
	30-60	840	73	87	Loamy sand
2	0-15	847	107	47	Loamy sand
	15-30	873	73	53	Loamy sand
	30-60	847	87	67	Loamy sand
3	0-15	833	147	20	Loamy sand
	15-30	847	100	53	Loamy sand
	30-60	853	93	53	Loamy sand
4.	0-15	867	100	33	Loamy sand
	15-30	827	107	67	Loamy sand
	30-60	840	67	93	Loamy sand
Control	0-15	887	87	27	Sand
	15-30	867	87	47	Loamy sand
	30-60	873	73	53	Loamy sand

Table 2: Mean, standard deviation and standard error of mean of soil bulk density under *Acacia senegal* plantation and natural woodland

Treatment	Mean (g/cm^3)
Plot 1	1.6±0.026
Plot 2	1.6±0.035
Plot 3	1.7±0.031
Plot 4	1.6±0.012
Woodland (Control)	1.8±0.032

Table 3: ANOVA result for the Mean Soil Bulk Density

Parameter	Df	MS	F	P-level
Plot	4	.021	8.532	0.003*
Error	10	.002		

** = Significant*

The amount of silt and clay in the plantation was small compared to the value obtained for the sand. The silt contents were higher at 0 - 15 cm depths both in the plantation and under the natural open land. However, the content of silt was much higher in the plantation than in the open land. The clay content was also high at 0 - 15 cm soil depth both in the plantation and the open land but not as high as that of silt and it increased along the soil depth. The highest mean soil bulk density of 1.8 g/cm^3 was recorded in the open land used as control and the lowest of 1.6 g/cm^3 mean value was found under the *Acacia senegal* plantation (Table 2). The high mean values obtained might be ascribed to the loss of organic matter through constant exposure of the plantation to sandstorms that usually blow away the rich fine particles of the top soil and the compaction of the soil by the roaming animals that were usually found grazing in the plantation. The case of the open land (control) is a good example of a plot devoid of vegetation that could hardly prevent the sandstorms from blowing away the fine soil particles that are rich in organic matter. However, the results of analysis of variance indicated a positively high significant value at $p < 0.05$ (Table 3).

Soil chemical properties: The general distribution of soil pH trend was a decrease from the top (0-15 cm) to the lower soil depth (30–60 cm). The results of analysis of variance tests for pH (H_20) indicated significant differences at different soil depths, while across the plots, there was no significant difference at $p = 0.05$. Also, for the pH ($CaCl_2$), there were significant differences among soil depths but not across plots (Tables 4 and 5). However, soil pH in water was found to be greater than that of pH ($CaCl_2$) both in the open land and under the Acacia plantation. The pH observed in the study were within the ranges of strongly acidic to slightly acidic. The low soil pH values may be attributed to intense leaching. These results could depict a decrease in organic matter content, basic cations uptake by trees and leaching of cations with increasing soil depth as noted by Samndi (2005) who worked on characterization and classification of soils under *Tectona grandis*.

The amount of organic carbon was significantly higher in the topsoil and decreased with soil depth and following the same trend for total nitrogen (Table 4). The carbon-nitrogen ratio (C/N) in the plantation and open land decreased with increasing soil depth following the pattern of organic matter distribution (Table 4). This is in line with some studies (Jackson et al 1996; Carter et al 1997; Mohamed, 2005). Since *A. senegal* is a deciduous tree that sheds its leaves during the dry season and is adapted to harsh environmental conditions, the accumulation of Organic Carbon in the topsoil may be as a result of leaf litter decomposition. According to Schlesinger et al (1996) and Burke et al (1998), soil Organic Carbon storage and distribution are controlled by the balance of carbon inputs from plant production and outputs through decomposition. The analysis of variance showed that differences in the C/N ratio were statistically significant across the soil depths. Next to water availability, Nitrogen seems to be the most important factor limiting productivity in arid land ecosystem (Gutierrez Whitford 1987).

. The amount of Nitrogen in the topsoil was higher than at other soil depths. This is in line with other studies that have shown that Nitrogen availability is highest in the topsoil, declining strongly with depth (Jobbagy Jackson 2001; Mohamed 2005). This probably explains the high concentration of lateral and fine roots of the *A. senegal* near the soil surface. The low C/N values of the 0-15 cm soil depth may be ascribed to higher fresh litter accumulation, which lowers the rates of mineralization. The Carbon to Nitrogen ratio also decreased with soil depth following the pattern of organic matter distribution. The mean value of available phosphorous was statistically significant both for the soil depth and across the plots. It should be noted that available P under the open land was low and also decreased with soil depth. The decrease with depth is ascribed to decrease in organic matter levels as noted by Samndi (2005) under *Tectona grandis* plantation in Nimbia forest, Kaduna State, Nigeria. This phenomenon was also observed by Ogunyebi (2008) in the study of decomposition of *Gmelina arborea* leaf litter in the lowland rainforest of Nigeria.

