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AGROFORESTRY A SUSTAINABLE WAY TO ADAPT TO CLIMATE CHANGE

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ABSTRACT

Agricultural production across most of the dry regions of the world, especially in sub Saharan Africa is faced by multiple range of biophysical, socio-economic and policy constraints. In addition, the vulnerability of climate is considered the main obstruction that stands facing the sustainability of dry farming systems. Therefore, the inhabitants of these areas are often faced with high incidence of malnutrition and poverty caused by conflicts, harsh environment conditions such as low and unreliable rainfall, frequent droughts and fragile ecosystem resulting in low and declining land productivity. In Sudan, the total arid and semi arid lands is about half of the total country's area. This has a tremendous effect on the rural inhabitants given that agriculture is the source of living for more than 75% of the rural populations. As communities are exposed to unexpected or unforeseen changes in weather patterns and increased risk, there are growing concerns about the need for a farming system that can provide human needs while benefiting the ecological systems and their services. This paper portrays the variability of the ecological and socioeconomic conditions in the rainfed dry farming system of the Sudan and its problems. An in-depth correlation between land degradation, crop yield decline and the impact of climate variability or climate change on the sustainability of the rainfed farming system is presented. Then agroforestry was presented, using the previous and current research results outcomes, as one of the adaptation strategies to mitigate climate change and the vulnerability of the rainfed agriculture. Agroforestry with its diverse systems, products and services, management practices, can be tailored to suit different ecological and economical conditions of the rainfed dry farming system. Agroforestry systems can play a critical role in moderating the microclimate; and have potential to

limit carbon emissions and sequester carbon. They provide economically viable and environmentally friendly means to improve soil fertility; and have the capacity to enhance the efficiency use of rain water; as well as offering a major pathway for sustainable diversification of agricultural systems and incomes. Hence, agroforestry systems should be given special attention in the Sudan for their multidisciplinary nature where their usefulness is needed to reclaim degraded ecosystems or improve and sustain the current farming systems, where it can be adapted to counter foreseen or unforeseen climate changes.

Introduction:

Sustainability is a compromise between resource conservation and productivity of any land use system. Sustainable land use is that achieves production mutual with conservation of resources on which the production depends, thereby permitting the maintenance of productivity. Thus the objective of sustainable land use is the continuation of production over long period of time, from generation to another. Given the current food shortage, especially in the arid and semiarid regions of the world, and the virtually inevitable population increase, these call form of land use that will not only allow maintenance of current levels of production, but will sustain production at higher levels than at present. Hence, the aim of this paper is to presents problems of production in the dry farming system, with reference to rainfed agriculture in the Sudan, and thrash out the agroforestry land use system as a sustainable way to adapt to climate change under for the rainfed dry farming conditions.

Rainfed Dry Farming Land Use and Agroforestry:

In rainfed dry farming system one can distinct three land use systems, namely, crop production (agriculture), pastoral (animal production) and forestry (tree production). The spatial combination, in time and/or space, of these land use systems will result in a fourth land use system, known as “agroforestry”. Hence, agroforestry can be defined as a multifaceted land use, in which an intentional association of woody perennials (trees or shrubs) with crops and/or livestock to achieve ecological and economical interactions. Such association could be in time, for example, the rotation between tree components and crop and/or livestock components on the same land. This association, also, might be a simultaneous use of the land by the tree component and one or both of the other components in certain arrangements.

The agroforestry system, in the drylands, can be classified in three subsystems according to the associations between its three main components; trees, seasonal crops and animals (or pastures): agrosilvicultural systems (trees and seasonal crops), silvopastoral systems (trees and animals/pastures) and agrosilvopastoral systems (trees, seasonal crops and animals/pastures) (*Huxley, 1983; Nair, 1985*).

Dry farming system by definition is situated primarily in the drylands and its main source of water is rainwater (rainfed agriculture), where the average annual rainfall ranges between 250-600 mm (arid and semiarid regions). However, drylands represents a sizable portion of the Earth's potentially arable land surface. They range from the hyperarid regions in classic desert areas to more common semiarid and subhumid areas. The arid and semiarid regions are characterized with variability of rainfall in time and space, as well as the degradability of its natural resources (water, soil and vegetation); making them vulnerable ecosystems. Therefore, the production systems, especially that of rainfed system (dry farming), in these regions, with its current practices (such as monoculture), has impulsive productivity and no sustainability.

