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RESEARCH PAPER

EFFECTS OF REFORESTATION ON DEGRADED SOILS IN THE MOIST SEMI DECIDUOUS ZONE OF WEST AFRICA

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ABSTRACT
Reforestation with trees and shrubs may be an effective means of increasing soil organic matter content and for regeneration of degraded lands. A study was conducted on a degraded farmland Chromic Luvisol (UNESCO/FAO) or Udic Rhodustalf (USDA, 1999) in the moist semi deciduous zone of West Africa, near Onwe, located at latitude 06^o 41' N, longitude 01^o 28' W, and at an altitude of 305m asl. The objective of the study was to quantify the improvement in soil physico-chemical properties of degraded Chromic Luvisol with exotic leguminous tree species compared to grass vegetation in the moist semi-deciduous zone of West Africa. To quantify changes due to reforestation, we measured some physical and chemical properties of soil after 20 years (1989 – 2009) of reforestation with Acacia angustissima (Acacia), Cassia siamea (Cassia), and Leucaena leucocephala (Leucaena) mixed and compared with soils under natural grass vegetation. Experimental design used for soil sampling and for evaluating the soil properties was randomized complete block with three replications. Soil organic matter increased from 1.19% to 2.02% while pH dropped from 5.65 to 4.79 in the reforested soils. Cumulative infiltration, infiltration rate, and gravimetric water content showed significant improvement under reforestation compared with soils under natural vegetation. Total porosity increased from 36.7% in the natural grass cover to 51.3% in the reforested soils. Reforestation resulted in significant reduction in bulk density from 1.67 to 1.26g/cm^3. Improvement of soil properties under reforestation indicates that planting of well-adapted and fast-growing exotic tree species can gradually improve soil quality and regenerate degraded lands. Reforestation may be thus recommended as a way of regenerating degraded land.

Keywords: *Degraded soil, reforestation, trees, soil organic matter*

INTRODUCTION
Slash-and-burn system is the most common means of land preparation by many small scale farmers in the moist semi-deciduous zone of West Africa. The burning serve as a means of controlling pest and disease and makes land

preparation easier. However, it destroys the litter layer and so decreases the amount of organic matter returned to the soil. Shifting cultivation, a dominant land-use system in the tropics has sustained agricultural productivity for many generations (Lckowitz, 2006; Nair, 1990). However, the rapid population growth in many developing countries has forced farmers to cultivate the land almost without break with low or no external inputs. According to Sanchez *et al*. (1997), soil fertility depletion is the fundamental biophysical cause of the decreasing per capita food production in Sub-Saharan Africa.

In Africa it is estimated that only 30% of the land is cultivable (FAO, 1990). It is even more alarming to know that each year about six million hectares of formerly productive land in Africa is turned into desert and a further twenty one million hectares reduced to a condition of zero productivity (Ferrari, 1989). This implies that even the 30% potentially cultivable land faces great threat in the face of increasing population and continuous cultivation.

The socio-economic constraints in many sub Saharan African countries has necessitated developing low external input strategies to improve the degraded soil. For instance, improvement and maintenance of soil quality has been achieved with the cultivation of crops and leguminous trees together (Kang *et al.,* 1981; Abunyewa *et al.,* 2004). Also planting of fast growing nitrogen fixing trees as improved fallows has been found to increase productivity in many parts of Africa (Sanchez *et al*., 1997). However, the type of trees and shrubs used for reforestation may be influenced by climate, type of soil and the purpose of reforestation (Lal, 2005). Nitrogen-fixing and non N-fixing tree species and native and exotic species can differ in their influence on soil properties (Binkley *et al*., 2000; Giardina *et al.,* 2001; Kaye *et al.,* 2002). Fisher (1995) indicated four mechanisms by which trees might ameliorate degraded soil: (i) increase the amount of soil N, particularly if the species fix nitrogen; (ii) alter the quantity and quality of soil organic matter and associated soil properties; (iii) enrich surface soil nutrients, particularly in deep-rooted species; and (iv) alter the microclimate by reducing temperature and moisture extremes.

The study was set up with the overall objective of assessing the comparative advantage of improved tree fallows against the traditional natural fallow systems with respect to their ability to regenerate degraded soils. The specific objective was to quantify the improvement in soil physico-chemical properties of degraded Chromic Luvisol (FAO/UNESCO, 1990) with exotic leguminous tree species compared to grass vegetation in the moist semi-deciduous zone of West Africa.

