EFFECTS OF MULCHING, FERTILIZER, SEEDING AND SEEDLING TREATMENTS ON PLANT SPECIES RECOVERY IN KONDOA IRANGI HILLS, TANZANIA

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ABSTRACT

Fertilization, mulching, imported seed bank seeding and seedlings were applied to triplicates of 1m x1m plots at Chakwe and Gubali sites in Kondoa Irangi Hills, Tanzania. Responses tested were seedling recruitment, species turnover, species' biomass, mortality of seedlings, total number of perennial and woody species recruited and leguminous species. There were high significant correlations of 0.85 and 0.87 between seedling recruitment and mortality in both sites, indicating that other factors, probably aridity, rather than prevailing site conditions were likely to be important determinants of mortality. Inorganic fertilization was not an efficient means of improving short-term productivity, seedling recruitment or increased number of species. In other words, fertilization was negatively correlated to the above factors mentioned. Mulching treatment had an effect of increasing mortality of non-woody species and selectively favoring the establishment of woody species. The interactions between seeding, seed bank and seedlings treatments increased the overall number of species (species turnover) in the study area. Direct sowing of seeds with desired traits into the soil to enhance seedling recruitment and species diversity is recommended over imported seed bank due to the costs involved in mobilizing large volumes of soil as well as availability of proper seed bank soil.

INTRODUCTION

The study dealt with degraded Kondoa Irangi Hills (hereinafter called KIH) in central Tanzania where former bad land use practices resulted in severe soil erosion leaving some parts of the hills beyond recovery. The problem of land degradation in the hills started ca. 150 years ago when the Rangi people settled in the area. The regeneration process in the hills has been very slow, considering a period of 36 years since activities such as grazing, tree-felling and hill slope cultivation were abandoned. Depending on the level of degradation, both primary and secondary succession proceeds simultaneously in different parts of the hills. In principle, regeneration succession in severely degraded habitats generally begins with dispersal and establishment from seed of one or a few fast growing annual or perennial species. The further development is dependent on the outcome of three possible plant interactions, namely facilitation, competition and tolerance (Connel and Slatyer 1977). In facilitation, the first plants to be established in a site also known as pioneer nurse plants modify the microenvironment in such a way that it becomes more suitable for late successional species, which finally replace the pioneers. Contrary to this pattern, secondary succession often involves the replacement of the pre-existing vegetation following disturbance from its own seed or seedling bank.

Another factor which pre-determines the successional path is whether the disturbance was accompanied by deterioration of soil and water quality and the microclimate. Degraded savanna ecosystems are in most cases characterized by soils of very low fertility (Hogberg 1992), and most soil nitrogen exists in organic form which is not readily available to plants. Moreover, in semi-arid regions, nitrogen mineralization is limited by dry conditions (Booysen and Tainton 1984) and low levels of phosphorus (Hogberg 1992). Therefore in such ecosystems, nitrogen fertilization may be essential to correct nutrient deficiencies in theses soils. The importance of dry land fertilization is that it promoted root development so that soil water is used to greater depth, an advantage to woody species succession over grasses (Smith and Shackleton 1988).

Several approaches have been used to manipulate regeneration process in various environments to include nitrogen fertilization (Sandhu *et al*. 1992, Chapman and Younger 1995, Crusiol and Sorrato 2009), mulching (Larsson *et al*. 1997), application of seed mixtures (Marquez and Allen, 1996), planting seedlings (Gupta and Singh 1997) and enrichment of the soil with diaspores from imported seed bank.

Organic mulches are effective in improving soil moisture storage, thermal insulation, and protection of the soil surface thereby improving infiltration and decreasing runoff as well as adding to the fertility of the soil (Bautista *et al*. 1996). Mulching is reported to increase water-use efficiency of seedlings (Smith and Shackleton 1988), and to reduce soil surface crusting, thereby promoting seedling establishment (Hien et al. 1997). With termite activity, mulching is also known to improve humidification and water conservation in crusted soils of semi-arid regions (Mando *et al.* 1996). Apart from altered nutrient levels, degraded savanna ecosystems are impoverished of seeds, and in succession process, supplementation with seeds from other sources is recommended.