Rainfed Agriculture in The Sudan:

***Overview*:**

Sudan, in land area is the largest country in Africa, covering some 2.5 million km^2 (250 million ha) and stretches from 4º to 22º N, where about one third of it is desert (Fig. 1). Its vegetation cover is mainly governed by the amount of rainfall, which is ranging from virtual zero in the north to more than 1400 mm in the south. This dictated its climatic-ecological zones: desert (hyperarid) in the north, passing through semi-desert and savanna (arid, semiarid and subhumid) in the central belt to a true equatorial zone (humid) in the south (Jackson and Harrison, 1958; Andrews, 1948; Goda, 1977; World bank, 1987). The Sudan has population approaching to 40 million with growth rate about 2.8 to 3%. It is primarily an agricultural country with 75% of the labour force engaged in cropping, pastoral and forestry activities. The cultivable area is about 96 million ha of which 1.9 million ha is irrigated and 9.6 million ha is rainfed. The irrigated produces 95 % of the cotton, 32 % of the groundnuts, most of the vegetables and fruits, and all wheat and sugar grown in the Sudan. Irrigation water is provided from the River Nile, its tributaries, and to a limited scale from groundwater. The rainfed sector produces sorghum and millet, which are the most important staple food for the inhabitants, as well as sesame, short staple cotton, groundnuts and sunflower, which are cash crops. Rainfed agriculture has a very important role in the national economy and food security as it provides a large share

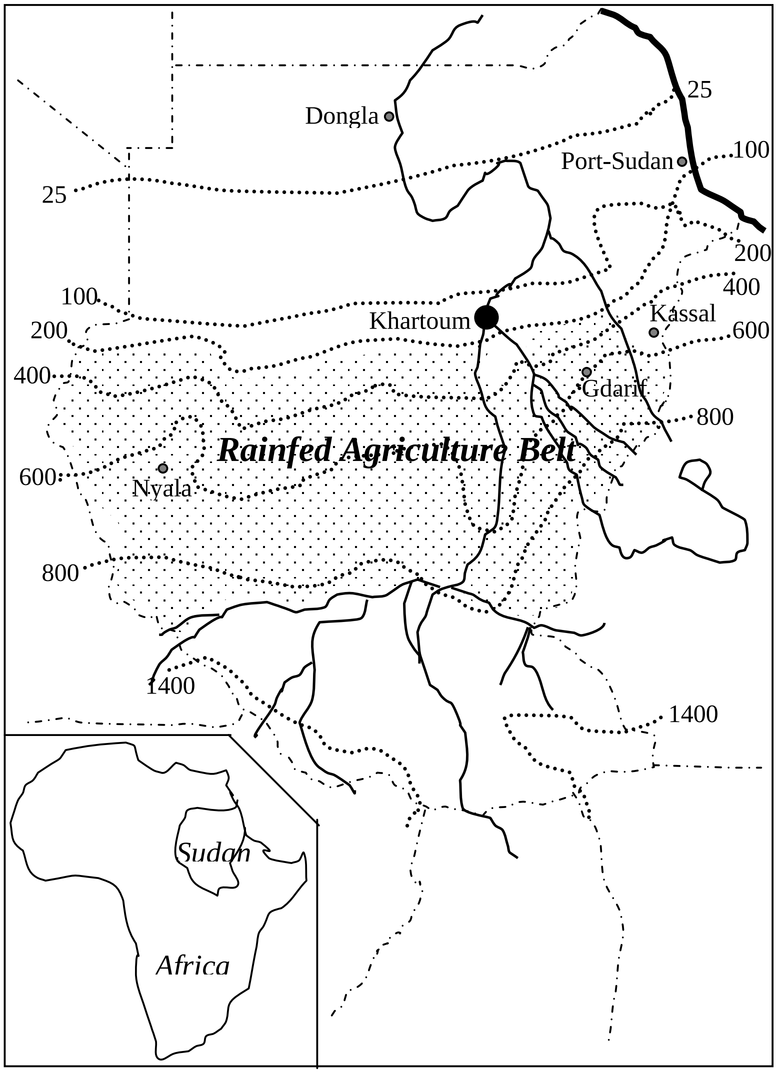

Figure 1. *Map of the Sudan showing the rainfall and rainfed agriculture belt.*

of the staple food (about 90 percent) and employs 66 percent of the total population. Besides, it has the capability for substantial horizontal and vertical expansions of the potential resources with low cost.

