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COMPARATIVE STUDY OF SOIL PHYSICO-CHEMICAL PROPERTIES UNDER *ACACIA SENEGAL* IN THREE DIFFERENTPLANTATIONS IN MAIFARI, JIGAWA STATE, NIGERIA

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ABSRACT
Acacia senegal is a multipurpose drought-tolerant tree or shrub legume, and is commonly used in agroforestry systems in sub-Saharan Africa for gum arabic production and soil fertility improvement. Despite its relatively wide distribution in Nigeria, there has not been exhaustive evaluation on the effects of the tree/shrub on soil physicochemical properties under its canopy forsustainable utilization of the tree. Accordingly, three sitesin the semi-arid regionof Nigeria representing three plantation ages of 7, 27and 37 years old were selected for assessment. Soil samples were collected under tree canopies and were compared with the soils from the open canopies. Results indicated that there were significant differences in soil physicochemical properties among the three ages (P<0.05 and P< 0.01). Generally, soil nutrients under the canopies were higher than in the open canopiesirrespective of the age mainly due to effects of litter accumulation. The tree/shrubhas beneficial effects on soil nutrient status in their natural ecosystems and would most likely improve crop productivity in agroforestry systems such as alley cropping. The resultant improvement in soil nutrients status can increase herbage production in agricultural rangelands thus enhancing animal production in the study area. The tree/shrub growing under different soil types may have an effect on their gum Arabic production and quality.
Keywords:Acacia senegal,plantation ages, soil nutrients accumulation, sustainable utilization.

INTRODUCTION

Acacia senegal (L.) Willd is a tree or shrub legumewidely distributed in sub SaharanAfrica, extending to Arabian Peninsula, Pakistan and India (Fagg and Allison,2004). It is mostly found in the arid and semi-arid zones of Nigeria. It is a drought tolerant species and grows in areas with low rainfall of 300 to 400 mm per year, but can grow in areas with as little as 100 mm, and a dry period of 8 to 11 months (Joker, 2000). It is commonly used in agroforestry systems such as shifting cultivation where it is inter cropped with crops such as millet, sorghum, sesame and ground nuts. The tree/shrub produces gum arabic and improves soil fertility (Ballal *et al*., 2005; Elmqvist *et al*., 2005; Gaafar *et al*, 2006). It has also been reported that Organic carbon, available P and total N content per-hectare under *A. nepalensis* canopyincreased soil nutrients with increasing plantation age (Ballal *et al*., 2005; Nijhoff and Junk (1985). Soils under the canopy of the tree/shrub have been reported to have high exchangeable bases with low to moderate micronutrient content(JARDA, 2002).Verunumbe (1987) reported that increased crop yields observed under trees in Nigerian drylands have been correlated with increased Zn, Mn, and Cu. It has also been reported that there was a substantial increase in soil Zn, Mn, and Cu in sub-Saharan tree canopies (Rao *et al.,* 1990). Chima *et al.,* 2004 noted that a lot of interest is being shown in Nigeria towards incorporation of indigenous tree species like *Acacia senegal* in reforestation programs since it has the ability to survive well and strongly influence the soil. Moreover, *Acacia senegal*can play a key role in combating land degradation .The roots are highly effective in enriching the soil by improving its water and nutrient levels, through the fixation of nitrogen and can also be used to re-vegetate degraded and denuded landscapes. Similarly, Eisa *et al*., (2008) reported that *Acacia senegal*can restore the fertility of degraded soils through litter falls and its potential to fix nitrogen in the soil.

However, despite the immense recognition of the importance of *Acacia senegal*tree in agroforestry systems e.g. alley cropping, restoration of soil fertility and degraded land coupled with the need to understand the role of *Acacia senegal* in improving soil properties, and an understanding of how nutrient availability changes under the tree of different ages, there is the need to evaluate these key areas particularly in the research area.This study is an attempt in this direction.

MATERIALS AND METHODS

The Study Site

The site lies in the Sudan Savanna zone between longitudes 9° 43′27.7″ E to 9° 45′26.5″ E and latitudes 12° 34′58.3″ N to 12° 35′37.9″ N with an elevation of about 351m above sea level(Figure 1).No anthropological activities were recorded in the study area before the establishment of the plantations.

