Int. J. Forest, Soil and Erosion, 2011 1 (1):5-10
ISSN 2251-6387

Full Length Research Paper

Biotic and abiotic constraints to revegetation and establishment of functional ecosystem in degraded lands in a tropical environment

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Received: October 06, 2011 **Accepted:** October 14, 2011

Abstract: Land degradation and deforestation connote loss of biological and economic productivity, and confounds the widespread and increasing need for environmental conservation in the tropics and elsewhere in the world. Vast expanse of land are left bare, degraded and subjected to accelerated erosion and threat of desertification as a result of mining, agricultural and urban development activities in the tropics. Such degradation manifests in form of soil disturbance, accelerate environmental pollution, changes in physical and chemical properties of the soil, loss of forest covers and biodiversity, nutrient cycling and energy balances, and climatic stress factors. The accompanying deforestation brings about shifts in plant community and structure and strongly affect the survival and competitive advantage of native and alien (invaded) plant species. Abiotic stress factors will affect the ec-ophysiological attributes of plant species important to species diversity and adaptation or tolerance to degraded ecosystems characterised by microclimatic gradients and other stress factors. Remediation measures had been achieved through organic wastes amendments, topsoil replacement (soil reconstruction). Biorestoration of degraded landscapes for environmental protection may also be built on the recruitment of native components of biodiversity (tracts of vegetation from existing plant communities and remnants of primary forests and late successional species) for revegetation. In the tropics, there is therefore increasing and urgent need for remediation of degraded lands and to restore productive (functional) ecosystem. These efforts will assist in the development and sustainable management of degraded landscapes for agricultural production, biodiversity conservation and ecosystem health. The recuperation (restoration of the ecological balance and productivity of degraded lands) of degraded ecosystems will provide alternative land uses such as wild life/amenity parks, forest reserves, pasture/range lands and horticultural plantations, and preserve environmental quality. The reclamation and revegetation of degraded/eroded soils will improve ecosystem functioning and arrest further degradation.

Keywords: Land use, ecosystem, degradation, microclimate, restoration, organic wastes, amendment, vegetation.

This article should be referenced as follows:
Agele S O (2011). Biotic and Abiotic Constraints to Revegetation and Establishment of Functional Ecosystem in Degraded Lands in a Tropical Environment, **International Journal of Forest, Soil and Erosion**, 1 (1):5-10.

