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/cm³ in the plantation to 1.8g/cm³ 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 ECCE 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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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
plantation covered an area of 20 hectares with an
espanement of 6 x 6 m between and within the rows.
The plantation lies between latitudes 12° 48 and 18° 20
N and longitudes 9° 27 and 52° 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 °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 CaCl₂ 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 NH₄OAC (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 NH₄OAc
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 textual 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 |
|------------|------------|-------------|-------------|-------------|----------------|
| Control    | 0-15       | 833         | 47          | 47          | Loamy sand     |
|            | 15-30      | 860         | 60          | 60          | Loamy sand     |
|            | 30-60      | 840         | 87          | 87          | Loamy sand     |
| 2          | 0-15       | 847         | 47          | 47          | Loamy sand     |
|            | 15-30      | 873         | 53          | 53          | Loamy sand     |
|            | 30-60      | 847         | 67          | 67          | Loamy sand     |
| 3          | 0-15       | 833         | 20          | 20          | Loamy sand     |
|            | 15-30      | 847         | 53          | 53          | Loamy sand     |
|            | 30-60      | 853         | 53          | 53          | Loamy sand     |
| 4.         | 0-15       | 867         | 33          | 33          | Loamy sand     |
|            | 15-30      | 827         | 67          | 67          | Loamy sand     |
|            | 30-60      | 840         | 93          | 93          | Loamy sand     |
| Control    | 0-15       | 887         | 27          | 27          | Sand           |
|            | 15-30      | 867         | 47          | 47          | Sand           |
|            | 30-60      | 873         | 53          | 53          | Loamy sand     |

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

| Treatment      | Mean (g/cm²) | Standard Deviation | Standard Error |
|----------------|--------------|--------------------|----------------|
| Plot 1         | 1.62±0.026   |                    |                |
| Plot 2         | 1.62±0.035   |                    |                |
| Plot 3         | 1.72±0.031   |                    |                |
| Plot 4         | 1.6±0.012    |                    |                |
| Woodland (Control) | 1.82±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/cm² was recorded in the open land
used as control and the lowest of 1.6 g/cm² 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 (H₂O) indicated significant differences at different soil depths, while across the plots, there was no significant difference at p = 0.05. Also, for the pH (CaCl₂), 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 (CaCl₂) 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 Samindi (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 Whiford 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 (Jobbargy 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 Samindi (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.
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. And the improvement of soil properties often related to the decomposition of litter, which leads to mineralization of litter and depletion of fertility. 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. 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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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 (H₂O) | pH (CaCl₂) | 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 Acacia senegal plantation in Jigawa State, Nigeria

| Plot     | Clay | Silt | Sand | pH (H₂O) | pH (CaCl₂) | OC | TN | C:N | AP | Ca | Mg | K | Na | ECEC | CEC |
|----------|------|------|------|----------|------------|-----|-----|-----|----|----|----|---|----|------|-----|
| Control  | 4.22a| 8.22a| 85.56b| 4.73a | 4.32a | 0.11a| 0.04a| 6.35b| 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.

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