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The Effect of Silvicultural Management on Regeneration, Growth and Yield of *Arundinaria alpina* (Highland bamboo) at Choke Mountain, East Gojam, Northwest Ethiopia

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Abstract

With the objective of determining the effects of silvicultural management on regeneration and growth of mismanaged ***Arundinaria alpina*** *stands, an experiment was conducted in the Choke Mountain, northwest Ethiopia. Eight soil and plant management techniques that comprise soil loosening, selective thinning and removal of old stumps were splited on two levels of organic fertilizer and applied on one hectare communally owned bamboo stand. Effect of the treatments was observed from data collected in 2009 and 2010 rainy seasons. The number of recruited culms of previous years (2007 and 2008) which had intermittent protection from human and livestock interference was also quantified employing culm age determination techniques. Result of combined analysis of 2009 and 2010 indicated that soil loosening combined with selective thinning and removal of old stumps resulted in culm recruitment of 13,750 plants ha^{-1}, i.e. 37% higher than the control plot. This treatment combination decreased shoot mortality by 61% less than the control and increased culm recruitment by 40 % more than the control plot during the 2009 shooting season. Culm diameter and height of individual culms recruited in 2009 and 2010 showed increasing trend across the two years. Comparison of culm recruitment of previous years with recruitments after treatment application indicated that with improved management, including protection from interference, culm yield of communally owned bamboo stands can be maximized by 158-589%.*

Key words: soil loosening, selective thinning, highland bamboo, silviculture, *Yushania alpina*

Introduction

Arundinaria alpina is a giant woody grass found naturally or planted in highlands (altitude 2200-4000 masl, temperature 10–20°C and annual rainfall 1400-2000 mm) (Phillips 1995; LUSO 1997; Azene Bekele 2007). From classification made based on the vegetative state and its rhizome morphology, this species has been reclassified differently as *Yushania alpina* and *Sinarundinaria alpina* (PROTA 1989; Phillips 1995) but naming of the species still remained uncertain as allies in the phylogenic analysis remained unclear (PROTA 1989). Because of this problem, the old name *Arundinaria* *alpina* is maintained in this paper. Flora books of the Ethiopian National Herbarium also still maintained the old name until naming becomes clear (Phillips 1995).

The total area of naturally grown (mapped) and planted highland bamboo forest in Ethiopia is reported to be 148,626 ha (FAO and INBAR 2005). It is an important part of the farming system serving as a major source of livelihood in highlands; farmers use the resource as their bank account (UNIDO 2007) to get a ready resource of cash. Currently industrial application of the species is recognized making its demand escalating (EABP 2008). On the contrary, the extremely traditional management system of individually owned stands (UNIDO 2006) and mismanagement of communally owned and government bamboo stands caused deterioration in productivity. Moreover, the more emphasis on its economic value before adequate works done on the production and management might further deplete the resource (UNIDO 2007). Accordingly, the issue of maximizing productivity of the resource base through management of existing stands has become an important research and development concern (Yigardu Mulatu and Mengistie Kindu 2009).

Productivity of bamboo stands can deteriorate because of different reasons. In ancient China overharvesting of 1-year-old culms for papermaking harmed bamboo populations (Fu and Banik 1995), while harvesting of 2-year-old culms resulted in depleted bamboo stands in Indonesia (Sutiyono 1987). Anthropogenic factors like intensive shoot harvesting and herbivory can also reduce timber yield (Wang et al. 2007; Suzuki and Nakagoshi 2008). Regeneration of *Bambusa bambos* was adversely affected in the inappropriately harvested clumps and resulted in the depletion of the resource (Krishnankutty 2005). If plantations are left unmanaged, productivity declines after six years of age (Shanmughavel 1997a), because of decline in photosynthesis, congestion and reduction in number of upcoming culms. Clump congestion in bamboos is one of the most serious management problems (Were 1988; Shanmughavel 1997b; Kleinhenz and Midmore 2001). It may be due to a) too much soil compaction mainly by animals, b) insufficient soil depth for rhizomes and c) development of too many rhizomes especially on river banks (Shanmughavel 1997b).