MATERIALS AND METHODS

The study was conducted on degraded and abandoned farmland near the University of Education, Winneba, Mampong Campus, in the moist semi-deciduous zone of West Africa, located at latitude 07^{o} 04' N, longitude 01^{o} 24' W, and at an altitude of 350m asl. The site experiences a double maximum rainfall pattern with peak rainfall periods in May-June and September-October and dry periods between November-February. The climate is typically tropical, with total annual rainfall between 1200 - 1500mm (GMET, 2006), annual average of 1270mm. The mean monthly temperature is about 25-32^{o}C. The potential evapotranspiration (PET) is estimated at 1450mm per annum. The average humidity during the wet season is typically high at 86% and falls to about 57% in the dry period (GMET, 2006). The soil at the study site is classified as Chromic Luvisol (FAO-UNESCO, 1990) or Udic Rhodustalf (USDA, 1999) and locally referred to as Peduase series (Asiamah, 1998).

In 1989, a degraded land under natural grass cover with grass species such as *Imperata cylindrical* (Imperata), *Penicum maximum* (Panicum) and sedges such as *Cyperus spp* was divided into two equal portions of one hectare (10,000m^2) each. One portion of the land was reforested with a mixture of *Acacia angustissima* (Acacia), *Leucaena leucocephala* (Leucaena), and *Cassia siamea* (Cassia) in a mixed stand. Although all the tree species used were exotic, they are well adapted to many climatic environment in sub-humid and semi arid zone of West Africa and are fast growing with high biomass production potential. The soil was not reconditioned and the trees were planted at tree population of 1250 trees/ha. The adjacent degraded land was left under the natural grass cover. The two portions of land had the same climate, soil type, and pre-experiment management. Both sites were not cultivated over the period under investigation.

Soil sampling and analysis

Before start of the study, soil samples to the depth of 300mm were randomly collected from the site, bulked and sub-sampled, air dried and stored for laboratory analysis. In April 2009, the reforested and the natural grass land cover were each sub-divided into three equal portions and assigned randomly as blocks 1, 2 or 3. Soil samples were randomly taken to a depth of 300 mm from each block, bulked and sub-sampled to represent that block. Soil samples collected from both reforested and natural vegetation cover were air-dried, ground, and sieved with 2 -mm mesh and stored for physico-chemical analysis. Soil pH was determined with 0.01 M $CaCl_2$ solution in a 1:2.5 soil: solution ratio, and soil organic carbon content was determined by the wet combustion method of Walkley-Black method as described in TSBF (1998). The conversion between organic matter by Walkley-Black and organic C was 1.724 (Nelson and Sommers, 1996).

The gravimetric water content of the soil samples were determined by the method described by Schmugge *et al.,* (1980). Two soil cores (total of six in each land cover) were randomly collected from each section to determine the bulk density as described by Lowery *et al.,* (1995). Total porosity (*f*) was determined from the particle density (PD) and the bulk density (BD) (Hillel, 1982) using the relationship:

$$f = 1 - BD/PD \qquad (1)$$

The double-ring infiltrometer method by Hillel (1982) was used for infiltration measurements. Under each land cover, a double-ring infiltrometer was installed at two sites to a depth of 150 mm to determine the cumulative infiltration and infiltration rates. Both the inner and outer rings of the infiltrometer were filled with water to 150mm mark. The water in the outer ring was maintained through constant addition as the water level fell. By means of a meter scale changes in water levels through soil intake were determined. The cumulative infiltration (I) was determined by finding the total water intake of the soil with time. The infiltration rate, *i* was determined by the relationship:

$$i = \Delta I/\Delta t \qquad (2)$$

ΔI= change in cumulative infiltration
Δt= change in time

The mean values of calculated parameters were determined for graphical presentations of the results.

Analysis of variance was carried out to compare mean values of parameters measured. When an F-test was significant at $P \leq 0.05$, the least significant difference (Fisher's protected LSD) at $P \leq 0.05$ was calculated and used to separate treatment means.

RESULTS AND DISCUSSION

The study site was an abandoned land that was degraded due to several years of cultivation with no external nutrient application. The initial soil characteristics showed that the soil had low total nitrogen and organic matter content with pH in acidic range and low exchangeable cations (Table 1).

Due to high vegetation cover in the moist semi-deciduous environment, and lack of mechanization, many small scale farmers practice slash and burn as a means of land preparation. Subsequent weed control is done mainly by tillage practices. With all-year round high temperature

Table 1: Some initial chemical properties of degraded Udic Rhodustalf in the moist semi deciduous West Africa

Parameter	Value
pH	5.3
Organic matter (%)	1.04
Total N (%)	0.10
Exchangeable K (cmol(+)kg^{-1})	0.11
Bray-1 P (mg kg^{-1})	3.05
Exchangeable Ca (cmol(+)kg^{-1})	4.32
Exchangeable Mg (cmol(+)kg^{-1})	1.28

as well as high soil water content during the cropping season, tillage practices enhance aeration which creates conducive environment for microbial decomposition and mineralization. However, reforestation and other practices that incorporate crop and other organic residues into the soil can regenerate degraded land by increasing soil organic matter content (Atsivor *et al.,* 2001; Macyk and Richens, 2002, Abunyewa *et al.*, 2004; Abunyewa *et al.*, 2005).

