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Optimum Land Use System for Soil Maintenance: Case of Agroforestry Practice in North Kordofan Gum Belt, Sudan

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ABSTRACT

Kordofan, a vast semi-arid region in mid-west Sudan, lies within the savannah zone, where bush fallow is the main production system. Due to climate change and recurrent drought spells, this farming system has been changing. The aim of this study was to analyze different agroforestry practices in the gum belt of North Kordofan with special focus on the effect of trees in improving soil fertility. Twelve villages were randomly selected in the study area, where soil samples at depths 0-20cm, 20-40cm and 40-60cm were taken to represent both agroforestry and monoculture sites in a trial to assess the effect of trees on soil nutrients. Structured questionnaires for 164 household farmers representing 11% of the total population were conducted to identify agroforestry practices. Land Equivalent Ratio (LER) was used for determining the best land-use practice. Descriptive statistics, regressions, chi-squire and other related equations were used to achieve the results. The findings of the study showed that agroforestry practices have a significant effect (α .05) in improving some soil physical properties, namely bulk density, porosity and permeability, as well as they increase N, P, Ca, Mg, Cl an d HCO_3 content of the soil. The study concluded that, LER=/> 1 was reported by almost 77% of the respondents, meaning that agroforestry practices are the appropriate farming systems in terms of increasing crop yields and land area saving. The study recommended that, *Acacia senegal* has to be integrated in all farming practices in the gum belt of North Kordofan to enhance sustainable production and stable environment.

INTRODUCTION

Sudan suffers from desertification, deforestation and environmental degradation. Deforestation causes degradation by the elimination of natural habitats for plants and animals, in which case it contributes to the destruction of ecosystems and wildlife. Desertification is defined as the process of fertile land transforming into desert typically as a result of deforestation, drought or improper/inappropriate agriculture (Pr. Uni., 2014). According to Enviro Facts (2014), desertification is the process which turns productive land into non-productive desert as a result of poor land-management, occurring mainly in semi-arid areas receiving an average annual rainfall less than 600mm.

Kordofan, a vast semi-arid region in mid-west Sudan, lies within the savannah zone of the Sudan between latitudes 9º 5' and 11º 7' N and longitudes 27º and 32º E; has an area of approximately 850,000 Km^2. The gum Arabic belt passes along the region, it denotes the area of central Sudan between latitude 10-14° north together with minor protrusions (Chikamai, 1996). Ecologically the belt covers most of the low rainfall wood land Savannah. It is a tropical continental area with mild short winter and hot long summer; it is the main producing area of gum Arabic. The basic information on the soil and vegetation in the western extension of the gum belt, particularly Kordofan have been obtained after the survey conducted by Hunting Technical Services in 1963. Generally, the gum belt in Sudan comprised a number of soil types; the two major types are the sandy soil and the dark cracking clay soils. The sandy soils are of stabilised sand dune types, commonly known as *qoz* lands, which extend between latitudes 14° 30' and 11°30' north. They dominate most of Kordofan State.

Sudan depends economically upon agriculture. The main farming practice is the traditional bush fallow system that is followed with a 20 year’s rotation during which time *Acacia senegal* is grown for 15 years, agricultural crops (millet, sesame, sorghum and groundnut) are grown for 5 years. Such traditional bush fallow practices, which are recently known as agroforestry systems, are predominantly *Acacia* species based in the Africa’s Sahel region (Raddad, 2006).

Due to environmental changes and consecutive drought years, in addition to population pressure and recurring food shortage, farmers find it difficult to practice traditional fallow agriculture. They have been forced to lengthen the cropping period, while reducing the number of years the land is in fallow. The deterioration of the traditional system is the resultant consequence of combined effects of excessive tree cutting, desertification, and unfavorable socio-economic conditions (Barbier, 1992). At the end such factors have caused serious loss of soil fertility, aggravated by continuous sole cropping, decreased crop production and outmigration of the farmers and gum producers.

The objectives of this study are to assess the effect of agroforestry practices on soil fertility as compared to sole cropping. It is also envisaged to compare the relative yields of agricultural crops both in agroforestry and sole farming systems.