The broad objective of this project was to explore the possibility of speeding up the regeneration process of the severely degraded Kondoa Irangi Hills using different soil treatments. The assumption underlying this research was that succession will enhance recruitment of individual plant species and the overall productivity of the ecosystem in general. In the context of this study, seedling recruitment refers to the total number of seedlings recorded from the experimental plots either from seeding, seedlings and seed bank applications. Species' turnover refers to the ability of individuals recorded in the previous recording to be enumerated in at least two subsequent recordings. Species' biomass refers to the to the plant material harvested upon completion of the experiment (both dead and living) in each experimental plot. This material was dried to constant weight and their weights recorded for various treatments. Mortality refers to individual plant species which did not survive to be counted twice.

MATERIAL AND METHODS

Brief description of the study site

Kondoa Irangi Hills can be regarded as a focal point of restoration activities dealing with reclamation *of* degraded and marginal lands in Tanzania (Mbegu and Mlenge 1984, Christiansson *et al*. 1991). For detailed description of the study site see Lyaruu (1995). The overall climate of the area is semi-arid to more or less sub-humid at high elevations. It has a weakly bi-modal annual precipitation of 400 – 800 mm (Ngana 1992), but precipitation is higher in the elevated parts of KIH. The rain season extends from late November to May and it comes in the form of short intense storms. The soils are texturally coarse loamy sands to sandy loams (Mbegu and Mlenge 1984), but in flatter areas black cotton soils (vertisols) are common.

Field experiments commenced in March 1995 at Chakwe and Gubali (KIH) and were monitored up to December 1997. Chakwe site has been described as grassland on disturbed soil (Backeus *et al*. 1994); the Gubali site is grassland vegetation on transition to woodland. Soil analysis and biomass determination were done in the laboratory at the University of Dar es Salaam.

Table 1: Comparison of environmental attributes of the two sites studied. For soil analysis results, means ± s.ds (n=8) are given.

Attribute	Chakwe	Gubali	t-value	Significance
1. Moisture Factor (%)	0.208 ± 0.008	0.508 ± 0.008	7.650	***
2. Soil Texture				
a) Gravel	34.30 ± 16.270	0.03 ± 0.020	9.830	***
b) Sand	62.14 ± 15.460	90.99 ± 0.710	6.950	***
c) Silt	2.89 ± 0.790	7.74 ± 0.420	8.040	***
d) Clay	0.32 ± 0.080	1.25 ± 0.430	15.140	***
3. Organic Matter (%)	0.97 ± 0.210	1.73 ± 0.220	11.160	***
4. Soil Reaction (pH)	5.64 ± 0.010	6.11 ± 0.010	2.990	**
5. Exchangeable Bases (Meq/100g soil)				
a) Ca^{++}	2.75 ± 0.580	5.19 ± 0.990	6.650	***
b) Mg^{++}	1.16 ± 0.070	2.91 ± 0.520	16.970	***
c) K^{+}	0.79 ± 0.320	1.79 ± 0.460	10.720	***
d) Na^{+}	0.063 ± 0.008	0.078 ± 0.013	9.440	***
6. Cation Exchange Capacity (Meq/100g soil)	17.77 ± 2.640	19.83 ± 3.110	1.370	ns
7. Available Phosphorus (mg/100g soil)	2.34 ± 0.320	2.76 ± 0.340	2.240	**
8. Total Nitrogen (%)	0.08± 0.02	0.08 ± 0.010	0	ns
9. Others				
a) Slope (0)	10	3		
b) Altitude (m)	1530	1620		

Difference between means was tested by t- Test for pair wise comparison. Ns stands for not significant; * significant at p ‹ 0.1; ** at p ‹ 0.05 and *** at p ‹ 0.01

Experimental Layout and Design

A factorial design experiment in which five treatments and their combinations were replicated three times in a systematic manner in each site was conducted. For each site, a total of 50 1m x 1m plots were established, 45 being treatment plots and five left without treatment to serve as controls. The treatments and their combinations were as follows: fertilization (coded FE throughout the text), mulching (MU), imported seed bank (SB), seeding (SD) and seedlings (SDL). Thus a combination of seeding and mulching is denoted as SD + MU.

Before the experiment started, the sites were tilled and all plant material removed. The plots were fenced and fire breaks were created to prevent experimental plots from fire, which did not occur during the period of study. The treatments were applied only once at the beginning of the experiment.