Rainfed agriculture is practiced largely in the semiarid and sub-humid zones in extended belt from the Western Regions to the Central and Eastern Regions of the country (Fig. 1), with exceptions to irrigated agriculture along the Nile and its tributaries. It comprises two subsectors: Traditional (TA) and Mechanized (MA). The

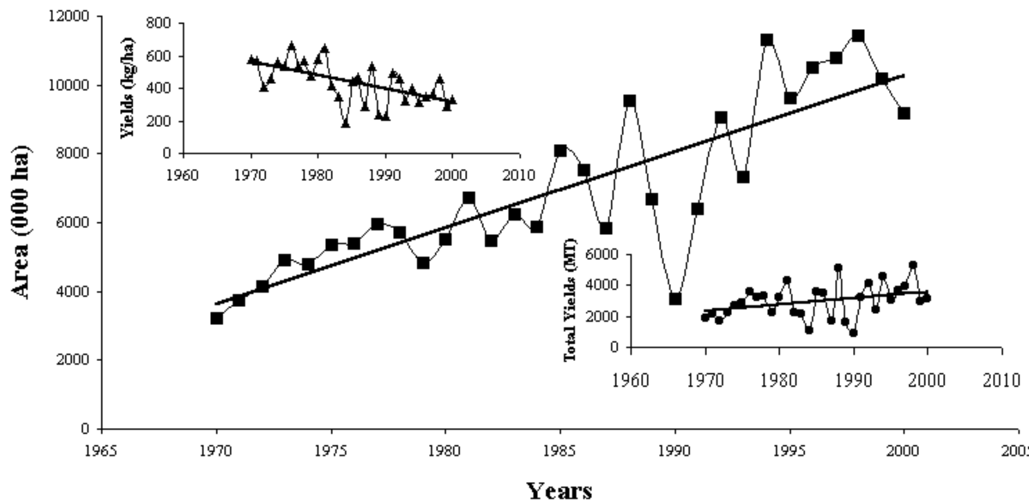

Figure 2. *Increases in rainfed agricultural areas, total yields and decline in land productivity in the Sudan. (Data source: AAS, 2001).*

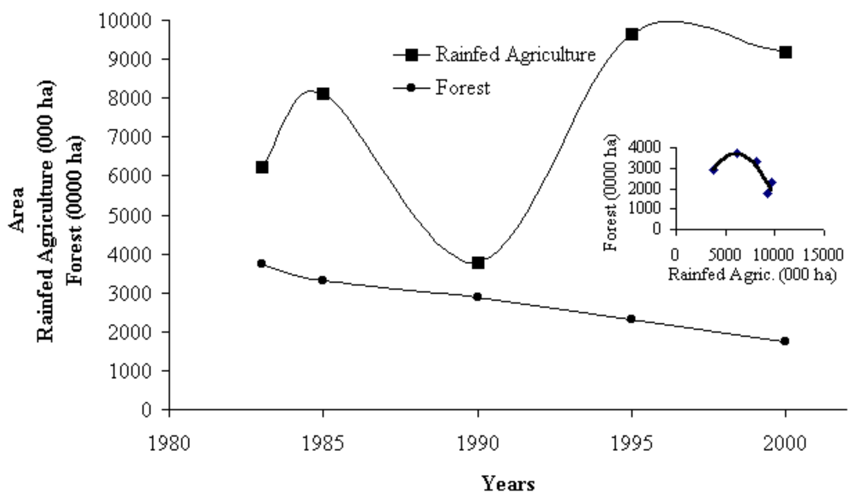

Figure 3. *Increases of rainfed land and decreases of forests from 1983 to 2000 in the Western-Central-Eastern regions of the Sudan. (Data source: World Bank. 1986: AAS. 2001)*