The study area is made up of unconsolidated sediments of Chad formation, uppermost in the stratigraphic sequence. It is underlain by the Kerri Kerri formation. The sediments are of lacustrine origin and vary lithologically both laterally and vertically. The formation is essentially an argillaceous (clayey) sequence but well defined arenaceous (sandy) horizon occurs. The climate of the area is influenced by both the Equatorial Maritime and the Tropical Continental air masses. There are two distinct seasons; namely dry and wet seasons lasting between October and April, and between June to September, respectively (JARDA, 2002). Rainfall ranged from 6 (April) to 221 mm (August) in the study year (2013). During the peak of the dry season the temperature can be as high as 38^{o}C in the day time (Abba, 2002).

The original vegetation was made up of various species of grasses, bushes and trees, the latter two being relatively fire resistant. Intensive cultivation, both shifting and static, have very considerably changed the natural vegetation which now only exists in relatively small pockets in forest or game reserves and in non-arable areas (JARDA, 2002).

FIELD STUDIES

Soil Sampling

Three compartments of three (3) hectares each were selected for soil sampling. The sampling was done during the dry season. Each compartment represented 7, 27, and 37 year-old plantations. A control where no plantations ever existed was also sampled for comparison giving a total of four (4) treatments. The treatments were laid out in a completely randomized block design (CRBD) since samples were taken from each compartment or block. A 2-meter space was left between the borders andtransects to reduce error during sampling. Composite soil samples were taken at random along transects including the control from 0 – 45 cm soil depth. The soil samples were analyzed for soil physical and chemical properties.

SOIL ANALYTICAL METHODS

The soil samples were air-dried and gently crushed and passed through a 2mm sieve to remove coarse fragments. Mechanical analysis was carried out using the hydrometer method (Day, 1965). Soil pH was read with a pH-meter. Organic C and total N were estimated by Walkley-Black wet combustion (Black, 1965) and Macro-Kjeldahl digestion-distillation (Bremner, 1965), respectively. Available P was determined by the Bray-I method (Bray and Kurtz, 1945). Cation exchange capacity was determined by the ammonium-saturation method (Page *et al.*, 1982). Potassium and Na were read from the undiluted extract on a flame photometer, while Ca and Mg in solution were read with atomic absorption spectrophotometer (AAS) at 423 and 485nm wavelengths respectively. The sum of Ca, Mg, Na and K gave total exchangeable bases.Exchangeable acidity was determined using 1*M* KCl.Exchangeable sodium percentage (ESP) was calculated using the following formula:

$$\text{ESP} = \frac{Na^{+}}{\text{CEC}} x\,100$$

Where, Na^{+} and CEC are in cmol(+)kg^{-1} soil.

Base saturation was calculated by dividing the total exchangeable cations by the cation exchange capacity (CEC) obtained by 1M NH_4OAc (pH 7.0) method as follows:-

$$\% \text{ Base Saturation} = \frac{\text{Total exchangeable bases}}{\text{CEC } (NH_4OAc)} \times 100$$

STATISTICAL ANALYSIS

Data generated were subjected to Analysis of Variance (ANOVA).Where the means were significant, they were separated by Least Significant Difference (LSD). All computations were carried out using SAS 9.0 statistical package.

RESULTS AND DISCUSSION

The effect of plantation age on particle size distribution of the soils is presented in Table 1. The plantation soils at 7 and 27 years as well as the fallow (control) were found to be loamy sand in texture. However the soils under plantation age of 37 years were sandy loam. Differences between the silt content were highly significant ($P < 0.01$) at all the plantation ages including the control. The silt content ranged from 6.1(control) to 9.3 % (37 years). The higher silt content at 37 years over the control was probably due to the trapping of windborne silt particles by tree canopies (which are wider and more developed as the tree grows older) and their input to the soil through litter fall. Highly significant ($P < 0.01$) difference was found in the sand content between 37 – year old plantations (80.73 %) and the control (85.23 %) indicating the lowest and highest sand contents, respectively. Just like the silt, the clay content also exhibited highly significant ($P < 0.01$) difference between the control (8.6 %) and 37 – year old (10.18 %) plantation soils (Table 1). The higher clay observed at 37 years over the control may not be unconnected with trapping of clay particles by the trees as also observed earlier. The much higher sand content over above the silt and clay fractions (Table 1) may be attributed to the fact that soils in the study area were developed on unconsolidated sediments of the Chad formation characterized by sandy materials as reported by JARDA (2002).