The exchangeable cations: The Exchangeable cations investigated in the soil of the plantation and the open land were calcium (Ca), magnesium (Mg), potassium (K) and sodium (Na). While the calcium and potassium decreased as the soil depth increased, both magnesium and sodium increased as the soil depth increased. The ECEC decreased as the soil depth increased and is low in values while the CEC of soils range from 5.57 to 5.97. The results of decreasing Calcium and Potassium with soil depth were in agreement with the findings of Oyun (1991) and could be a result of large uptake and storage of Ca and K by the trees while the increasing of Mg and Na down the soil depths might be attributed to less utilization of these nutrients by the *Acacia senegal* and this increase along the soil depths agreed with the work of Tedela (2004). However, the increase of Na along the soil depth could cause soil salinity which is a common phenomenon in dry areas, such as this study area.

Data presented in table 5 show that the ECEC decreased as the soil depth increased and is low. According to Nwachokor et al (2009), a low ECEC less than 4 cmol/kg implies a low capacity for the soil holding cations against leaching. The CEC of soils commonly range from 3 to 50cmol/kg, comparatively therefore, the soil of the study area had low CEC. The low CEC values could probably be as a result of low organic matter in the soil which resulted in poor soil structure, nutrient availability, soil pH and soil reactions to fertilizer. This could be attributed to the fact that the soil of arid zones is characterized by low organic matter and clay, oxides and hydroxides of iron and aluminium; all these could lead to poor growth of *Acacia senegal* in the plantation.

A comparison of soil nutrient contents of the study area showed that the *Acacia senegal* plantation nutrient contents were higher than what were obtained in the natural open woodland. The higher nutrient contents obtained under the plantation plots may be as a result of mineralization resulting from higher number of *Acacia senegal* trees which shed their leaves making the leaves available for decomposition thereby increasing the soil organic matter, nitrogen content, increase availability of micro-nutrient (Zn, Mn and Cu) in the soil surface and improved the soil structure.

Table 4: Soil Physical and chemical properties as influenced by soil depth under *Acacia senegal* plantation in Jigawa State, Nigeria

Soil Depth	**Clay**	**Silt**	**Sand**	**pH H_2O**	**pH ($CaCl_2$)**	**OC**	**TN**	**C:N**	**AP**	**Ca**	**Mg**	**K**	**Na**	**ECEC**	**CEC**
0-15cm	3.47a	10.80b	85.73a	5.95c	5.55c	0.35b	0.09a	11.23b	5.25b	3.79b	0.28a	0.18b	0.11a	4.63b	5.97a
15-30cm	5.60b	8.33a	85.47a	5.16b	4.55b	0.13a	0.04a	4.92a	3.34a	2.89a	0.47b	0.11a	0.12a	4.02ab	5.57a
30-60cm	7.07c	7.87a	85.07a	4.71a	4.23a	0.08a	0.03a	3.47a	3.21a	2.37a	0.72c	0.09a	0.15b	3.93a	5.77a

**Mean values with the same letters are not significantly different at 5% probability level by DMRT*

Table 5. Soil physical and chemical properties as influenced by plots under *Acacica senegal* plantation in Jigawa State, Nigeria

Plot	**Clay**	**Silt**	**Sand**	**pH (H_2O)**	**pH $CaCl_2$**	**OC**	**TN**	**C:N**	**AP**	**Ca**	**Mg**	**K**	**Na**	**ECEC**	**CEC**
1	6.44b	8.44a	85.11a	5.57c	4.82b	0.21ab	0.13b	3.34a	6.35ab	2.23a	0.29a	0.09a	0.11a	3.18a	4.34a
2	5.56ab	8.89a	85.56a	5.19b	4.80b	0.19ab	0.03a	7.98ab	3.89b	2.68a	0.54b	0.14b	0.10a	3.79a	5.48b
3	4.22a	11.33b	84.44a	5.50bc	5.11b	0.25b	0.03a	9.77b	3.99b	3.87b	0.66c	0.14b	0.11a	5.12b	6.17bc
4	6.44b	9.11a	84.44a	5.38bc	4.84b	0.16ab	0.04a	5.24ab	4.47bc	3.81b	0.61bc	0.13b	0.15b	5.06b	6.82c
Control	4.22a	8.22a	85.56b	4.73a	4.32a	0.11a	0.04a	6.35ab	5.15c	2.49a	0.35a	0.12b	0.16b	3.81a	6.03c

**Mean values with the same letters are not significantly different at 5% probability level by DMRT*

It can therefore be concluded that the decline in soil fertility in the open land is often as a result of less mineralization of litter which leads to the depletion of the nutrient pool of organic matter.

The decline in soil fertility in the open land therefore, is often related to the depletion of the nutrient pool of organic matter. And the improvement of soil properties under *Acacia senegal* indicates that planting of well adapted tree species can gradually improve soil quality and regenerate degraded lands.

Conclusion: The study has shown that the removal of the vegetative cover from the soil results in increases in bulk density, decreases in porosity and reduction in infiltration rate. This ultimately will reduce land productivity if not properly taken care of. In line with this, researches have demonstrated influence of trees in reversing this problem. This effect was associated with the influence of tree roots and biomass return in terms of mulching or tree litter on the structure and texture of the soils.

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