Introduction

Vast expanse of land are left bare, degraded and subjected to accelerated erosion and threat of desertification as a result of mining, agricultural and urban development activities in the tropics. Soil degradation produces changes in nutrient cycling and energy balances, soil properties etc. The accompanying deforestation brings about shifts in plant community and structure in addition to accelerated erosion, threat of desertification and microclimatic gradients. These gradients in microclimate have implications for leaf to air vapour pressure differentials which control plant water relations and energy balances. The loss of forest covers and topsoil and habitat gradients are accompanied by loss of biodiversity, accelerated conversion of primary to secondary forests and savanna and invasion by weedy natives and exotic annuals. There is urgent need for soil reconstruction and restoration of productive and functional soil-plant systems on these widespread degraded lands. Concerted and urgent efforts must be geared towards reclamation and restoration of functional and productive soil-plant systems on these degraded sites. The recuperation of these degraded ecosystems will provide alternative land uses such as wild life/amenity parks, pasture/range lands and horticultural plantations. Sustainable land use options and restoration/rehabilitation of these degraded ecosystems will control erosion, halt further degradation and preserve environmental quality. Unsustainable land use practices accelerate environmental pollution, produce physical and chemical soil degradation, loss of forest covers and biodiversity and microclimatic gradients. Solid mineral mining (exploitation) is important to the economy of many developing countries. In Nigeria for example, there had been increased interest in the exploitation of these resources and hence the widespread and increasing numbers of open cast mines of solid minerals (limestone, granite, iron ore, gemstones etc) leaving behind vast expanse of bare and degraded land (>10 hectares per mine; Ministry of Environment, Abuja, Nigeria) at close of mining operation. For example, extensive mining activities are carried out in the Okpela, Itape and Ajaokuta belt in the rainforest zone of Nigeria. The resultant mine spoils pollute the land, degrade the soil and in addition, the vein outcrops of minerals present toxic and stressful growing environment to plants. Mine lands left bare and degraded are further exposed to erosion and threat of desertification. Land degradation produce disturbances in ecosystem function and drastic changes in soil quality and shifts in plant community and structure in addition to microclimatic gradients. Land degradation confounds the widespread and increasing need for soil and environmental conservation in the tropics. The degraded lands/ecosystems present different habitats and change in the structure of vegetation such as edge of gallery forest with shade plants, shrubs, savanna ecotypes, rock outcrops and open minespoils. These habitats are non-supportive of plant growth. The gradients in microclimate may manifest as variable and high irradiance, soil water deficits, high temperatures and vapour pressure deficits, variable substratum depths and toxic levels of some minerals (Abrol and Nararyana, 1990). The microclimatic and stress factors of degraded habitats strongly affect the survival and competitive advantage of native and alien (invaded) plant species. Consequently, plant species with high tolerance of such elements are at a competitive advantage during initial colonisation and subsequent establishment. In other circumstances, soil surface is scrapped coupled with huge deposition of minespoils producing increased soil bulk density and conditions inhibitory to root penetration. High soil strength resists root growth, compact pores inhibits aeration and reduced hydraulic conductivity. Compaction decreases total porosity and pore volume and shifts in pore size distribution towards smaller sized pores (Felton, 1995). Diversity of species involved in the colonization of these habitats must tolerate the prevailing harsh growing conditions. Ecosystem and soil disturbance may affect the stability of soil functional processes, facilitates rapid conversion of tropical rainforests from primary to secondary forests and savanna and invasion of weedy natives and exotic plants. The change in vegetation may affect the rates of C and N cycling, ecosystem productivity, microbial community and structure and soil functional processes. There is therefore great need to protect/conserve tracts of vegetation (remnants of primary forests and late successional species). Thus the recruitment of these native components of biodiversity will reduce initial and maintenance costs of reclamation process thereby promoting the feasibility of restoring vegetation by using species important in the existing plant communities. The diversity among colonising species and ecophysiological strategies underlying species adaptations/tolerance to these stress factors need be evaluated. Information is also required on mineral uptake and its growth regulator status within plants growing under these conditions and the effects of these elements on the ultimate health of plants.

Materials and Methods

Experiment One

The effects of soil incorporation of some organic wastes on the establishment and growth of grasses were studied on degraded/eroded site in Akure, humid southern Nigeria. The experimental site was an uncontaminated urban clearance characterized by varying degrees of erosion, compaction and excavation (scrapping) of surface (top) layers of soil. This degradation processes produced soil containing excavated materials, decomposing brick wastes/concrete slabs, subsoil overlying hard coarse rubble of varying top soil thickness. The severity of erosion/degradation was classified using top soil thickness and other profile characteristics (Kaihura *et al.*, 1996). One hectare of land area was selected, divided into 5-m grids and a profile (60 x 60 cm) was dug at each grid point to a depth of 60 cm. Soil properties were used to define top soil thickness (TST) and ranges of TST established were used to define different erosion classes. This technique was based on paired comparisons between selected eroded phases within the site. Established erosion classes were therefore slight/none (A), moderate (B) and severe (C), the least (non-eroded) class had the highest TST. The slope and landscape effects between erosion phases were reduced by locating comparable plots on same landscape position with similar slope characteristics. Soil samples were collected from the respective established erosion classes, air dried, and ground, passed through a 2mm sieve. The samples were analysed for some physical and chemical properties using standard procedures. Treatments and data collection. On the surface of erosion classes A, B and C, was an application of zero, 10cm and 20 cm layers of substrate samples collected respectively from old (abandoned) municipal refuse dump, site affected by long-term surface disposal of poultry litter and top soil under fallow vegetation. In addition, there was application of 200 kg/ha NPK fertilizer on the erosion classes. The treatments were laid out using randomized complete block design with four replications. A mixture of native grass species (*Axenopus compresus, Cynodon dactledon* and *Elusine indica*) selected from the existing plant communities were established in May, 1999 from seeds which were collected locally. Biomass harvests were made in October, 1999 and June 2000. N uptake and concentration in plant tissue and the dynamics of total N and NO_3-N in soil were determined from replicate plant/soil samples collected from the different treatments.