The effect of plantation age on chemical properties of the soils is presented in Table 2. There was great variability ($P < 0.01$) in soil reaction between 7- year old plantation (5.5), control (5.6) and 27 (6.0), 37 (6.1) years old plantations. The soil reaction was observed to be acidic which is in agreement with the findings of Wang *et al.,* (2010). This situation may be attributed to several mechanisms that release H^{+}, such as soil base cation uptake (or depletion) by the trees, decomposition of organic matter to organic acids and CO_2, root respiration and nitrification.

However, stronger acidity was observed in soils from the 7- year old plantation. This may be as a result of lower organic carbon content (5.2 gkg^{-1},Table 2).

The differences in organic carbon (OC) and total N among the ages including the control were highly significant ($P < 0.01$) while concentration of available P was only significant at $P < 0.05$. The OC and total N ranged from 3.2 (control) to 6.8 gkg^{-1} (27 years) and 0.06 (control) to 1.17 gkg^{-1} (37 years), respectively. This is most probably due to higher accumulation of litter with increasing plantation age under the tree canopy than in the absolute control. Soil OC and N were higher under thecanopies in all the agescompared to the open canopies (Wang *et al.,* 2010). It is known that litter production and the rate of litter decomposition are the most important factors by which tree species regulate the size and distribution of soil C and N pools (Wang *et al.,* 2010). This is because under canopy the soil moisture status is increased, which increases the moisture content of the surface litter, litter breaks down and hence mineralization of organic matter (Meenakshi and Kailash, 2002). The increase of nutrient accumulation under canopies may be due to the nutrient input by tree litter. In this sense, Aweto and Dikinya (2003) studied the effects of *apiculatum* and *P. africanum* on the soil under their canopies in semi-arid traditional grazing land in south eastern Botswana and found that the mean organic carbon and N levels under the canopies were higher than in the open grassland. Pandey *et al.* (2000) reported that *Acacia nilotica* trees had enriched the organic matter and nutrient levels in the soil under their canopies.

The current study indicates that the *Acacia senegal* has the potential of enhancing herbageproduction as they improve soil fertility under their canopies.This is particularly important in dryland rangelands.

There was significant ($P < 0.05$) variation in available P among the ages including the absolute control which showed higher content (15 .16 $mgkg^{-1}$). The content was found to be moderate in all the treatments. The variation as well as the moderate content of available P may be ascribed to litter accumulation and subsequent decomposition rather than the nature of the parent material since it is homogenous in the study area indicating that litter fall is a major source of P in the area rather than parent material. The higher content observed in the control may not be unconnected with higher soil temperatures in the open canopy which accelerated decomposition and release of P. Differences in exchangeable bases and exchangeable acidity were not significant (Table 2). However the concentrations of the exchangeable bases, with the exception of Ca which is low, were moderate.

The effect of plantation age on chemical properties of soil under Gum Arabic plantations is presented in Table 3. The CEC and EC did not vary significantly among the treatments. There were highly significant ($P < 0.01$) differences in the base saturation among the treatments. It increased with plantation age ranging from 36.82 (control) to 53.97 % (37 years). The higher base saturation at the older plantation may be attributed to corresponding moderate level of CEC observed (Table 3) which in turn is related to the moderate levels of Mg, K and Na (Table 2).

This generally implies that older plantations are more fertile than the open canopy in terms of base saturation. This is similar to the findings of Githae *et al.* (2011).

The correlations between soil physical and chemical properties investigated for *A. senegal* are shown in Table 4.There were significant positive correlations between OC and pH, N with r values of 0.56 ($P < 0.01$), 0.59 ($P < 0.01$) respectively indicating that increase in OC increased pH and nitrogen in the soils beneath the canopies irrespective of plantation age. This finding is in agreement with the findings of Githae *et al.* (2011). It is known that soil organic C is a major source of N and has the tendency to reduce soil acidity. Though not significantly different, OC and total N were positively correlated with CEC (Table 4) with r values of 0.28 and 0.23 respectively implying that regardless of plantation age, CEC of the soils increases with increase in OC and N. Significant positive correlation was observed between exchangeable Na ($r = 0.36$, $P < 0.05$), K ($r = 0.38$, $P < 0.01$) and pH. Exchangeable Mg was also positively correlated with pH even though the relationship fell short of statistical significance ($r = 0.09$, Table 4). It is well known that exchangeable bases, by their name, tend to reduce soil acidity. However, exchangeable Ca was negatively correlated with pH ($r = -0.03$).