On the other hand, many studies indicated that application of different management practices including cultural operations and appropriate harvesting techniques help to rehabilitate bamboo stands and sustainably increase growth (the number of shoots, culm diameter and height) and yield (Kleinhenz and Midmore 2001). Accordingly, different plant and soil management practices (intensive and extensive management) such as soil loosening and deep tilling, fertilization and weeding were applied for different Asian bamboo species (Azmy et al. 2004; Nath et al. 2006; Othman et al., 2007). Selective thinning of natural bamboo forests, i.e. selectively removing old, malformed and congested culms accompanied by soil loosening was one important silvicultural measure helped boosting up of bamboo productivity (Midmore 2009). Removing old stumps (degenerated bamboo rhizomes) is applied in intensively managed high-yield model stand of moso bamboo for pulp-making in China to increase culm production (INBAR 2005).

Problems of bamboo stand management in the Choke Mountain, northwest Ethiopia, are not different from management problems in the country. From reconnaissance survey made at the beginning of this experiment and discussion made with the community, bamboo stands in the area are manmade and mainly meant for culm production. However, stand management is hardly practiced. During dry seasons, bamboo stands, mainly communally owned stands are used for browse by livestock resulting in soil compaction. Besides, creating access for livestock browse by bending culms brought about dominance of poor quality culms and reduced value of the stand, from timber production point of view. The higher cutting position while felling and subsequent shoot abortion also resulted in undecomposed old stumps that might hinder further shooting. Though the community harvests matured bamboo culms every 3-4 years, illegal cutting is common in between two harvesting periods. In general the bamboo forest is suffering from the "tragedy of the commons. In general these management problems reduced growth and productivity of communally owned bamboo stands in the Choke Mountain

Thus, identifying silvicultural techniques that can rehabilitate mismanaged stands and improve their productivity through field experiments is one most important research priority. Therefore, the objective of the research was to study the effect of plant and soil management techniques on regeneration, growth and yield of communally owned mismanaged bamboo stands.

Materials and Methods

Description of the study site and the bamboo forest

The study site is found in East Gojam Administrative Zone of Amhara National Regional State, within the Choke Mountain. It is located 330 km Northwest of Addis Ababa and 30 km to the north of the zonal city, Debre-Markos (Fig. 1). Altitude and geographical coordinates at the center of the studied forest read as 2849 masl, 10° 33'49.9'' N and 037° 45' 30.7'' E (Fig. 1, GPS readings recorded during field study), respectively.. The site has a slope gradient of about 14%. Mean annual rain fall of the area is 1447 mm (20 years average data collected from Rebu Gebeya Meteorological station of the Ethiopian Meteorology Agency). Average temperature is 17.9°C (extrapolated from nearby stations using LocClime 2.0). The main rainy season extends from June to September and the high temperature months are from January to April. The season that extends from June to September is the shooting and recruitment time for bamboo in the area.