Experiment Two

Vegetation survey was carried out to identify changes in plant community, structure composition and dominance (diversity) of species (physiotypes) which colonies' the different sites along the transects of abandoned/degraded open cast minelands in some part of humid southern Nigeria. Some soil and climatic variables (substrate composition from mine spoil cover, rock outcrops and undisturbed/native soil was assessed. The vegetation (species diversity, composition and dominance) was assessed from 100 m^2 transects including adjacent undisturbed soil (non-degraded) on top and floor of quarry using 3 x 3 m plots/quadrants (Shankar Raman *et al.*, 1998). The structure of the vegetation is characterised by the growth and establishment of natives (remnants of primary forest species and colonizers/the weedy natives) and invasion by weedy aliens. This was assessed through the examination of species composition and density through the identification of most important member of each component species. Shifts in plant community/structure due to open cast mining activities reflected in the different fractions of richness constituted by natives (remnants of primary forest species) and invasion by weedy aliens. The composition of different species in the vegetation presumably through invasion by colonizers (the weedy natives) and exotic species of grasses (annual/perennial graminoids), shrubs/herbs (broad leaved plants) and remnants of primary forests was examined through the identification of numbers of each component species in the sampled quadrant. Complicating factors affecting plant success such as water and nutrient stress, soil physicochemical status was assessed by detailed sampling and analysis of the growth substrate (soil). Soil physicochemical properties namely infiltration rate (double ring infitrometer), bulk density (core samples), substratum depth (soil profile characteristics) and soil temperature were measured. Mineral elements concentrations in soil and plant uptake and accumulation (Na, N, P, K, Ca, Mg, Zn, Cd, Bo, Cu and Fe) were determined using atomic absorption and photo-spectrometric devices.

Results and Discussion

The agronomic benefits of organic waste incorporation stemmed from improved soil properties in surface horizon and contents of essential nutrients supportive of the establishment and development of plant cover. Nutrient supply is related to soil organic matter status, organic wastes are therefore important to the reconstruction of effective nutrient cycling and the eventual functional soil-plant system on this degraded ecosystem. The goals of revegetation efforts are to improve soil and plant productivity, plant diversity, conservation of native grasslands and aesthetic. In this study, fast recovery of the established/replanted native grass species was attained, thus promoting the feasibility of using species important in the existing plant communities in the restoration of vegetation and soil productivity on degraded lands. Methodological detailed survey and assessment of soil properties supported association of TST with severity of soil degradation. Degradation manifested in decreased TST and induced adverse changes in soil properties, but organic amendments improved soil CEC, total N and organic matter contents and enhanced plant performance. Previous work has demonstrated the agronomic benefits of soil incorporation of organic wastes for the revegetation of degraded soils (Wong and Wong, 1989, Chu and Bradshaw, 1996, Agele, 2007).

In this study, surface application of topsoil, municipal waste and NPK fertilizer created artificial topsoil layer and/or overcome structural and nutrient stresses in the surface horizon and provided a store of nutrients (organic matter) which through mineralisation released nutrients slowly to the nutrient pool and become available for plant uptake. The materials tested in this study are valuable resources while their use in this form will reduce the need for disposal in landfill. Nevertheless, there is high potential health impacts of biological reutilisation of organic wastes particularly unsorted municipal refuse in terms of the degree to which this material may not meet national or state requirements for toxic elements. The potential health impacts will depend on the nature of the refuse input and care taken in the analysis of inputs, sorting and exclusion of hazardous materials before incineration/composting and disposal to landfill sites or reuse in the restoration of the productivity of degraded ecosystems. With respect to ultimate ecosystem health, the examination of the contents of organic wastes and amended soil for phytotoxicity effects, nutrient uptake and concentrations in plant tissue and on soil quality parameters is strongly recommended.

