

# Physico-Chemical Properties of Soil Under Acacia Senegal (L) Willd Plantation in Sahel Zone of Nigeria

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## Research

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# Abstract

## Background

*Acacia senegal* (L) Wild known as gum Arabic tree, is a nitrogen fixing tree and a drought resistant species with potentials to improve infertile soils is planted in Sahel zone of Jigawa State, Nigeria for the production of gum arabic. However, there is dearth of information on the soil physico-chemical properties under plantation.

## Methods

Soil samples were collected from four 30 x 30m plots in the plantation and another plot in open woodland (control). In each plot, three replicate soil samples were taken from 0-15cm, 15-30cm and 30-60cm soil depths analyzed for micro and macronutrients, while soil acidity was determined both in water and 0.01M CaCl<sub>2</sub>.

## Results

The general soil texture of the plantation is loamy sand but with slight textural differentiation under the open woodland. Results indicated that physico-chemical properties of soils under the plantation were significantly different at  $P < 0.05$  compared with the control. The mean soil bulk density ranged from 1.6g/cm<sup>3</sup> in the plantation to 1.8g/cm<sup>3</sup> 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.

## Conclusion

From the result of the study soil physico-chemical properties under the plantation are high and have more beneficial effects on the trees unlike the open woodland.

# Background

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). *Acacia senegal* for example, 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 physico-chemical properties of *Acacia senegal* (L) Wild trees in plantation in the Sahel zone of Nigeria where it is found in the wilds and plantations and that makes this study necessary.

# Materials And Methods

Soil fertility study was carried out in Maifari Gum Arabic plantations in Maigatari Local Government Area of Jigawa State, Nigeria. The 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<sup>o</sup> 48 and 18<sup>o</sup> 20 N and longitudes 9<sup>o</sup> 27 and 52<sup>o</sup> 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<sup>o</sup>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<sub>2</sub> solution using a soil solution ratio of 1:2.5 (IITA, 1979; AWWA, 1992). Cation exchange capacity (CEC) of the soil was determined with 1M NH<sub>4</sub>OAc (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<sub>4</sub>OAc extraction and the exchange acidity by 1M KCl extraction (Anderson and Ingram, 1998). Organic carbon was determined by chromic acid digestion method of Walkley and Black (1934). Total N was determined using the micro-Kjeldahl digestion technique (Bremner, 1982), while available P was estimated colorimetrically by the molybdo-phosphoric- blue method using

ascorbic acid as a reducing agent (Bray and 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

The general soil texture of the plantation is loamy sand. However, under the open woodland used as the control (natural open woodland), the soil had a slight textural differentiation (Table 1). The texture of the soil is sandy, especially at the top soil (0 -15 cm depth). This is so as the study area is a part of Sahel savanna of Nigeria which is characterized by sandy to sandy loam soils (Odunze and Ogunwole, 2000).

**Table 1: Mean soil physical properties at different depths under *Acacia senegalensis* plantation and natural woodland**

Plot	Depth (cm)	Sand (g/kg)	Silt (g/kg)	Clay (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
Natural woodland (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 senegalensis* plantation and natural woodland**

Treatment	Mean (g/cm <sup>3</sup> )
Plot 1	1.6
Plot 2	1.60.035
Plot 3	1.7
Plot 4	1.6
Woodland (Control)	1.8

**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 woodland. However, the content of silt was much higher in the plantation than in the natural open woodland. This could be attributed to the vegetation cover of the *Acacia senegal* which helps to prevent soil erosion within the plantation. The clay content was also high at 0

- 15 cm soil depth both in the plantation and the natural open woodland but not as high as that of silt and it increased along the soil depth. This may be as a result of inadequate plant materials (litter). In a similar study under *Prosopis cineraria* plantation in semi-arid areas in India, Shankarnarayan *et al.*, (1986) observed that silt and clay content of soil increased up to a depth of 120 cm as compared to the surrounding open fields which are devoid of trees. These changes in soil physical properties resulted in the maintenance of soil moisture beneath the trees.

The mean soil bulk density ranged from 1.6 g/cm<sup>3</sup> in plot 1 to 1.8 g/cm<sup>3</sup> in the natural open woodland (Table 2). However, the results of analysis of variance indicated a positively high significant value at P < 0.05 (Table 3). The high mean values of soil bulk density obtained in both the plantation and the natural open woodland 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 natural open woodland 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.