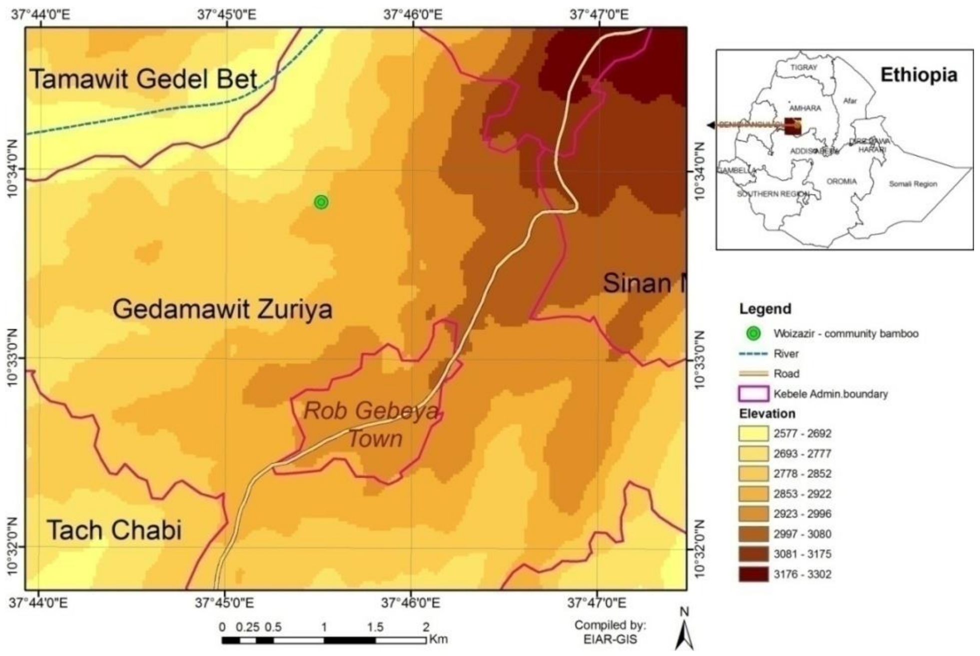

Figure 1: Study site (Woizazir-community bamboo forest)

The study was conducted on one ha of communally owned bamboo stand. According to local informants, the bamboo forest had been under private holding during the Hailesislase-I regime (1930-1974), but since from the Dergue regime (1974), it has been transferred to Geltima-Gank community. During the field assessment, it was observed that 50-75% of the culms are deliberately bent to create access for livestock browse.

Application of treatments

Application of silvicultural treatments was conducted from 4-8 April 2009, i.e. prior to the start of the shooting season. Hand tools such as Mattock+pick axe, grab hoe, and axe were used for digging the soil, removing degenerated rhizomes and selectively thinning of old culms. Soil loosening was done by cultivating the soil to 15-20 cm depth and covering the culm base and exposed rhizome parts with the excavated-out soil. Removing old stump was made mainly to avoid degenerated stumps of harvested plants of the previous years. Care was taken so as not to damage rhizomes and underground shoots while soil loosening and removing old stumps by avoiding digging and cutting very close to plants. Selective thinning was done by removing all plants which were four and more years old. Bent stems were uncurved and intermingled branches were separated prior to removing the selected plants so as to ease thinning. After the establishment of the experiment, the site was entirely protected from livestock and human interference by fencing and guarding the experimental area.

Experimental design

Two factors split plot design under RCBD across two years was used. Factor 1: organic fertilizer with two levels (with compost in 12 t ha^{-1} basis i.e. 60 kg per plot and without compost); Factor 2: other silvicultural management techniques (eight levels of soil and plant management techniques). Organic fertilizer was the main plot and silvicultural management techniques were applied as sub plots splited on the main plot. Compost used in the experiment was prepared using livestock dung, green leaves, ash and local soil for two month. The total N (Kjeldahl method), organic C (dichromate oxidation method) and phosphorus contents (Bray I method) of the compost were 0.613%, 13.275% and 0.878 mg P/g of soil, respectively (determined at the Eco-Physiology Laboratory of Addis Ababa University). Accordingly, the equivalent amounts of the compost used were 74 kg ha^{-1} N and 105 Kg ha^{-1} P. The experiment was replicated three times, making the total number of plots (including the control) 48. Plot size was 10 m x 5 m and distance between blocks was 20 m. The silvicultural treatments in Factor 2 consists of (1) removing old stumps (ROS); (2) soil loosening and removing old stumps and (SL+ROS); (3) selective thinning and removing old stumps (ST+ROS); (4) soil loosening, selective thinning and removing old stumps(SL+ST+ROS); (5) soil loosening (SL); (6) soil loosening and selective thinning (SL+ST); (7) selective tinning (ST); and (8) control. Selective thinning was done by removing all culms of >3 years of age.