TA is practiced on small holding of 8-10 ha for growing sorghum, millet, sesame, and groundnuts in rotation, mainly by manual labor. Crops are produced for 5-10 seasons, and then interrupted by putting the land under *Acacia senegal*, for gum arabic production, for about 10 seasons (regarded as traditional agroforestry). The MA is practiced on large areas of 210-8,000 ha for growing mainly sorghum in a monocropping system and agricultural operations are partially mechanized by individual owners or companies. MA came into existence in the 1940s for provision of food to the British and their allied troops in eastern Sudan and Eritrea after World War II. More interest in the system by the government was shown in the 1950s to meet food security needs and to provide other crops for local industries and export. Due to monocropping system of MA, however, land became exhausted, leading to more land under cultivation to attain an equal amount of yield (Mensching and Ibrahim, 1976; Olsson, 1993). As a result of extensive horizontal expansion of the MA, the rainfed agriculture cropped area increased more than five-fold between 1970 and 2000, while total production unstable and land productivity tended to decrease with time (Fig. 2). This expansion is due to the MA cultivated lands and on the expense of the natural pastures and forests (Fig. 3). This antagonism between the MA and natural pastures and forests resulted in land degradation and desertification, which are intimidating the productivity and sustainability of the current land use system.

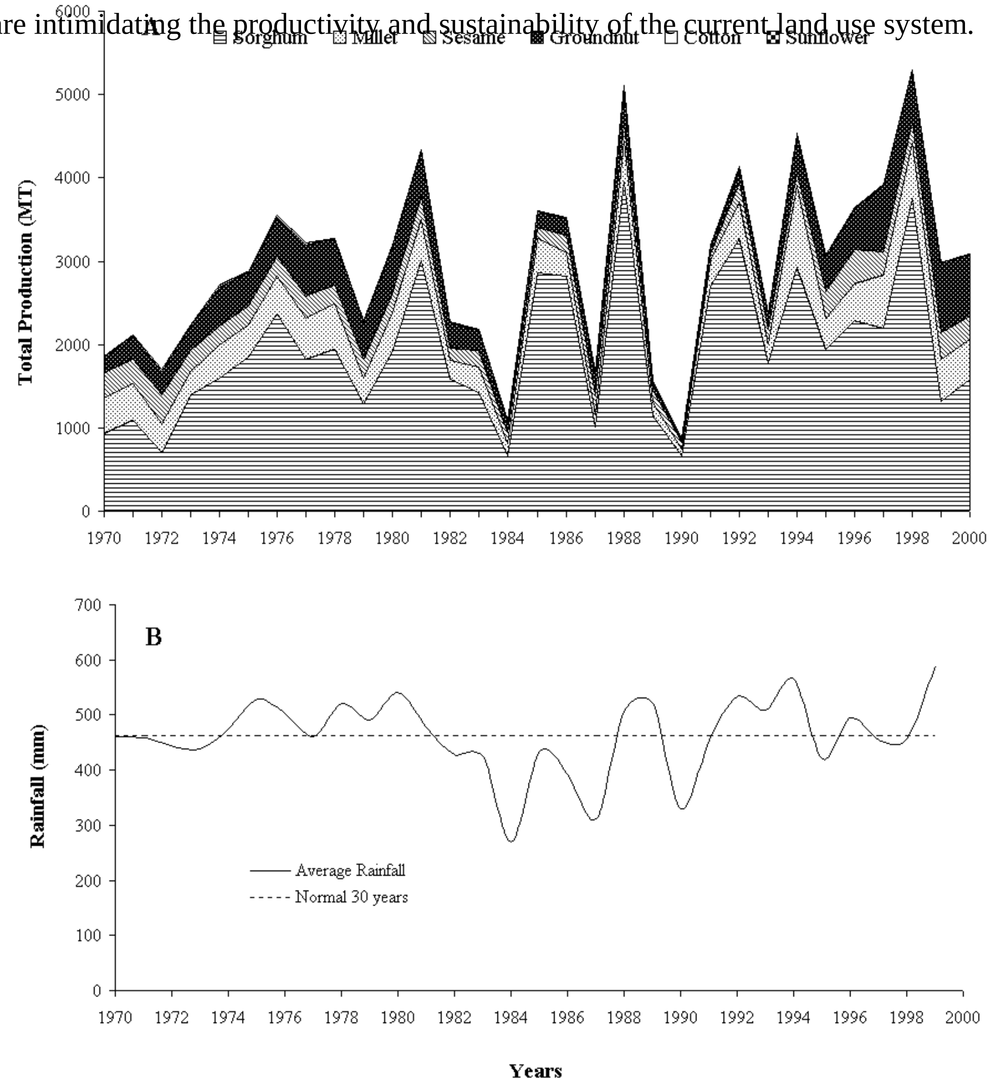

Figure 4. *Total production in rainfed sector (A), and rainfall (B) in the Western-Central-Eastern regions of the Sudan during the period 1970-2000 (Data source: AAS, 2001; Met. Dept., 2000).*

Problems:

Two major problems that hamper productivity and unsustainably of the rainfed agriculture in the Sudan can be identified. These are: a) variability in climatic conditions, and b) land degradation.

Climate:

The impact of climatic conditions on the rainfed agriculture in the arid and semiarid zones (dry farms) is mainly attributed to high variability of rainfall in time and space. Crop yields in the rainfed areas are generally correlated with seasonal rainfall. Fig.4A shows the yields of sorghum, millet, sesame, groundnuts, cotton and sunflower for the period 1970-2000. Referring to rainfall deviations from the normal in Western, Central and Eastern Sudan (Fig. 4B), it is evident that the lowest yields in 1984 and 1990 seasons, have coincided with the lowest rainfall during the two seasons. However, the impact of rainfall on crop yields is not always dependent upon seasonal total rainfall. Equally, rainfall distribution within the season has very significant implications on the yields. This could be illustrated by analyzing the effects of two seasons with equal rainfall, but very different in their sorghum yields (Fig.5). Splitting the seasonal rainfall in the two seasons into monthly totals would

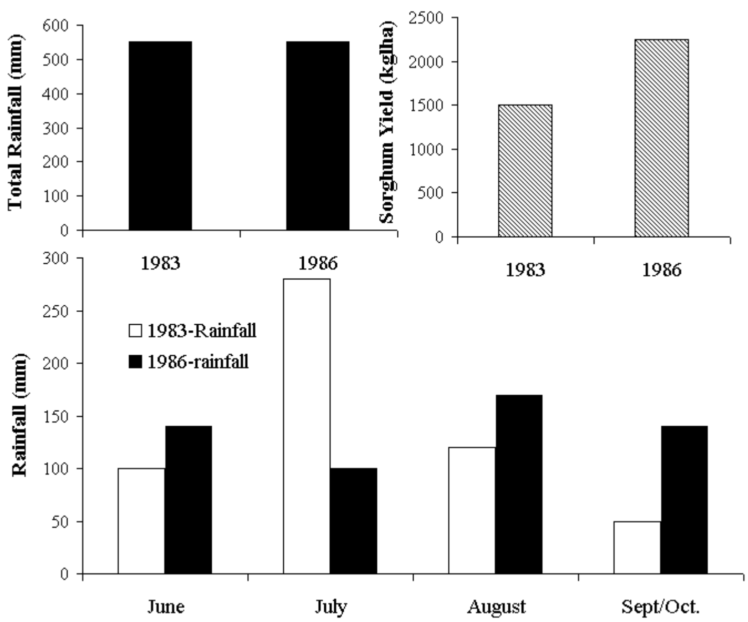

Figure 5. *Rainfall and sorghum yield during two seasons under rainfed conditions (Source: Farah et al., 1996).*

give an explanation of the reasons. The season of 1983 was characterized by a dry June, which delayed planting. The high rainfall of July and August adversely affected the seedlings growth, being small in size, and the low rainfall in September/October, which coincided with the grain filling stage. On the other hand, the season of 1986 had a higher rainfall in June, which permitted early planting so that the seedlings grow larger in size; not adversely affected by July rainfall and benefited from the high rainfall of August, September/October.

The significant role of rainfall distribution rather than its total amount in determining crop yield was clearly shown when the number of days with rainfall were considered for millet yields in central Sudan (Olsson and Rapp, 1991) and millet and sorghum yields in Kordofan and Central Sudan (Olsson, 1993). Regarding effects of climatic factors, the number of days with rainfall (>1 mm) showed the highest impact and accounted for 66% and 55% of the variation in millet and sorghum yields, respectively.