In fertilization treatments, 100g of inorganic fertilizer NPK (20% nitrogen, 10% phosphorus and 10% potassium) was applied once. Imported soil seed bank ca. 7 dm^3 (assuming bulky density of soil to be 1.5 gcm^{-3}) was thoroughly mixed with soil from the experimental plots, and was evenly spread in each plot. A reasonable amount of mulch collected from seed-free broad leaved herbs and trees in the vicinity was applied to cover the mulched plots. Seeds of *Acacia tortilis*; *Acacia saligna*; *Dodonaea angustifolia*, *Khaya nyasica* and *Psoropsis* *juliflora* were sown in each plot. Each species contributed 20 seeds.

Both seeds and seedlings used in this experiment were obtained from the government nursery in Kondoa, and only two seedlings of each species per plot were planted in order to minimize competition. In all plots, all emerging individuals were identified, counted and recorded in the first data collection after three months. In the subsequent recordings, which were done after every one month, species recorded previously were noted as well as new species unrecorded previously. The data were collected five times in the period of study, to include three dry and rainy seasons. Species difficult to identify in the field were identified using available herbarium specimens at the University of Dare s Salaam and by using Flora of Tropical East Africa (Turrill & Milne-Redhead, 1952).

At the beginning of the experiment, a total of four composite soil samples were collected at a depth of 0 – 10 cm from each site for laboratory analysis of soil physico-chemical characteristics (Table 1) following the procedure outlined in Metson (1956) and Tucker (1974).

At the end of the study, all dead and living plant material, in each experimental plot, were harvested for biomass determination. To minimize decomposition of the harvested plant material, pre-drying commenced in the field by spreading the material in the open air. The material was stored in plastic bags and transported to Dar es Salaam, where it was carefully spread on newspapers in the greenhouse with mean temperature of 34 ± 5^0C and dried to constant mass.

Data Analysis
The data were more or less normally distributed as determined by Shapiro & Wilks' Test and were therefore subjected to parametric statistical tests. Only the number of woody species were log-transformed using the relation $\boldsymbol{y = \log_{10}(y + 1)}$.

All statistical analyses were done using SAS statistical package (SAS Institute Inc. 1990). Seven responses were tested i.e. total seedling number, total species number, mortality (% of recruited seedlings, dry matter (biomass) production, number of perennial woody species and legumes. The sites were compared using paired t-tests and one way ANOVAs. The GLM procedure for multiple regression was used to detect partial correlation and statistical differences ($p < 0.05$) between treatments and the dependent variables. Since the experiment did not have full factorial design, only the main factors and their first order interactions were studied using the SAS GLM procedure for analysis of variance. Where significant differences were found ($p < 0.05$), Tukey's Studentized Range (HSD) Test was applied.

RESULTS
Results from treatments applied in this study and their interactions with sites to overall seedling recruitment, mortality, total number of species recruited and biomass are presented in Table 2 below.

Table 2 Summarized data showing the responses of the two sites (subscripts 1 for Chakwe & 2 for Gubali) in terms of seedling recruitment, mortality, number of species recruited and biomass against the treatments applied.