Significant differences were observed between reforested and natural grass cover soils in terms of physico-chemical parameters measured. The reforested land had significantly higher organic matter content than the land under natural vegetation cover (Fig. 1).

Soil organic matter content almost doubled under reforested condition compared with the land under natural vegetation cover and the

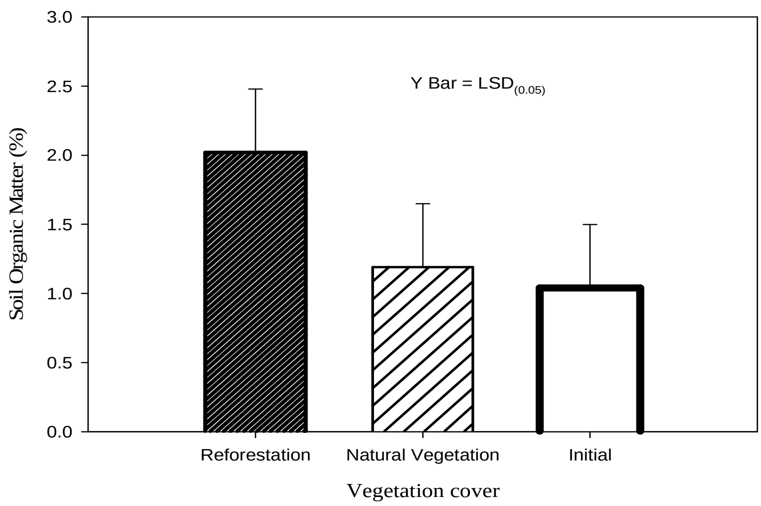

Fig. 1: Effect of vegetation on soil organic matter after 20 years of fallow in a moist semi deciduous West Africa

initial status. There was low soil organic matter accumulation on the grass cover due to low vegetation cover and poor biomass turnover. In the tropical zone, removal of vegetation cover and tillage practices generally results in high mineralization and reduction in soil organic matter status. Lui *et al.,* (2006) reported that soil organic carbon and total nitrogen on reforested soils had a linear relationship with length of years of reforestation. The higher level in the organic matter content of the reforested land may be attributed to accumulation and decomposition of plant residue and leaf litter (Brady, 1988). Besides adding organic matter to the system, perennial trees and shrubs recycle plant nutrients from deeper soil layers through their rooting system (Kanmegne *et al.,* 1999). Valverde-Barrantes *et al.,* (2007) observed that 68% of the fine root situated in the top 150 mm excrete root exudates and decaying root cells, which in turn are used as energy source by soil microorganisms. Thus the food web in the soil is maintained, even when no annual crops are grown.

Bulk density of soils under natural vegetation cover was significantly higher than that of the reforested land (Table 2). According to Brown *et al.* (1994), humid micro-climate created by the forest cover, and higher litter output from the trees enhanced activities of soil microorganisms, leading to fine textured soil and higher soil pore spaces. The humus that results from the organic matter decomposition tends to decrease soil bulk density and promote aggregate stability (Tester, 1990). This may account for the lower soil bulk density with reforested soil compared to the soil under natural vegetation cover. For mineral soils, lower bulk density is desirable since it enhances water intake and root penetration, making such soils more productive.

The reforested land had significantly higher gravimetric water content than the land under natural vegetation cover (Table 2). The presence of forest cover and higher leaf litter that served as mulch to increase water retention capacity and reduce soil evaporation may account for the higher mean gravimetric moisture value for the reforested land (Tian *et al*., 1993). The mean values of total porosity for the reforested land, 51.3% was significantly higher than that of the natural vegetation cover, 36.7% (Table 2). The difference could be attributed to higher soil organic matter content of the reforested land. The protective effects of the tree cover, both extracellular polysaccharides produced during decomposition of leaf litter and other organic material such as roots and root exudates, and fungal hyphae associated with the extensive perennial roots systems of the trees could be important binding agents for development of macroaggregates (Tisdale and Oades, 1982; Elliott, 1983; Macyk and Richens, 2002).

Cumulative infiltration (Fig. 2) indicates that water infiltration was significantly higher in the reforested land than the land under natural vegetation. Rate of water infiltration was significantly higher with the reforested land than

Table 2: Effect of vegetation cover on some soil physical properties after 20 years of fallow in a moist semi deciduous West Africa.