Conclusion

The study shows that *Acacia senegal* rangingfrom seven and thirty seven years old has beneficial effects on soil fertility improvement such as reduction in soil reaction by organic carbon and nitrogen. According to this study, *Acacia senegal* can grow well on different soil types ranging from sandy loam to loamy sand showing different characteristics with age.

REFERENCES

Abba, A. A. (2002). Briefs on Jigawa State Wetlands Potentials, Desertification and Gum Arabic Production. Pp. 1-2.

Aweto AO, and Dikinya O (2003). The beneficial effects of two tree species on soil properties in a semi-arid savanna rangeland in Botswana. Land Cont. Reclam., 11: 339-344.

Ballal, M.E., El Siddig, E.A., Elfadl, M.A. and Luukkanen, O. (2005). Gum arabic yield in differently managed *Acacia senegal* stands in western Sudan. *Agroforestry Forum* **63**: 237-245.

Black, C. A. (1965). **Methods of Soil Analysis.** Agronomy, No. 9 ASA. Madison, Wisconsin.

Bray, R.H. and L.T. Kurtz, 1945. Determination of total organic and available forms of phosphorus in soils. Soil Sci., 59: 39-45.

Bremner, J.M., 1982. Inorganic Nitrogen. In: Page, A.L., R.H. Miller and D.R. Keeney, (Eds.), Methods of Soil Analysis. Part 2. 2nd Edn., Amer. Soc. of Agron, Madison, pp: 595-624.

Chima, U.D., Popo-ola, F.S. and Ume, K.K (2004). Physico-chemical properties of top soil under indigenous and exotic monoculture plantations in Omo Biosphere reserve, Nigeria. *Ethiopia Journal of Environmental Studies and Management* **7(22**)117-125.

Day, P.R. (1965). Particle fractionation and particle size analysis. In: Black, C.A. (ed.). Methods of Soil Analysis. Part 2. *Agronomy*. 9, ASA, Madison, Wisconsin.

Eisa MA, Roth M. and Sama G. (2008). *Acacia senegal* (Gum Arabic Tree): present role and need for future conservation in Sudan. "Competition for resources in a changing world: New drive for rural development."Deutscher-Tropentag, Germany. 14 pp.

Elmqvist, B., Olsson, L., Elamin E.M. and Warren, A. (2005). A traditional agroforestry system under threat: An analysis of the gum Arabic market and cultivation in Sudan. *Agroforestry System* **64:** 211-218.

Fagg CW, Allison GE (2004). *Acacia senegal* and the gum arabic trade.Monograph and annotated bibliography. Tropical Forestry Papers No. 42, Alden Group, Oxford. P. 261.

Gaafar, A.M, Salih, A.A. Luukkanen O., Fadl, M.A. and Kaarakka, V. (2006). Improving the traditional *Acacia senegal*-crop system in Sudan: the effect of tree density on water use, gum production and crop yields. *Agroforestry System***66:** 1-11.

Githae, E. W., Gachene, C. K. K.,Njoka, J. T. (2011). Soil physicochemical properties under *Acacia senegal* varieties in the dryland areas of Kenya. *African Journal of Plant Science*5(8), pp. 475-482.

JARDA, (2002). Feasibility study on Irrigated Agricultural Potentials of Jigawa state, Nigeria. pp. 7 - 77.

Joker, D. 2000. Acacia senegal (L.) Willd., Danida Forest Seed Centre, Denmark, Seed Leaflet No. 5.

Meenakshi K, Kailash L (2002). Effect of *Albizzia lebbeck* plantation onthe nutrient cycling in a semi-arid grazing land. Trop. Ecol., 43: 305-314.