An Overview

Acacia senegal Tree

In the gum belt, *Acacia senegal* (L.), occurs naturally within the thorn woodlands of the African Savannah. The tree is found in sandy areas receiving between 280 and 450 mm annual rainfall and in clay areas where the rainfall is 500mm or more (Ballal, 1996). It is widely recognized that establishing trees in degraded ecosystems improves soil quality. As well, growing trees in association with crops can either improve soil quality or reduce the risk of soil degradation (Montagnini, 2007). *Acacia senegal* is habitually managed under agroforestry systems in gum gardens (locally known as *Hashab* gardens) for production of gum as well as agricultural crops, relying on its ability to restore soil fertility; it increases crop yield through nitrogen fixation. The tree also provides invaluable environmental benefits to the large gum belt area of Sudan. Moreover, the *Acacia senegal* trees offer protection to soils against desertification which is a phenomenon of a perpetual declining soil productivity hazard resulting from climate variation and human use of the land (Hussein, 1983).

The Importence of Agroforestry

Agroforestry is a dynamic, ecologically based natural resource management system, which through the integration of trees in farmlands and rangelands, diversifies and sustains production for increased social, economic and environmental benefits for land users at all levels (Alice, 2002). It is a suitable form of land use for fragile marginal areas in the tropical regions with a high risk of environmental degradation (Wiersum, 1986). It has been also defined as a sustainable land management system that increases the overall yield of land combining the production of crops and forest trees. From literature, it has been also emphasized that integration of trees, particularly *Acacia senegal* in degraded sites of some parts of the Sudan, in the form of agroforestry, would regenerate and maintain soil fertility through litter mineralization, nutrients cycling and most likely nitrogen fixation. Agroforestry systems can provide ecological benefits, such as recovery of biodiversity (Montagnini *et al.*, 2005).

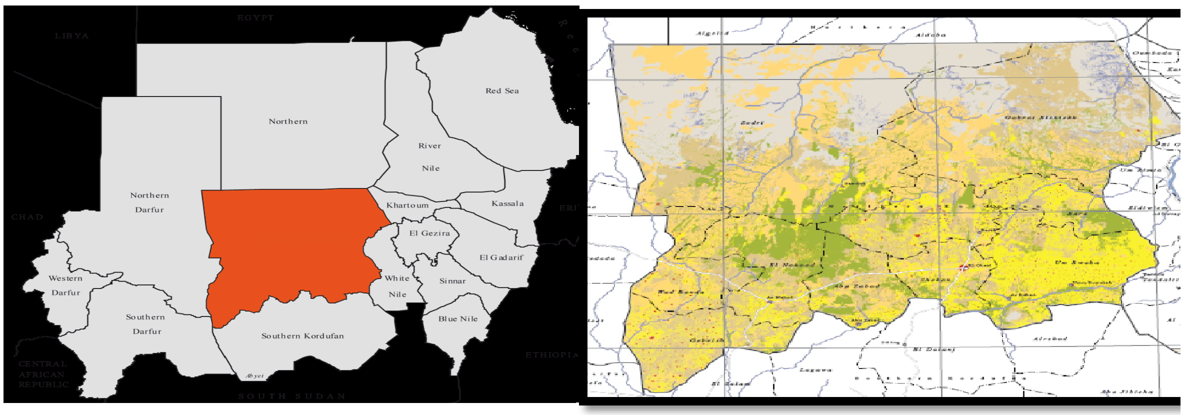
Agroforestry Systems and Soil Fertility

Improvement of soil quality as a result of establishing trees in degraded ecosystems is a process of accumulating Carbon and Nitrogen, which are higher under old forest sites than younger forest sitesHussein and El Tohami (1998). Old forest site contains more than twice as much Carbon and Nitrogen as the adjacent arable land open for grazing, on *qoz* soils under *Acacia senegal* and traditional agriculture where sorghum, millet, sesame and groundnut are cropped. Several investigations have been carried out on soil fertility aspects of some tree-based systems. It has been suggested that the presence of trees would also lead to an improvement in soil-water supplies. It was found that, under agroforestry land use system incorporating *Acacia senegal*, soil properties have been greatly influenced by tree cover; total organic carbon and nitrogen are more under the tree than cultivated agricultural schemes in the vicinity, and the cation exchange capacity is greatest under *Acacia senegal*, indicating more available nutrients under the trees (Amira and Ahmed, 2002). The same authors Amira and Ahmed (2002) reported that, soils under *Acacia senegal* trees had less bulk density than in the cultivated fields, indicating favourable physical soil conditions. For providing more food, an extra certain and rapid means of restoring soil fertility is required. Agroforestry systems would appear to ensure a more quick recovery and longer maintenance of soil fertility.