Plot characteristics (Stocking, age structure and plant size-initial data)

Prior to application of treatments data on stocking, age structure and size of plants were collected and plants were grouped into three age groups following Ronald (2005) (Table 1). (because it is already stated in the next section)

Table 1: Stocking of plants of different ages and their size in blocks, main plots and sub plots of the studied forest before treatment application (plot size 50 m^2, Mean ± SE; n=6)

Factor	No.	No. of plants $plot^{-1}$ of age: 1year (2008 recruit- ments)	2 years (2007 recruit- ments)	≥3years (recruitments before 2007)	Proportion of erect plants (%)	Average plant size: DBH (cm)	Height (m)
Block	1	52 ± 5	22 ±2	46 ±4	33 ±4	2.7 ± 0.05	4.9± 0.14
	2	49 ±2	27 ±3	47 ±4	36 ±3	2.6 ± 0.03	4.5± 0.12
	3	108 ±15	21 ±4	64 ±5	51 ±5	2.6 ± 0.11	4.6± 0.11
Main plot	1	59 ±4	20 ±2	53 ±3	39 ±20	2.7 ± 0.04	4.6± 0.09
	2	79 ±12	27 ±3	51 ±5	41 ±4	2.6 ± 0.05	4.7± 0.07
Treatment	1	61 ±10	26 ±5	54 ±5	39 ±4	2.7 ± 0.10	4.8± 0.19
	2	55 ±12	24 ±4	48 ±11	38 ±6	2.6 ±0.12	4.5± 0.29
	3	71 ±12	19 ±3	36 ±6	39 ±40	2.8 ± 0.11	5.1± 0.28
	4	78 ±15	24 ±4	68 ±5	45 ±7	2.6 ± 0.07	4.6± 0.21
	5	94 ±39	28 ±10	47 ±6	49 ±12	2.7 ± 0.06	4.8± 0.12
	6	76 ±20	22 ±50	52 ±5	41 ±10	2.5 ± 0.05	4.4± 0.16
	7	52 ±7	20 ±3	56 ±12	33±5	2.7 ± 0.11	4.7± 0.22
	8	66 ±18	26 ±5	57 ±4	34±6	2.6 ± 0.04	4.6± 0.15

Data collection

After application of the treatments, data was collected twice, the first one in 2009 shooting season (5 months after establishment) and the second one in 2010 shooting season (18 months after establishment). The data collected includes number of recruited culms and number of aborted shoots after emergence of the whole plot and DBH and height of **10** stems from the center of each plot.

Data analysis

Combined analysis over years of two factor split plot ANOVA and one-way ANOVA were used to evaluate how the overall and single year culm recruitments were affected by silvicultural management techniques and application of organic fertilizer. Duncan Multiple Range Test was used when statistically significant differences (p<0.05) were observed. Sigma Plot 10 was used to construct graphs.

Result and Discussion

Culm recruitment and shoot mortality rate

Analysis of newly recruited culms five months after application of the treatments (September 2009) showed that the number of newly recruited culms was statistically significant (α=0.05) among treatments (Fig. 2). Soil loosening + selective thinning + removal of old stumps (Treatment 4), removing old stump + selective thinning (Treatment 3) and soil loosening (Treatment 5) had 40% (122 plants plot), 28% (112 plants plot) and 8% (94 plants plot) more recruited culms than the control plot (87 plants plot) (Fig. 2A). Shoot mortality rate of the respective treatments was 60, 72 and 76% lower than the control plot (Fig. 2B). The 2010 rainy season was an off-season for bamboo in the study area. There was no statistical difference in the number of recruited culms among treatments (Fig. 2C).