Factor(s)	Seedling recruitment	Mortality	Species	Biomass(g)
1. SB_1	372.3(4.1)	200.3(34.5)	10.0(1.4)	438.7(167.0)
SB_2	165.3(64.8)	79.3(35.0)	8.7(0.9)	141.3(86.0)
2. $SB+MU_1$	344.3(70.2)	226.0(79.0)	12.7(2.5)	363.0(15.0)
$SB+MU_2$	174.3(90.8)	116.7(81.3)	9.7(3.4)	165.7(141.7)
3. $SB+FE_1$	244.0(67.1)	131.3(46.0)	9.0(2.9)	325.7(112.5)
$SB+FE_2$	143.3(31.6)	59.3(2.6)	9.7(1.7)	105.5(84.5)
4. $SB+SD_1$	358.3(20.9)	247.0(34.2)	11.0(1.6)	434.7(83.8)
$SB+SD_2$	156.7(30.2)	54.6(6.1)	12.7(1.7)	117.0(11.4)
5. $SB+SDL_1$	365.7(112.9)	232.0(78.5)	12.7(1.7)	329.3(55.0)
$SB+SDL_2$	141.3(27.5)	70.3(26.0)	9.0(1.4)	159.3(116.5)
6. MU_1	344.0(75.4)	217.7(37.2)	11.7(2.9)	469.0(161.2)
MU_2	189.3(26.2)	99.0(42.2)	11.3(0.5)	141.3(34.4)
7. $MU+FE_1$	273.7(28.7)	168.7(18.2)	11.3(2.9)	433.3(205.0)
$MU+FE_2$	118.7(42.1)	62.7(26.9)	9.3(0.5)	76.0(13.4)
8. $MU+SD_1$	264.0(55.0)	164.7(34.0)	8.2(0.0)	391.7(184.9)
$MU+SD_2$	297.3(57.0)	168.0(37.4)	9.3(2.1)	170.0(179.7)
9. $MU+SDL_1$	268.3(45.6)	192.3(22.4)	9.0(0.8)	387.3(157.9)
$MU+SDL_2$	148.3(14.6)	91.3(18.7)	9.0(1.6)	236.7(130.8)
10. FE_1	232.3(45.1)	118.7(49.4)	10.3(1.7)	284.0(50.8)
FE_2	79.0(0.2)	42.0(14.4)	7.7(1.7)	71.0(36.3)
11. $FE+SD_1$	263.7(46.9)	152.0(73.4)	9.7(2.6)	452.0(104.3)
$FE+SD_2$	124.3(38.1)	67.7(9.3)	9.0(1.4)	207.3(85.9)
12. $FE+SDL_1$	262.7(54.0)	148.3(60.3)	10.0(3.7)	379.7(61.8)
$FE+SDL_2$	104.0(26.7)	48.0(16.8)	9.7(2.5)	218.7(222.3)
13. SD_1	330.7(74.0)	227.3(87.4)	10.7(2.5)	317.0(118.9)
SD_2	164.37(60.4)	93.3(29.8)	8.7(1.2)	205.7(124.8)
14. $SD+ SDL_1$	318.7(68.2)	185.0(72.9)	11.7(0.5)	310.3(146.0)
$SD+SDL_2$	154.7(32.1)	77.7(23.9)	11.7(0.9)	165.3(69.6)
15. SDL	315.3(42.1)	181.0(63.8)	11.0(2.4)	241.7(56.2)
SDL	159.3(38.4)	95.3(27.6)	9.7(1.2)	135.6(51.1)
16. CONTR	246.0(67.3)	155.3(40.8)	11.7(1.9)	248.0(28.4)
CONTR	94.0(13.9)	36.6(5.0)	9.0(1.4)	98.7(26.9)

Mean (s.d. in brackets) of the three replicates are included. SB stands for imported seed bank; MU for mulching; FE for fertilization; SD for seeding; SDL for seedlings and CONTR for untreated plots

Correlation between the Dependent Variables

Correlation analysis results for the two sites are presented in Table 3. In both sites, seedling recruitment and mortality showed highest significant positive correlation of 0.850 and 0.870 for Chakwe and Gubali sites respectively. Seedling recruitment was positively correlated to the total number of species in both sites. For Gubali, there was a very significant positive correlation ($p < 0.001$) between total number of species recruited and woody species, and for Chakwe the number of species and mortality had significant positive correlation ($p < 0.001$).

Table3: Correlation analysis results of the dependent variables. Only variables with significant correlations (p< 0.05) are considered. Recruitment stands for overall seedling recruitment; turnover stands for total number of species recruited; perennial species for the number of perennial species and woody species for the number of woody species recorded

Factor	Pearson's Correlation Coefficient ®	P-value
a) Chakwe		
1. Recruitment vs Mortality	0.850	0.001
2. Recruitment vs Turnover	0.470	0.001
3. Turnover vs Mortality	0.380	0.007
4. Turnover vs Biomass	0.290	0.045
5. Turnover vs Perennial species	0.310	0.035
6. Perennial species vs Woody species	0.310	0.030
b) Gubali		
1. Recruitment vs Mortality	0.870	0.001
2. Recruitment vs Turnover	0.390	0.005
3. Recruitment vs Biomass	0.390	0.006
4. Turnover vs Woody species	0.380	0.008
5. Mortality vs Biomass	0.400	0.005
6. Perennial species vs Woody species	0.490	0.004