#### 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<sub>2</sub>O) 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<sub>2</sub>), there were significant differences among soil depths but not across plots (Tables 4 and 5). A similar trend was observed along soil depth by Lechisa *et al.* (2014) under different land use systems in Gindeberet district, Ethiopia. The reason attributed was the reduction of Ca and Mg ions along soil depth which lower soil pH from top to down the soil layers (Soto and Diazfieroz, 1993).

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). 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 carbon-nitrogen ratio (C/N) in the plantation and natural open woodland decreased with increasing soil depth following the pattern of organic matter distribution (Table 4). The analysis of variance showed that differences in the C/N ratio were statistically significant across the soil depths. But 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 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 natural woodland 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 observed by Ogunyebi (2008) in the study of decomposition of *Gmelina arborea* leaf litter in the lowland rainforest of Nigeria.

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

Soil Depth	Clay	Silt	Sand	pH H <sub>2</sub> O	pH (CaCl <sub>2</sub> )	OC	TN	C:N	AP	Ca	Mg	K	Na
0-15cm	3.467a	10.800b	85.733a	5.947c	5.553c	0.352b	0.086a	11.227b	5.251b	3.787b	0.280a	0.177b	0.114a
15-30cm	5.600b	8.933a	85.467a	5.160b	4.553b	0.127a	0.035a	4.915a	3.327a	2.886a	0.473b	0.107a	0.116a
30-60cm	7.067c	7.867a	85.067a	4.713a	4.233a	0.075a	0.025a	3.465a	3.209a	2.377a	0.716c	0.089a	0.145b

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 plot under *Acacia senegal* plantation in Jigawa State**

Plot	Clay	Silt	Sand	pH H <sub>2</sub> O	pH (CaCl <sub>2</sub> )	OC	TN	C:N	AP	Ca	Mg	K	Na
1	6.444b	8.444a	85.111a	5.567c	4.822b	0.207ab	0.127b	3.341a	2.139a	2.231a	0.292a	0.088a	0.106a
2	5.556ab	8.889a	85.556a	5.189b	4.800b	0.1889ab	0.029a	7.977ab	3.891b	2.680a	0.540b	0.138b	0.102a
3	4.222a	11.333b	84.444a	5.500bc	5.111b	0.253b	0.027a	9.772b	3.988b	3.874b	0.660c	0.139b	0.111a
4	6.444b	9.111a	84.444a	5.378bc	4.844b	0.162ab	0.035a	5.236ab	4.473bc	3.809b	0.611bc	0.134b	0.148b
Control	4.222a	8.222a	85.556b	4.733a	4.322a	0.111a	0.026a	6.354ab	5.154c	2.489a	0.346a	0.123b	0.159b

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

### ***The exchangeable cations***

The Exchangeable cations investigated in the soil of the plantation and the natural open woodland are 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 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. The increase of Mg and Na down the soil depths is in consonance with Tedela (2004) and might be attributed to less utilization of these nutrients by *Acacia senegal*. However, the increase of Na along the soil depth could cause soil salinity which is a common phenomenon in dry areas, such as the study area (Oyun, 1991).

The ECEC decreased as the soil depth increased and is low in values. 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. 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 senegalensis* in the plantation.

## **Conclusion**

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

The study has also shown the influence of trees in soil physical properties which are very important in augmenting the overall capacity of the land to produce. 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.

### **Recommendation**

Judging from the above, the soil quality and productivity of the natural open woodland can be restored by planting the area up with *Acacia senegal* trees or any other tree(s) as trees will promote high biological activities of soil fauna, improve soil organic matter content and replacing the nutrients lost to soil or wind erosion and animal grazing on the land.

## **Declarations**

**Ethics approval and consent to participate:** *Not applicable*

**Consent for publication:** *Not applicable*

**Availability of data and materials:** *All data generated or analysed during the study are included in this manuscript.*

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**Acceptance and Confirmation:** *All authors of the publication have read and agreed to its content and we are accountable for all aspects of the accuracy and integrity of the publication in accordance with ICMJE criteria. We (ATA and ADI) state that the article is original and has not already been published in a journal and is not currently under consideration by another journal. That we agree to terms of the SpringerOpen Copyright and License Agreement.*

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