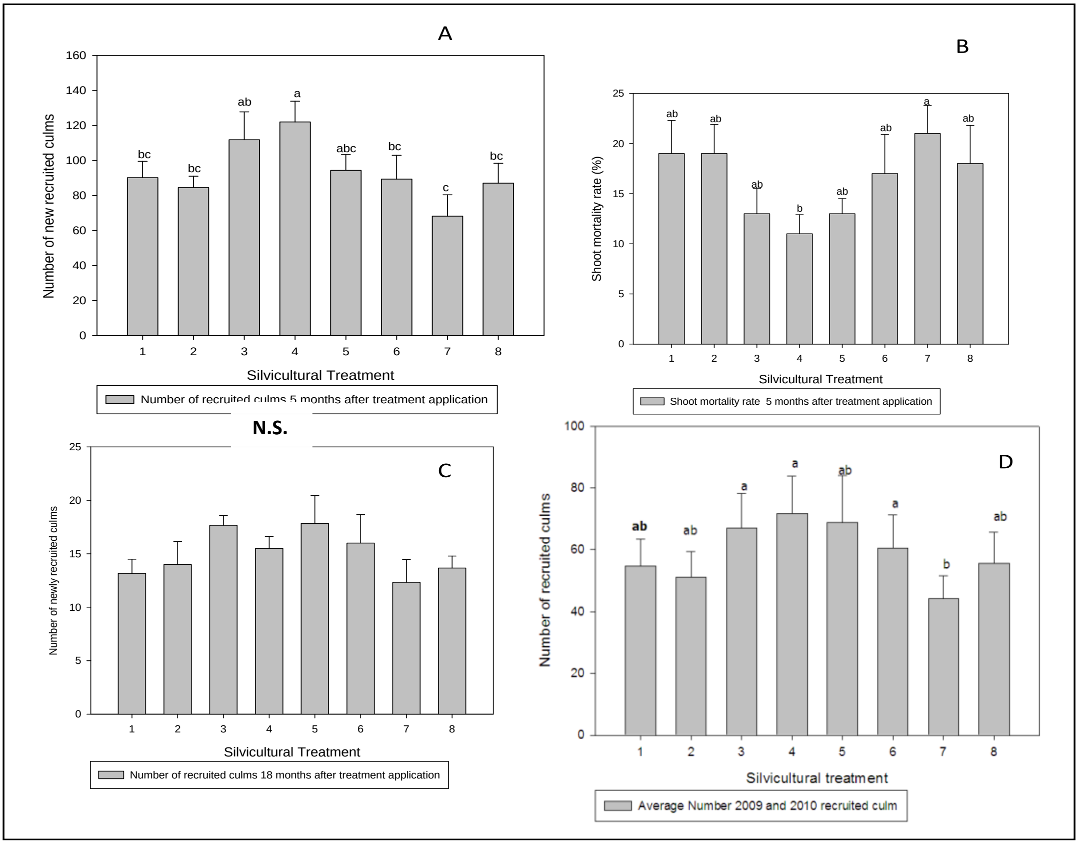

Figure 2. Culm recruitment and shoot mortality as affected by application of silvicultural management techniques (treatments): (A) culm recruitment 5 months after treatment; (B) shoot mortality rate 5 months after treatment; (C) culm recruitment 18 months after treatment; (D) two years average culm recruitment (5 and 18 months after treatment)

Bars with same letter are not statistically different. N.S indicates the Non-significant difference among treatments 18 months after treatment application.

Treatments: (1) Removing old stumps, (2) soil loosening +Removing old stumps, (3) selective thinning +Removing old stumps, (4) soil loosening + selective thinning +Removing old stumps, (5) soil loosening, (6) soil loosening + selective thinning, (7) Selective tinning and (8) Control.

Combined analysis of the two factor split plot ANOVA indicated that shoot recruitment, significantly varied between the two shooting seasons of 2009 and 2010 (Table 2). The 2009 shooting season had significantly higher number of recruited culms than the 2010 shooting season. The number of recruited culms was also significantly different among silvicultural management practices. The combined analysis also showed that soil loosening accompanied by removal of old stumps and selective thinning (Treatment 4) yielded 37% more number of recruited culms than the control plot.

Table 2. ANOVA of the combined analysis of 2009 and 2010 culm recruitments as affected by silvicultural management techniques and organic fertilizer application

Source	df	Mean Square	F-value	Prob.
Year	1	147501.760	443.47	0.0005
Organic fertilizer	1	14.260	0.04	0.8366
Year x Organic fertilizer	1	21.094	0.06	0.8019
Error	4	637.427		
Silvicultural treatment	7	976.070	2.93	0.0097
Year x Silvicultural treatment	7	714.332	2.15	0.0502
Organic fertilizer x Silvicultural treatment	7	460.070	1.38	0.2269
Year x Organic fertilizer x Silvicultural treatment	7	310.570	1.2077	0.3139
Error	56	257.162		
Total	95			