RESEACH METHODOLOGY

The Study Area

Sudan is situated in northern Africa, lying between latitudes 8° - 22° N and longitudes 22°- 38° E sharing common borders with nine countries with an area of 728215 square miles and has an estimated total population of 30,894,000, 70% of them live in rural areas (Facts on Sudan, 2014). The study area was the gum belt of Kordofan in Western Sudan (Figure 1). Three main gum production sites were selected: Sheikan, Om Rowaba, and El Nuhud; they contribute considerably to the total gum production of the country.



Sudan map   North Kordofan State map

Figure 1: Location of the Sudan and the Study Area

Methods for Data Collection and Analysis

In each site, four villages were randomly selected; Um kitaira, Eldemokeya, Umsimaima & Elhimaira in Sheikan Locality,Abutilaih, Umelsheikh, Umgezira & Elailafoun from Om Rowaba Locality and Rawyana, wadelhilaiw, abumaraiga & Abuhimaira (El Nuhud Locality). From each village, three soil samples (1 kg per each sample) from both agroforestry and sole cropping systems were randomly taken using the auger at three different depths: 0-20, 20-40 and 40-60 cm. Therefore, the number of replicates was:

3 (production sites) × 4 (villages) × 2 (farming systems) × 3 (depths) = 72 samples

Physical and chemical analyses were made for different soil samples. The soil physical analysis was performed using the Modified Hydrometer Method and the textural classes were determined according to the American System using the USDA Classification Scheme. The soil chemical analysis covered determination of PH, electric conductivity (EC), and Calcium, Magnesium, Bicarbonate and Chloride content. The total Nitrogen content was determined using Micro Kjeldhal Method. Then after, the soil samples were air dried and sieved (using a 2 mm sieve), mixed and kept for subsequent analyses. Specially designed questionnaires have been distributed to

164 household farmers in the selected villages to collect data pertaining to land productivity in agroforestry and mono cropping farming practices, in addition to other social data related to resource management. The SPSS program was used for data analysis and interpretation.

Crop yields under different farming systems were obtained; accordingly the Land Equivalent Ratio (LER) was calculated based on Sylvia (1999) using the following equation:

LER = $Intercrop_1$ yield ⁄ pure $crop_1$ yield + $Intercrop_2$ yield ⁄ pure $crop_2$,…..etc

Whereas:

$intercrop_1$, $intercrop_2$ refers to different crop types used in agroforestry.

Pure $crop_1$, pure $crop_2$ refers to different crop types used in mono cropping.

The partial LER for different crops was obtained and finally the average LER for different farming systems was calculated using the SPSS program, regardless of the combined crop incorporated.

RESULTS and DISCUSSION

Soil results

As has been presented in Appendix 1, the findings of the study showed that agroforestry practices have a positive effect in improving some soil physical properties namely bulk density, porosity and permeability. Improvement of such physical properties is recognized to reduce surface runoff and erosion, improve soil water holding capacity and enhance efficiency of nutrient use. This result has come in line with the literature that reported; crop production is improved and sustained as a consequence of positive effects of trees on soil physical properties. It was also mentioned that lower soil bulk density under such trend is partly due to inputs of the organic matter from trees (Bayala *et al.*, 2003).

The study results shown in Figure (2) indicated an increase in N, P, Ca, Mg, Cl and HCO3 content under agroforestry involving Groundnut, Sorghum, Millet and/or Sesame compared to sole cropping practices. The soil was found to be slightly acidic with very low electrical conductivity under the two practices. Nevertheless, soil reaction was somewhat acidic; this might be attributed to the presence of organic acids. The observed values of electric conductivity were not alarming as far as salinity risk is concerned. Chlorine and Bicarbonate contents were found to be almost similar, however lower than the values reported by Amira and Ahmed (2002).