Land Degradation:

The problem of land degradation is manifested in decreased soil fertility (low nitrogen and organic matter) and enhanced topsoil erosion by water runoff and wind. This could be ascribed to the rapid increases of human and animal populations, which necessitated the expansion of the cultivated area, resulting in overutilization of the land (Mensching and Ibrahim, 1976; El Karouri, 1986; Olsson, 1993). The extensive expansion of the cultivated area not only affected land and crops, but also wildlife. In some ecosystems, wildlife habitats have been adversely affected and their numbers have decreased; some species were completely vanished and those remaining were endangered (El Karouri, 1986).

Also, the mismanagement of agronomic and cultural practices has lead to deterioration of the land resources. The population in Sudan increased from about 19 million in 1980 to about more than 35 million in 2009 and the rural population from about 15 to 27 million during the same period. Likewise, the number of livestock increased about 20 times between 1917 and 1977 (Olsson and Rapp, 1991). Livestock numbers are maximized irrespective of their quality and availability of feed requirements, mainly to safeguard for losses resulting from epidemic diseases. Also, increasing the number of watering points regardless of the carrying capacity of pastures has resulted in overgrazing.

In the traditional agriculture (TA), preparation of the cultivated land starts with cutting down some of the trees to open cultivation space and cleaning the weeds to secure soil moisture and light for the crops. This is repeated year after year, which results in destruction of the vegetation cover and ultimately soil deterioration and reduced productivity. Although some rotation is practiced in the TA by rotating sorghum with other crops, e.g., sesame, groundouts and millet, the land fertility declines with time and needs to open a new cultivable area becomes necessary. In Kordofan and Dar Fur regions where bush-fallow system is practiced, the old land is usually used for Gum Arabic production by *Acacia spp.* trees, (traditional agroforestry or shifting cultivation) a practice that permits the regeneration of the soil fertility.

In the mechanized agriculture (MA), on the other hand, the trees are completely uprooted, when new land is opened, to facilitate mechanization. Moreover, there is no rotation and sorghum monocropping is the practice. The non-sustainability of the monocropping system could be due to number of facts. Cultivating the land with more than one crop could be an alternative option for spreading the risk so that if one crop fails, the others might compensate. Also, crops with different root systems can use the soil more completely and efficiently and help in eliminating the negative effects of the hard pan. Another drawback of the monocropping system is the spread of pests and parasitic weed species, which are associated with sorghum, e.g., *Striga sp.* It has been reported that yield losses due to infestation of sorghum by *Striga* are often significant and that complete crop failures are not uncommon (Ejeta *et al*., 1993). It has been shown that replacing the sorghum with sesame or leaving the land fallow, even for one season, could lead to substantial yield increases. Using rotations with different crop species would allow control of weeds and other pests effectively (Mahmoud, 1992).

Agroforestry for Sustainable Rainfed Agriculture System:

Due to the abovementioned drawbacks in the current cultural practices and irrational land use strategies, it can be inferred that rainfed agriculture, in the Sudan, is posed with serious land degradation and non-sustainable productivity. It is the tenet of this paper that an ecosystem approach, for the land use, will be a comprehensive elucidation of many of the problems that face the sustainability of the rainfed agriculture. The sanity suggests that agroforestry systems are likely to be more an ecosystem land use approach.

Hence, one might classify the problems related to the sustainability of rainfed agriculture, according to their sources, into three major classes; problems due to climatic factors, problems due to management factors and problems related to socioeconomic factors. Further, the management problems can be subdivided into problems related directly to the soil or problems related to the microenvironment.

Henceforth, based on literature review and very limited experimental data, we might point out the consistent potential of agroforestry in minimizing or overcoming the problems of the rainfed agriculture. One could start with the problems of the soil degradation, such as topsoil erosion, loss of fertility and development of hardpan.