The overall model used in the analyses predicted quality of the site as the most important factor which accounted for variations in seedling recruitment, total number of species, mortality, biomass production, perennial and woody species recruitment (Table 4). The two sites responded differently to various treatments and they differ in their recruitment ability, survivorship and biomass production. The two sites were significantly different in terms of total number of species recruited ($F_{(1, 30)} = 51.5$, $p < 0.001$); seedling recruitment ($F_{(1, 30)} = 494.2$, $p < 0.001$) and dry matter production ($F_{(1, 30)} = 156.1$, $p < 0.001$) (Table 3). Whereas site 1 had the highest seedling and species recruitment, biomass and mortality, site 2 had the lowest mortality ($F_{(1, 30)} = 12.75$, $p < 0.005$) among seedlings recruited and the highest recruitment of woody species ($F_{(1, 30)} = 32.47$, $p < 0.001$). The sites showed no significant differences in the recruitment of legumes, and there was no factor or any of its combination which significantly influenced recruitment of legumes at the two sites.

Table 4: ANOVA testing effects of fertilization, mulching, seed bank, seeding and seedlings and their interactions on seedling recruitment, total number of species, mortality, biomass production, woody species recruitment, legumes recruitment and perennial species recruitment. Only significant factors [Tukey's Studentized Range (HSD) Test] and interactions are shown. Degrees of freedom (df) error = 77, Model df = 18 for all responses

Source of variation	df	F	P-value	Result/effect
		Seedling recruitment		
FE	1	12.140	0.001	-
SB	1	7.940	0.006	+
SITE	1	171.590	0.001	SITE1 > SITE 2
MUxSB	1	4.790	0.032	+
		Mortality		
MU	1	6.660	0.012	-
FE	1	10.430	0.002	-
SITE	1	111.880	0.001	SITE1 > SITE 2
		Total number of species		
FE	1	6.410	0.013	-
SB	1	14.680	0.003	+
SD	1	7.260	0.009	+
SITE	1	88.240	0.001	SITE 1 > SITE 2
MUxSDL	1	4.920	0.030	-
		Biomass production		
SITE	1	47.720	0.001	SITE 1 > SITE 2
		Number of perennial species		
SD	1	4.870	0.030	+
SB	1	4.110	0.046	+
SITE	1	7.990	0.006	SITE 2 > SITE 1

Main Factors with Significant Responses

Fertilization (FE) and seed bank (SB) treatments had opposite effects in the overall seedling recruitment and total number of species, with FE treatment having negative influence. They also differed in that FE treatment in addition decreased mortality and the number of perennial species (Table 4).

In terms of seedling establishment, FE significantly increased survivorship of seedlings, whereas the effect of mulching was to increase seedling mortality only at Gubali site (Table 5). At Chakwe site, FE treatment alone decreased seedling recruitment by ca. 20%, but at Gubali, the decrease was even much higher to ca. 27%. SB treatment increased seedling recruitment, and the number of species in both sites (Table 5). Both SD (seeding) and SDL (seedling) treatments were more important to Gubali site than to Chakwe site in that they increased woody species recruitment and the turnover of perennial species.

Table 5: Overall treatment effect of factors at two levels (i.e. present = 1, absent = 0) on seedling recruitment, total number of species, mortality, number of woody species and number of perennial species. Statistical analyses consist of one-way ANOVA, followed by Tukey's Studentized Range (HSD) Test among treatments. Mean values designated with the same letter are not significantly different at p < 0.05. Only factors with statistically different means from at least one site are considered. Site 1 = Chakwe & site 2 = Gubali

Factor	Level	Site 1	Site 2	(Sites 1+2)
		Seedling recruitment		
FE	0	321.2±77.0a	155.6±57.0a	238.4± 67.3a
FE	1	256.3±57.1b	113.2 ± 40.6b	133.8 ±48.6b
SB	0	284.5±68.6a	135.8 ± 54.1a	210.2 ±61.4a
SB	1	337.1±85.3b	156.7± 57.0b	246.9 ±71.8b
		Total number of species		
FE	0	25.9±4.43a	18.6±3.7a	22.3±4.0a
FE	1	22.5±3.8b	17.4±3.3a	20.0±3.5b
SB	0	23.9±4.4a	17.4±2.9a	20.6±3.6a
SB	1	27.0±4.1b	20.1±4.2b	23.6±4.2b
SD	0	24.1±4.5a	17.9±3.8a	21.0±4.1a
SD	1	26.5±4.2b	19.0±3.0a	22.8±3.6b
		Mortality		
FE	0	199.8±64.7a	83.8±47.4a	141.8±56.1a
FE	1	144.3±59.8b	55.3±20.5b	99.8±40.2b
MU	0	176.4±73.7a	64.9±29.4a	120.7±51.6a
MU	1	195.6±52.1b	96.9±53.6b	146.3±55.4b
		Number of woody species		
SDL	0	1.3±0.9a	1.6±0.8a	1.4±0.9a
SDL	1	1.1±0.7a	2.1±1.1b	1.6±0.9a
SD	0	1.2±0.8a	1.5±0.9a	1.4±0.9a
SD	1	1.2±0.9a	2.3±0.9b	1.7±0.9b
SB	0	1.1± 0.8a	1.7±1.0a	1.4±0.9a
SB	1	1.6± 0.8a	1.9 ±0.9a	1.8± 0.9b
		Number of perennial species		
SDL	0	5.9±1.5a	5.5±1.3a	5.4±1.4a
SDL	1	5.9±1.5a	6.4±1.4b	6.2±1.4a
FE	0	6.2±1.5a	6.0±1.4a	6.1±1.5a
FE	1	5.5±1.5a	5.2±1.1b	5.3±1.3b