The effect of agroforestry practices in improving soil elements was reflected in high crop productivity compared to relatively low values in case of sole cropping. Typical example was reported for the per unit area production values of two main agricultural crops, which are of great importance to people in the area, these are Groundnut and Sesame (Figures 3and 4). This would in turn improve the farm income and hence the farmers livelihood and living standard.

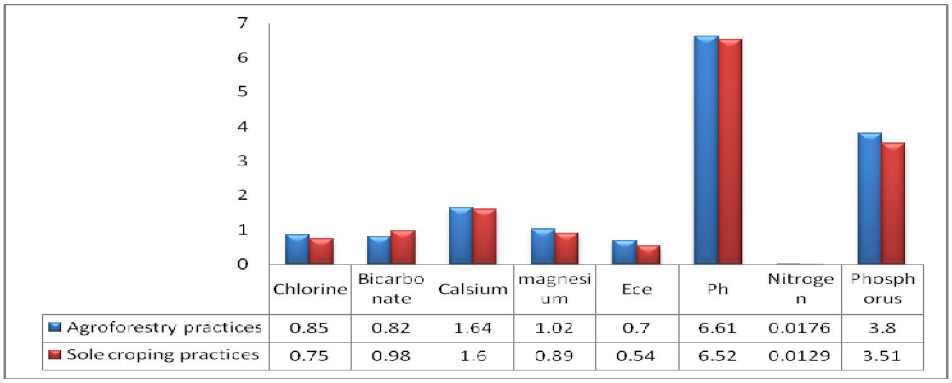


Figure 2: Amount of Some Soil Elements under Agroforestry System Compared to Mono-cropping in the gum belt

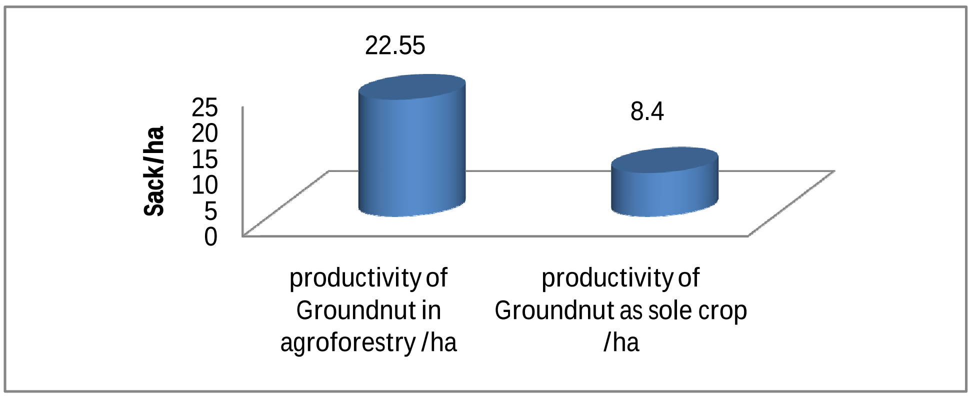


Figure 3: Productivity of Groundnut in Agroforesrty System Compared with the Sole Crop/ha

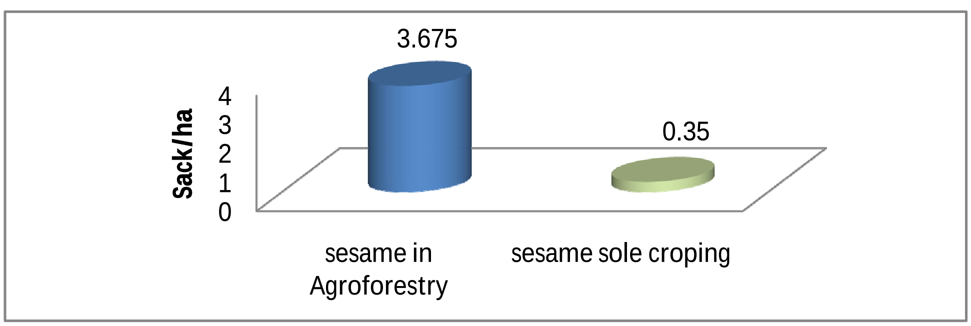


Figure4: Productivity of Sesame in Agroforesrty System Compared with the Sole Crop/ha

Tree Crop Interaction as Reflected in Land Equivalent Ratio

The study results presented in Table (1) are exemplification of the land productivity expressed by the average land equivalent ratio (LER) of different agricultural crops used in combination with the *Acacia senegal* tree.