Njihoff, M. and Junk, W. (1985). Chemical soil properties under five age series of *Alnus nepalensis* plantations in the Eastern Himalayas. *Journal of Plant and Soil* 84 (1), pp. 105 - 113

Page, A. I. P., Miller, and R. H. and Keeney, D.R. (1982). Methods of Soil Analysis. Volume 2. second edition. American Society of Agronomy, Madison, Wisconsin.

Pandey CB, Singh AK, Sharma DK (2000). Soil properties under *Acacianilotica* trees in a traditional agroforestry system in central India.*Agrofor. Syst.*, 49: 53-61.

Rao, M., Sharma, M., and Ong, C.K. (1990).A study of the potential of hedgerow intercropping in semi-arid India using a two-way systematic design. *Agroforestry Systems***11**: 243-258

Verinumbe, I. (1987). Crop production on soil under some forest plantations in the Sahel. *Agroforestry Systems***5**: 185–188.

Wang F, Li Z, Xia H, Zou B, Li N, Liu J, Zhu W (2010). Effects ofnitrogen-fixing and non-nitrogen-fixing tree species on soil properties and nitrogen transformation during forest restoration in southern China. Soil Sci. Plant Nutr., 56: 297-306.

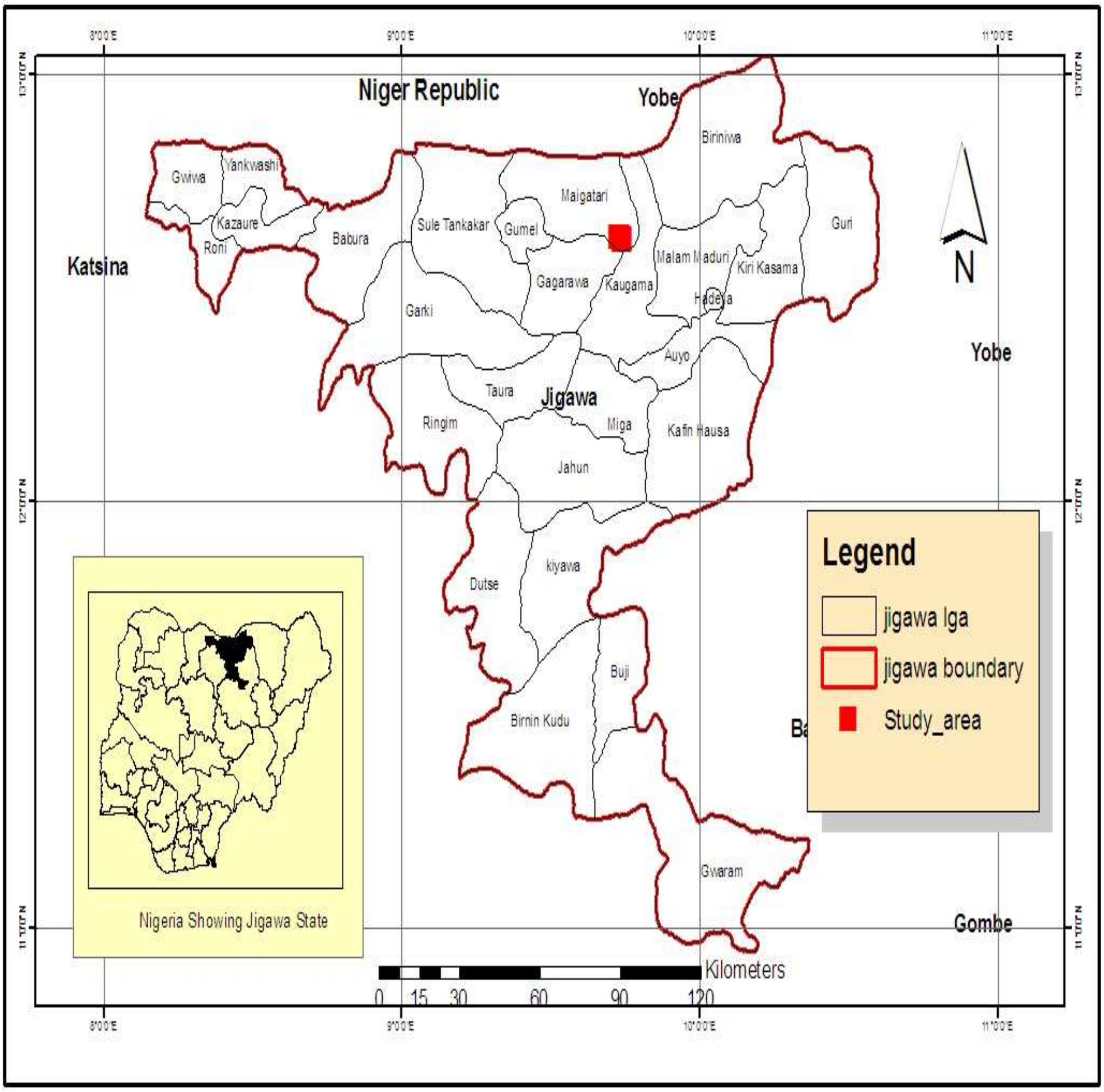

Figure 1: Location of study area

Table 1. Effect of Plantation Age on Particle Size Distribution of soil under Gum Arabic plantations

Plantation age (years)	Silt	Sand %	Clay	Textural type
7	8.3ab	83.06b	8.7b	loamy sand
27	7.3bc	83.89b	8.8b	loamy sand
37	9.3a	80.73c	10.18a	sandy loam
Fallow	6.1c	85.23a	8.6b	loamy sand
SE±	0.49	0.43	0.30	
	**	**	**	

Mean within a column followed by the same letter(s) are not significantly different at p = 0.05 by Least Significant Difference.

**= Highly significant

Table 2: Effect of Plantation Age on Chemical Properties of Soil under Gum Arabic Plantations