Combination of Significant Interactions

The combination of mulching (MU) and SB significantly increased total seedling recruitment in the study area (Table 4). There was a significant reduction in the total number of species recruited by the interaction between MU and SDL (see Table 4). Likewise, interaction between MU and SD reduced the number of perennial species recruited. By treating the two sites independently, a combination of SB and SDL increased species diversity at Chakwe site (Table 6). This implies that SDL treatment *i.e.* planting seedlings is an appropriate means of increasing species diversity of the study area.

Table 6: ANOVA results comparing responses at Chakwe and Gubali sites to fertilization mulching, seed bank seeding and seedlings effects with their interactions on seedling recruitment, total number of species, mortality, biomass production, woody species recruitment, legumes recruitment and number of perennial species. Only factors and interactions which are significantly different are shown. Degrees of freedom (df) error = 32, Model df = 15 for all responses

Site	Source of variation	df	F	P-value	Effect
		Seedling recruitment			
SITE 1	FE	1	5.910	0.021	-
	SB	1	5.140	0.030	+
SITE 2	FE	1	3.860	0.058	-
		Mortality			
SITE 1	FE	1	4.840	0.035	-
SITE 2	MU	1	5.960	0.020	+
		Total number of species			
SITE 1	FE	1	7.920	0.008	-
	SB	1	8.000	0.008	+
	MUxSD	1	7.380	0.011	-
	SDxSDL	1	10.830	0.002	+
SITE 2	SB	1	6.020	0.019	+
		Number of woody species			
SITE 2	SD	1	11.640	0.018	+
		Number of perennial species			
SITE 2	SDL	1	4.450	0.043	+
	SBxSDL	1	7.670	0.009	+
	FE	1	4.130	0.050	-

DISCUSSION

Seedling Recruitment and Species Turnover

The observed differences in seedling recruitment and survivorship between Chakwe and Gubali sites can be explained in terms of seed dynamics of the KIH ecosystem. Previous research (see Lyaruu 1997) indicates that grassland sites at Chakwe had much higher seed rain density than Gubali site (1667 seeds m^{-2} and 230 seeds m^{-2}, over 8 month's period respectively). The seed bank is also higher at Chakwe (2185 seeds m^{-2}) than at Gubali (1842 seeds m^{-2}). The seed bank is more diverse at Gubali than at Chakwe (11.5±2.500 and 8.7±3.950 species respectively). This can be implied that for some areas which are still in the early stages of recovery, seed bank enrichment may be an appropriate solution to increase species diversity. Presence of many seeds which readily germinate in response to amenable conditions during the rainy season, accounted for higher seedling recruitment at Chakwe site. The significantly higher seedling mortality recorded at Chakwe than at Gubali sites can be explained in terms of increased competition for nutrients, light, space and probably less favorable soil conditions for establishment (see Table 1) among the seedlings. The observed very high positive correlation between seedling recruitment and mortality in both sites is an indicative measure that soil moisture availability in the study area accounts for seedling mortality rather than site conditions.

Establishment from seed seemed to be more difficult at Chakwe than at Gubali site, where no seedling from the seeding treatment survived to be enumerated at least twice. On the other hand, most seedlings from the seeding treatment at Gubali site and the transplants survived for a much longer time; and seedlings of *Acacia saligna* attained 1.5 meter height during the period of study.