Soil Property	Reforestation	Natural grass cover	LSD
Bulk density (gcm^{-3})	1.26*	1.67	0.26
Gravitational water content (%)	11.93	8.73	1.32
Porosity (%)	51.30	36.74	2.89

**Mean of 3 samples*

the land under grass. The infiltration rate for the reforested land at five minutes of infiltration was 4.45 cm/minute and reduced to 2.78 cm/minute after one hour (Fig. 3). The rate for the land under natural vegetation was 0.75cm/ minute at five minutes and reduced to 0.25cm/ minute after one hour. High infiltration rate for the reforested land could be related to the in-

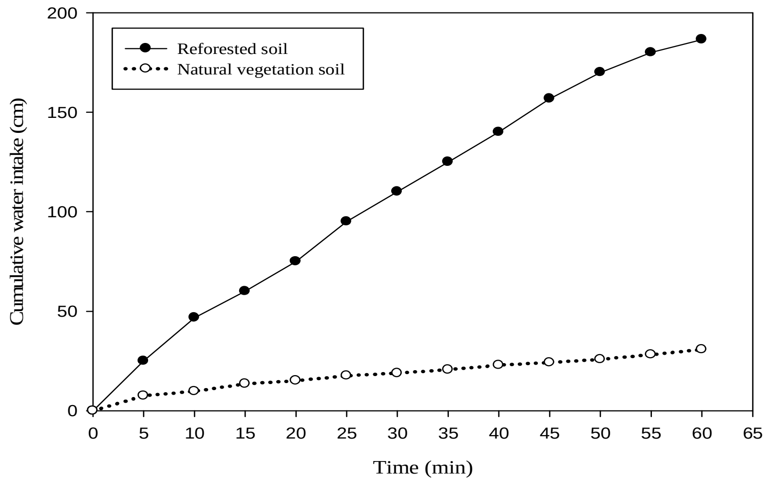

Fig. 2: Cumulative water intake with time of soil under reforestation and natural vegetation after 20 years of fallow in a moist semi deciduous West Africa

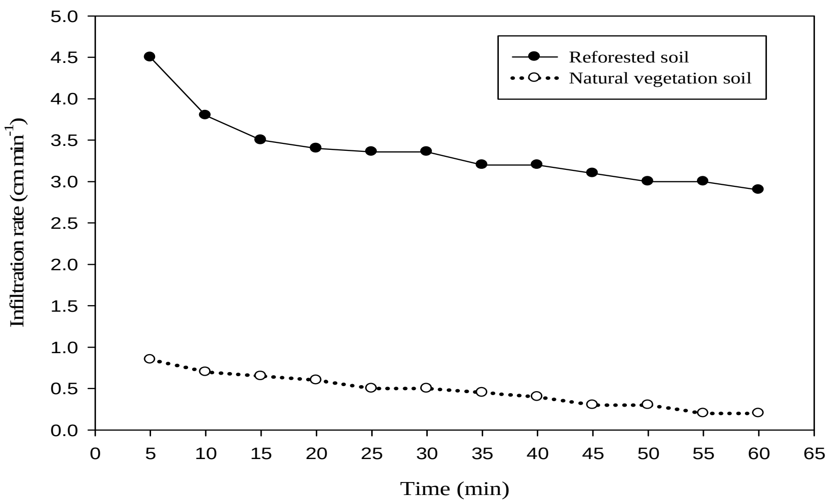

Fig. 3: Infiltration rate of soil under reforestation and natural vegetation after 20 years of fallow in a moist semi deciduous West Africa

creased humification of organic matter and increased activities of soil organisms as well as greater porosity and better structure of the soil (Tisdale and Oades, 1982; Elliott, 1983; Macyk and Richens, 2002). In separate studies, water conductivity in woodlots was found to be more than doubled as compared to the continuous cropping and natural fallow plots (Siriri and Raussen, 2003; Raussen *et al*., 1999). High infiltration rate with reforested soil may be responsible for the lower soil pH (4.79) observed compared to the pH of 5.65 under grass vegetation cover. Higher water infiltration rate of soil under the reforested land may enhance leaching of basic cations and thus leading to the lower pH (Islam and Weil, 2000). Also higher organic matter content of the reforested land could result in higher production of organic acids which may lower soil pH (Dijkstra and Smits, 2002).

CONCLUSION

Our study showed that reforestation improved some physic-chemical properties of the soil. Bulk density, total porosity, cumulative infiltration, infiltration rate, gravimetric moisture and organic matter contents all showed improved levels under reforestation than under natural grass cover. The study has confirmed that reforestation has beneficial effects on soil productivity of the Chromic Luvisol and is recommended as a natural, environmentally-friendly and low input method of regenerating degraded soils in semi deciduous moist zone. The study has shown the benefits of reforestation of degraded soils some with exotic nitrogen fixing tree species in the semi deciduous zone where poor farming practices had left many soils degraded. Reforestation may be thus recommended as a way of regenerating degraded lands.

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