The results show that there were changes in plant community, structure composition and dominance (diversity) of species (physiotypes) which colonise the different sites along the transects of abandoned/degraded open cast minelands in some part of humid southern Nigeria. The soil and climatic variables examined (substrate composition from mine spoil cover, rock outcrops and undisturbed/native soil) also established the fact that toxic elements and resultant mine spoils could affect the ultimate health of the species in the plant community. The chemical analysis of the mineral composition of plants and the soil substrate could therefore indicate that plant success is related to nutrient uptake or deficiency or the presence of toxic elements. The assessment of the processes of vegetation succession (revegetation dynamics) showed the recovery of the structural attributes of vegetation in relation to the time elapse since abandonment (5,10 over 20 years after abandonment). The recovery of each component of the vegetation (plant community) may be related to sources of propagules and life histories of species. Slower recovery of native species compared to the aggressive weeds/exotics was observed. The most important plant species identified were: tree species (remnants of primary forests; shrubs/herbs; broad leafed plants) *Albizia zygia, Ficus exsperat, Terminalia superba, Ceiba petandra.* Others are weedy (annuals/perennials; herbaceous species and grasses) either natives or exotic colonisers. *Chromalaena odorata, Elephant grass, Cynodon spp., Imperata cylindrical,* Mexican sunflower (*Titiana* spp.).The observed remnants of primary forests (shrubs/herbs; broad leafed plants) were dominated mainly by tree species such as *Albizia zygia, Ficus exsperat, Terminalia superba, Ceiba petandra.* The observed changes in the species composition in the vegetation is attributable to invasion by colonizers (the weedy natives) and exotic species of grasses (annual/perennial graminoids).

Table 1 Physical properties of surface soil of the degraded urban site amended with organic waste materials.

	Erosion/Degradation classes			
	Severe	Moderate	Slight/none	SE
Topsoil thickness ranges (cm)	10 - 15	16 - 25	27 - 45	
Average depth (cm)	13.3	20.5	32.2	2.62
Sand (%)	55	50	43	3.47
Silt (%)	11	15	21	3.11
Clay (%)	39	33	26	4 .23
Bulk density ($Mg.dm^{-3}$)	1.45	1.32	1.16	0.06
Field capacity moisture (%)	14.2	17.4.	22.5	1.47
1500kPa moisture (%)	6.3	7.5	9.6	0.09
Available water content	7.9	9.9	12.9	1.03
Infiltration rate ($cm.h^{-1}$)	32.2	30.3	28.8	0.39

The microclimatic gradients and other stress factors affect plant performance; the consequent environmental perturbations resulted in varying degrees of stability of soil functional processes. Ecosystem disturbances affect soil resources (pH, CEC, organic matter, N, P, K, Ca, Mg) and vegetation structure and richness. Changes in plant community, structure or richness and soil resources are therefore possible indicators of ecosystem disturbance. These degraded sites are characterised by different habitats, for example, edge of forest gallery, open minespoils and rock out crops. The accompanied microclimatic factors are high irradiance (1000 -1200 $mol/m^2/s$) with day time light doses typical of these sites are PPFD < 33.5 $mol/m^2/s$ (400-700 nm), high temperatures (between 29 – 43 ^oC), wet to dry season transitions, extreme soil moisture deficits, leaf to air water vapour pressure differences (VPD) and high concentrations of mineral nutrients and variable substratum depths. Soil surface is scrapped coupled with huge deposition of minespoils produce increased soil bulk density and conditions inhibitory to root penetration. High soil strength resists root growth, compact soil pores inhibits aeration and reduced hydraulic conductivity. Compaction decreases total porosity and pore volume and shifts in pore size distribution towards smaller sized pores (Felton, 1995). Soil disturbance due to open cast mining activities affect the stability of soil functional processes; it facilitates rapid conversion of tropical rainforests from primary to secondary forests and savanna and invasion of weedy natives and exotic plants. The change in vegetation affects the rates of C and N cycling, ecosystem productivity, microbial community and structure/soil functional processes (Kanamori and

Yasuda, 1979). Consequently, plant species with high tolerance of such degradation are at a competitive advantage during initial colonisation and subsequent establishment.

Table 2 Chemical properties of surface soil of the degraded urban site amended with organic waste materials.