Treatment Effects and their Relevance to Succession

Observations from this study indicate that inorganic fertilization is not an effective means of improving short-term productivity, seedling recruitment and enhancing species turnover in the study area. It negatively affected seedling recruitment, specie's turnover, mortality and biomass. Instead fertilization increases the potential for environmental stress by limiting water availability and consequently increasing mortality among the individuals recruited. In some occasions fertilization may prove useful especially if combined with other treatments such as seeding, but still not a useful means of manipulating regeneration. Importantly, fertilization is deleterious to soil quality because it depletes the soil organic matter, the reservoir of plant available nitrogen and phosphorus in weathered tropical soils (Goladi & Agbenin 1997).

Mulching is a useful treatment which increased seedling recruitment, species turnover and biomass, especially when combined with seed bank in the study area. Mulching applied alone has as effect of increasing mortality of the non-woody species but increase survivorship among woody species. The practical utility of mulching is to change the organic composition of the soil as well as increasing water-use efficiency of seedlings growing under mulch, properties which favor selective establishment of woody species. For KIH ecosystem, this is desirable particularly when the ultimate goal of the restoration process is to enhance woody species succession in the area. It has been observed that in the study area, addition of imported seed bank is an effective means of increasing species diversity and seedling recruitment, regardless of the nature of the site. All these treatments above are desired qualities needed for speedy recovery of disturbed vegetation, where probably the disturbance agent has impoverished the soil seed bank.

Way forward to Successful Manipulation of Regeneration Process in KIH

Savannas are a result of interactions between soil water and nutrient availability with fire and grazing as ecosystem modifiers (Sarmiento 1992, Carlsson 2005). Direct additions of inorganic fertilizers to savanna soils is not recommended due to their negative impacts on soil quality to include depletion of soil organic matter, nitrogen and phosphorus as well as reducing cation exchange capacity of the soils. Herbivores and fire are known to speed up nutrient turnover rates in savannas (see Ruess & McNaughton 1987, Skarpe 1992). For a semi-arid ecosystem such as KIH where grazing animals were evicted ca. 36 years ago, low nitrogen mineralization and water stress are agents which slow down the succession process (Luken 1990). Although other limiting conditions such as seeds could be present. It is on this understanding that any model developed for speedy vegetation recovery of KIH should take into account the influence of grazing and fires which are integral part of savanna ecosystems.

Based on findings obtained from this study, two models or statements can be proposed on the manipulation of regeneration process on the two sites:

1) For early successional category, which includes areas where the disturbance agents are still operative such as Chakwe site, it is desirable to enhance recruitment of woody and perennial species in general. From this study, it was apparent that selective seeding and transplanting of seedlings increased the two properties. Combination of the two treatments with mulching maximized biomass production, possibly through increased water and nutrient-use efficiency.

2) For the second category which includes advanced mid-succession stage such as the Gubali site, only imported seed bank was necessary to increase woody species diversity. Findings from this study indicated that mulching application was useful to eliminate non-woody species and favor the more stable perennial woody species, by eliminating water competition with the shallow rooted species.

CONCLUSIONS

The study has proven that seed bank enrichment in form of imported seed bank or direct sowing of seeds improved seedling recruitment and enhanced species diversity. Direct addition of seeds of desired quality could be more appropriate than imported seed bank, due to technicalities involved in moving large volumes of soil, and most important, the availability of proper seed bank soil. The study revealed that planting seedlings with desired traits was another option to increase species diversity.

Bearing in mind that oligotrophic savanna soils are nutrient-deficient and that the existence of savanna ecosystems is dependent on herbivory and fire; then nitrogen deficiencies can be corrected naturally by fires and grazing animals and not by inorganic fertilization (see Higgins *et al*. 2007). This takes into account the shortcomings associated with inorganic fertilizers as well as their cost effectiveness. This suggests re-introduction of livestock in the hills assuming that cattle will add more nutrients (dung and urine) than they remove through grazing.

In severely degraded habitats in the early stages of succession such as the Chakwe site, introduction of seeding and desired transplants have shown to increase seedling recruitment and promoted co-existence of species. The above treatments when applied with mulching maximized biomass production, probably due to increased water and nutrient-use efficiencies. For habitats in the mid stages of succession, only imported seed bank was necessary to correct seed deficiencies in the soil.

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