Treatments	**pH**						**Exchangeable bases**					
	H_2O	**CaCl**	**dpH**	**OC (gkg^{-1})**	**TN (gkg^{-1})**	**AvP ($mgkg^{1}$)**	**Ca**	**Mg**	**K**	**Na**	**TEB**	**ExA**
							cmolkg $^{-1}$					
Plantation age(years)												
7	5.5c	4.2c	-1.28a	5.2b	1.14a	13.24ab	1.34	0.99	0.29a	0.15a	2.77	1.13
27	6.0a	4.8a	-1.17a	6.8a	1.14a	12.16b	1.50	1.07	0.29a	0.15a	2.97	1.36
37	6.1a	4.9a	-1.23a	6.0ab	1.17a	10.69b	1.11	1.03	0.30a	0.17a	2.85	0.82
Fallow(con)	5.6b	4.3b	-1.30a	3.2c	0.06b	15.16a	1.29	1.08	0.29a	0.16a	2.84	1.18
SE±	0.06	0.05	0.05	0.04	0.09	1.004	0.10	0.08	0.01	0.01	0.19	0.34
	**	**	NS	**	**	*	NS	NS	NS	NS	NS	NS

Mean within a column followed by the same letter(s) are not significantly different at p = 0.05 by Least Significant Difference. NS= Not significant, *=Significant, **=Highly significant

Table 3.Effect of Plantation Age on Chemical Properties of Soil under Gum Arabic Plantations

Treatments	**CEC ($cmolkg^{-1}$)**	**BS**	**ESP**
		(%)	
Plantation age (years)			
7	8.01	37.66b	8.01
27	9.71	52.76a	9.71
37	7.67	53.97a	7.67
Fallow	5.44	36.82b	5.43
SE±	1.29	4.11	1.29
	NS	**	NS

Mean within a column followed by the same letter(s) are not significantly different at p = 0.05 by Least Significant Difference, NS= Not significant, **= Highly significant

Table 4. Pearson correlation coefficients between soil physicochemical properties investigated for *A. senegal.*

Data	pH	CEC	P	% OC	% N	Ca	Mg	K	Na
pH	1								
CEC	0.03	1							
P	-0.18	-0.21	1						
% OC	0.56**	0.28	-0.09	1					
% N	0.37**	0.23	-0.16	0.59**	1				
Ca	-0.03	0.21	0.17	0.09	0.1	1			
Mg	0.09	0.01	0.14	-0.09	-0.11	0.76**	1		
K	0.38**	0.06	-0.12	0.35*	0.21	-0.12	-0.13	1	
Na	0.36*	0.03	-0.04	0.08	0.0002	0.13	0.18	0.57**	1

* P < 0.05; ** P < 0.01