Table 1: Percentage of farmers having different values of LER (< = or >1)

Crop type	Land Equivalent Ratio (LER)		
	<1	=1	>1
Sesame	24.1	24.1	51.8
Sorghum	18.7	25.0	56.3
Groundnut	31.6	36.8	31.6
Millet	16.7	44.4	38.9
Mean (%)	22.8	32.6	44.7

When the LER was calculated, a value of less than 1 is reported by 22.8% of respondent farmers, while LER value equals to one was found in case of 32.6% of the sample, and 44.7% of target farmers reported an average LER greater than 1. Accordingly, the study conclusions advocated that cultivating agricultural crops in combination with *Acacia senegal* tree is better than sole cropping in terms of land saving and productivity. This is absolutely true regardless of field crops used, as long as the LER is equal or greater than one, which the case proved by the majority (77.3%) of the target respondents.

CONCLUSIONS

Agroforestry practices involving *Acacia senegal* tree as a component of cropping patterns have a positive effect on soil properties and consequently on land productivity. Improvement of soil physical properties as well as increasing content of some elements, as was proved in results of analyzing soil samples, have been reflected in soil fertility.

The overall benefits from agroforestry farming systems proved to be better than sole cropping; this was expressed by high scores of LER. Therefore, it is reasonable to conclude that agroforestry provides guarantee for a sustainable farming system through maintaining soil fertility and increase of the land yield.

RECOMMENDATIONS

Agroforestry practices have to be adopted in all fragile lands of the gum belt of Kordofan to guarantee sustainable production and stable environment.

Further research in the field of land equivalent ratio and environmental services of agroforestry practice is urgently needed.

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Appendix 1: Some Soil Physical Properties under Agroforestry and Mono- Cropping in the gum belt of North Kordofan, Sudan

Domain	Exact site	Depth in cm	Particle density g/cm^3	Bulk density g/cm^3	Porosity %	Perm-ability cm/hr	Sand %	Silt %	Clay %	Textural class
Om Rowaba	monocropping	0-20	2.11	1.33	37.0	18.5	82.5	5.0	12.5	Loamy sand
		20-40	2.23	1.34	39.9	18.5	82.5	2.5	15.0	Loamy sand
		40-60	2.23	1.29	42.5	16.4	80.0	3.7	16.3	Loamy sand
	Agroforestry	0-20	2.23	1.35	39.5	27.2	85.0	2.5	12.5	Loamy sand
		20-40	2.14	1.31	38.8	34.8	83.7	1.3	15.0	Loamy sand
		40-60	2.61	1.34	48.7	29.3	81.1	1.4	17.5	Loamy sand
Sheikan	monocropping	0-20	2.43	1.33	45.3	29.6	85.0	1.2	13.8	Loamy sand
		20-40	2.57	1.36	47.1	29.2	50.0	1.2	48.8	Sandy clay
		40-60	2.36	1.37	42.0	28.0	51.2	1.3	47.5	Sandy clay
	Agroforestry	0-20	2.28	1.38	39.5	19.8	42.5	5.0	52.5	Clay
		20-40	2.39	1.33	44.4	20.7	45.0	2.5	52.5	Sandy clay
		40-60	2.39	1.40	41.4	22.7	52.5	1.2	46.3	Sandy clay
El Nuhud	monocropping	0-20	2.39	1.48	38.1	13.3	50.5	1.2	48.8	Sandy clay
		20-40	2.34	1.22	47.9	12.9	45.0	2.5	52.5	Sandy clay
		40-60	2.33	1.25	46.4	11.8	75.2	1.5	23.3	Sandy clay loam
	Agroforestry	0-20	2.38	1.28	46.2	12.2	76.5	1.5	22.0	Sandy clay loam
		20-40	2.39	1.43	40.2	14.1	74.0	1.5	24.5	Sandy clay loam
		40-60	2.38	1.30	45.4	17.4	75.2	0.3	24.5	Sandy clay loam