The current rainfed agriculture system is subjected to extensive topsoil erosion, which could be attributable to rainfall erosivity, soil erodibility, runoff, and/or wind. Wiersum (1985) showed that the presence of tree canopy decreased the raindrop energy (erosive power) by 24%. This indicated that the tree canopy couldn’t be expected to reduce rainfall erosivity to a substantial degree. However, soil with good structure has better infiltration rate and lower detachability. This is found under trees rather than under pure cultivation systems, which is most properly ascribed to the increase in the organic matter content under the trees. For this reason, most agroforestry systems are capable of maintaining soil organic matter at levels higher than under pure agriculture. In Fig. 6 the rates of erosion are compared for natural forest, agroforestry system and crop cultivation system (Adopted from Wiersum, 1984). This shows the potential of agroforestry to maintain or improve soil organic matter will help to check erosion and barrier tree hedges substantially increase infiltration and reduce runoff and wind speed (Young, 1989).

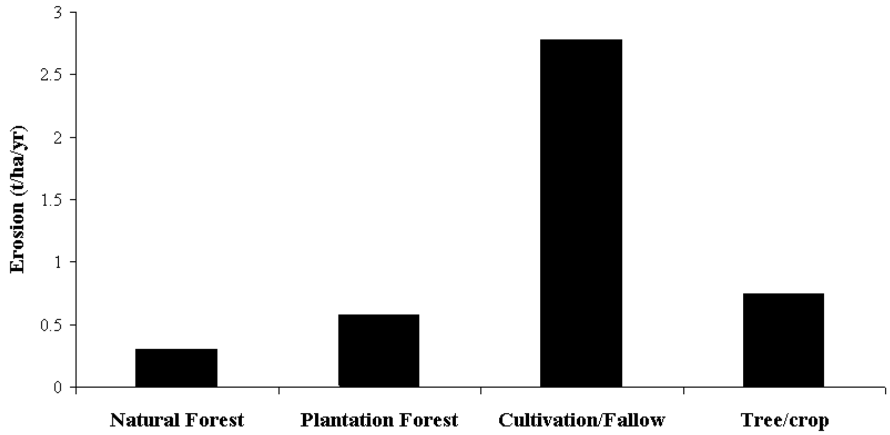

Figure 6. *Rate of soil erosion under different land-use systems (Wiersum, 1984).*

As a result of the monocropping practices in the rainfed agriculture the land productivity and soil fertility decline season after season. This could be attributed to a number of reasons. Such as, the same rooting depths in the soil profile of the same crop results in depletion of soil nutrients and development of hardpan. Also, the development of the hardpan results from continuous ploughing or land preparations to the same soil depth. Therefore, contribution of agroforestry in the elucidation of such problems will be through the deep spreading roots of the woody perennials that associate with the field crops. They are capable of exploiting more soil volume at deeper depths and taking up nutrients and water from layers that usually not reached by field crops. This eventually will result in nutrient extraction from deeper soil profiles and depositing at least part of them on the surface layers through litter fall. Nair (1984) cited some experimental and field evidences of improvement of soil fertility by the presence of trees or bushes. One advantage should be attributed to agroforestry is the possibility of improvement of fertility status of agriculture land through addition of nitrogen to the system through its fixation by the tree legume component. Cultivation of sorghum grain under the *Faidherbia albida* increased the yields over 10% compared to those of the pure crops stand (Fig. 8A). Also, significant increases in the yields attained by cultivation of groundnut, sesame and millet under *Acacia senegal* agroforestry (Fig. 8B). El Tahir *et.al* (2009), showed that conversion of *A. senegal* plantation to intercropping and or pure crop systems have resulted in significant changes in soil nutrients concentrations, stocks and dynamics of OC, N, P and K. While changes to some soil properties have appeared across all land management systems (Table 1). Their study revealed that tree-based systems enhanced soil fertility compared to pure cropping. On the basis of good soil quality under intercropped systems, it is suggested that whole-tree clearance does not only deprive the soil from organic matter but also leave it prone to wind and water erosion with subsequent decline in productivity. Intercropped systems in general, and particularly those at high-tree density, showed less decrease for the nutrient stocks.