Erosion/Degradation Phase	PH (water) (%)	Organic carbon (%)	Total N (mg/kg)	Bray 1 P (mg/kg)	Cation exchange CEC (cmol/kg soil)
Severe	5.9	2.2	0.17	8.8	22.4
Moderate	6.2	2.4	0.24	10.2	25.3
Slight/None	7.1	2.7	0.22	11.5	29.3

Table 3 Grass biomass yield and chemical properties of surface soil of the degraded urban site amended with organic waste materials (Mean values across all classes of erosion/degradation)

Biomass	NO_3-N (g/g)	Mineral N concentration (g/g)									
Amendments (Kg/ha)	(Kg/ha)	3	6	9	12	15 (WAP)	3	6	9	12	15 WAP)
Unamended (control)	1617; 1158	---	---	---	---	---	---	---	---	---	---
Mineral fertilizer	3283; 2269	---	---	---	---	---	---	---	---	---	---
Municipal waste	4179; 3548	113	96	65	73	81	21	74	38	63	57
Topsoil	3905; 3157	32	26	17	25	22	17	21	9	13	15
Poultry manure	5236; 3953	125	103	81	94	102	27	93	68	86	72

*WAP - weeks after planting

Table 4 Physical properties of surface soil samples from abandoned minespoil

Sand (%)	55
Silt (%)	11
Clay (%)	39
Bulk density (Mg.dm-3)	1.84
Field capacity moisture (%)	14.2
1500kPa moisture (%)	6.3
Available water content	4.9
Infiltration rate (cm.h-1)	13.3

Adaptation of plant species to new environments is a major evolutionary phenomenon as plants species involved in primary colonization of eroded and degraded habitats are vigorous competitors that are able to survive physiologically stressful conditions. Such stresses may include high concentrations of potentially toxic elements associated with mineral vein outcrops, dusts and biogenic gases. The success of any plant therefore depends on both the microclimate and influences of stresses due to toxic concentrations of mineral elements, drought, dusts and biogenic gases (Seaker and Sopper, 1984). The microclimatic and stress factors of degraded habitats strongly affect the survival and competitive advantage of native and alien (invaded) plant species. The understanding of the temporal dynamics of physiological flexibility in the native/exotic species, for example, will be useful in the evaluation of successional changes (diversity/dominance) and reforestation based on selection and use of plant species tolerant/adapted to stress factors inherent in abandoned and degraded habitats. The understanding of the strategies underlying species adaptation/tolerance to the different transects and stress factors in degraded habitats is basic to successional changes and selection of species for reforestation. This information is important to the success of biorestoration and management of functional soil-plant systems on the widespread degraded opencast minelands produced by solid mineral mining activities in Nigeria. It will in addition serve as useful component in the efforts and the feasibility of restoring vegetation on soils containing potentially toxic levels of certain elements and bare/degraded lands as a result of mining activities using species important in the existing plant communities. The research results will contribute towards control of erosion and further degradation of abandoned minespoils, ensuring reserve of natural woodland and development of humic topsoil.

Table 5 Elemental composition of substrate samples from abandoned minespoil

pH (water)	10.3
EC (mmho/cm/s)	13.5
Organic matter (g/kg)	1.6
Total N (%)	0.06
Total P(mg/kg soil)	26.4
K (cmol/kg)	2.37
Ca (cmol/kg)	15.4
Mg (cmol/kg)	9.5
Cu (mm/kg)	11.3
Fe (mm/kg)	1.14
Mn (mm/kg)	67.8
Mo (mm/kg)	14.2
Pb (mm/kg)	1.8
Zn (mm/kg)	13.7

Conclusion

Worldwide in general, it is urgently required to sustainably manage landscapes (ecosystems) for agricultural production, biodiversity conservation and ecosystem health. The effects of microclimatic and soil stress factors of degraded land on hydraulic properties and water relations and implications for revegetation efforts to restore functional ecosystem on degraded lands in a tropical environment need to be studied. Reclamation and restoration of productive ecosystems on degraded lands will help to promote and maintain ecosystem services (functions) essential for sustainable agriculture and local livelihoods, maintain healthy and diverse ecosystem and hence ecologically healthy ecosystems. Healthy agricultural systems support ecosystem function and contribute positively to the health of the surrounding environment. In the tropics, urgently required are changes in land use practices that will work with nature as much as possible. The development of ecologically-based resource exploitation and farming practices in the tropics will contribute to improved synergy between local livelihoods and maintenance of healthy ecosystem (thus harmonizing land use with sustainable ecosystem function). Sustainable land use options and restoration/rehabilitation of these degraded ecosystems will control erosion, halt further degradation and preserve environmental quality.

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