Table 1: Soil properties at topsoil (0.3 m depth) and Changes (from 1999 to 2002) in stocks of OC, N, P and K under different land management systems at El Demokeya Research Forest, North Kordofan, Sudan. (El Tahir *et.al*, 2009)

	Soil Nutrient Properties					Stocks loss (kg ha^{-1})			
LMS	OC (%)	N (%)	C/N	P (ppm)	K (c-mol kg^{-1})	OC	N	P	K
PL	0.17a	0.027a	6.3c	5.6a	0.16	-	-	-	-
HD+S	0.09d	0.020c	4.3e	2.4cd	0.15	3349ab	257d	14a	36
LD+S	0.10cd	0.019c	5.4d	2.6bc	0.14	2744abcd	323c	13ab	40
PS	0.10cd	0.012e	8.4a	2.3d	0.13	2990abc	630a	14a	27

LMS: Land Management Systems. PL: Plantation (pure *A. senegal)*. HD and LD denote 433 and 266 trees ha^{-1}, S denote sorghum PS denotes pure sorghum crop. Means followed by the same letter(s) in the column are not statistically different at the 5% level.

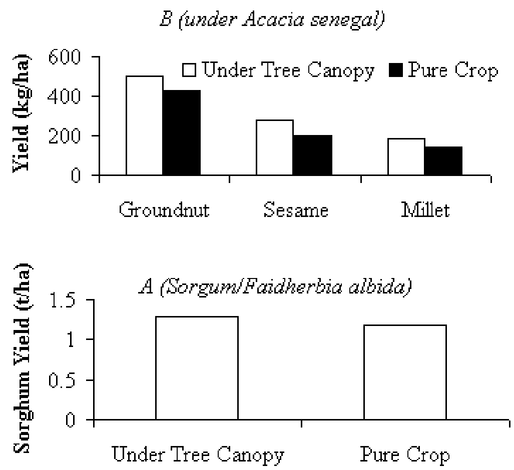

Figure 8. *Yields of different crops under tree canopy and in pure crop stand (Hamid, 1990; Fadul, 1999).*

In addition to the above mentioned advantages, the agroforestry has social and economical contribution besides the production of the ordinary field crops and/or livestock, which is the tree component. Trees are to contribute in different needs of the rural poor communities by enhancing the production diversity, such as supply of energy, food and shelters (building and furniture). In intercropped systems, trees can provide farmers with additional income from sale of gum Arabic during the dry seasons when crop production is curtailed. Hence, wholesale tree clearance of A. *senegal* for other land use systems on the sandy soils of western Sudan is the major cause of soil degradation that threatens the sustainability of the small holder farming systems in the region. Long-term sustainable agriculture in semi arid Sudan requires external inputs of nutrients and organic matter which can partly be provided by the intercropping of trees and crops. The tree component might compensate for crop failure in the unsuccessful seasons. Also, prospective potential in combating the variability in the rainfall and drought in the dry farming system is to combine agroforestry systems with water harvesting techniques.

Suggestions for Future Research:

Agroforestry system research-should be given special attention in the Sudan. It is a multidisciplinary in nature while is complex and its results are urgently usefully needed whether for reclamation of degraded ecosystems or future improvement. The following research activities are suggested:

i. Diagnostic survey should be conducted to identify farming systems that incorporate tree and shrub species as an integral component in order to help design the appropriate agroforestry modules to suit specified systems. The survey should also seek to (1) identify and classify the indigenous and exotic trees/shrubs species of an AF potential according to their uses, (2) identify existing local knowledge of the species and their uses and (3) investigate methods of maintaining and/or improving the productivity of the indigenous tree and shrubs species.

ii. Comparative trials on range of typical sites using indigenous and exotic fast-growing multi-purpose tree/shrubs to evaluate and test the species for different purposes and uses “drought tolerant, energy production, fodder and other products such as fruits, medicine, gums …etc”.

iii. Nitrogen fixation and multipurpose use of *Acacia senegal*, *Acacia seyal* and *Acacia tortilis* and other Nitrogen-fixing tree species (indigenous and exotic).

iv. Studies on the ecology, agroforestry and management of indigenous multi-purpose tree and shrub species.

v. Screening of drought tolerant and multi-purpose trees/shrub for planting in degraded semi-arid environment for sand dune stabilization and soil improvement.

vi. Application and evaluation of agroforestry combined with water-harvesting and management techniques for the establishment of the selected candidate species.

vii. Understanding tree-crop interaction and the processes controlling agroforestry yields, e.g. through eco-physiological, biophysical and socioeconomic research for modeling.

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