Depending on the nutrient reserve, current photosynthesis and optimal growth conditions, newly emerged shoots might either be recruited to full grown culms or abort some days after emergence and growth. The present study showed that Treatment 4 yielded the highest culm recruitment but the lowest shoot mortality rate. It may be because application of silvicultural treatments enhanced the amount of resources potentially available for growth, increased the ability of plants to acquire those resources and influenced the distribution of resources among different plant parts using the improved ecophysiological conditions (Long et al. 2004). Our results were in line with the reports of Fu and Banik (1995) and Zheng et al. (1996). Loosening the compacted soil and covering the culm base with soil (soil mounding) together with removal of unproductive plant parts could greatly improve physical soil conditions (moisture and aeration) and increased access to light. Therefore, improvements in availability of aboveground and belowground resources promote early but prolonged emergence of new shoots so that higher recruitment be possible.

The lowest shoot emergence (lowest culm recruitment) and highest shoot mortality rate was observed in plots which received only selectively thinning (Treatment 7), with no soil loosening and no removal of old stumps. Selective thinning is one of the silvicultural management techniques both in bamboo management and other forests particularly timber stands in forest science (Huberman 1959). The lowest recruitment observed in this previously unmanaged forest might be associated with the decrease in photosynthetic area due to thinned-out old and bent culms that had been harboring abnormally enormous leafy branches. Removal of all these culms might contribute to lowering down of rhizome food reserve generated from current photosynthesis that could have been translocated to new shoots, as compared to the unthinned control plot. According to Zeide (2001), thinning inevitably results in lower stand growth in the short term, because of reduced canopy and leaf area following thinning; but a stand returns to its prethinning stand-level leaf area within a certain duration of time that depends on the stand age, site quality and the intensity of thinning (Juodvalkis et al. 2005).

The statistically insignificant effects of organic fertilizer may be because of two main reasons. (1) organic fertilizer takes longer time to release nutrients hence its effect might not be reflected in one growing season. The generally lower culm recruitment (off-year) during the second year might also have influenced the full effects of organic fertilizer. Unlike inorganic fertilizers, the response might be slower immediately after application but could exert a longer-lasting effect on growth (Wang et al. 1985). (2) Besides, effect of organic fertilizer application may become more pronounced when applied continuously for a long period of time (Fernandez et al. 2003) as bamboo has never been negatively affected by high doses of organic fertilizer (Kleinhenz and Midmore 2001). The equivalent rates of the applied compost in this study (74 kg/ha N and 105 kg ha^{-1} P) is higher than the equivalent rates (72 kg ha^{-1} N and 46 kg ha^{-1}) of 5 t ha^{-1} compost recommended for maize production in western Oromiya, Ethiopia (Wakene et al. 2001; EIAR 2001). As there is no any study on fertilizer rate for bamboo in the country todate, comparing with other works in other countries may be possible. The applied rate in this study was lower than the average nutrient application rates (225, 135, and 89 kg ha^{-1} N, P and K, respectively) for timber-only stands for *B. bamboos, B. tulda, D. asper,* and *D. strictus* in Asia (Shanmughavel and Francis 1997; Raina et al. 1988).

Culm size

Five months after application of the treatments, mean DBH and height were not statistically different (Table 3). Eighteen months after application of the treatments *soil loosening* + *selective thinning* (Treatment 6) showed significantly higher diameter as compared to *soil loosening* + *selective thinning* +*Removing old stumps (*Treatment 4) but not with other treatments. The diameter of culms in Treatment 4 was not statistically different from the control plot. Applied compost did not show significantly different values both interms of diameter and height 5 and 18 months after treatment application.

Table 3: Average DBH and height for A. alpina unmanaged community bamboo stands based on application of silvicultural treatments, 5 and 18 months after treatment application

	DBH (cm)		Height (m)	
	5 MAE	18 MAE	5 MAE	18 MAE
Silvicultural Treatment				
1	3.0$^{N.S.}$	4.4±0.08^{ab}	6.8$^{N.S.}$	8.5$^{N.S.}$
2	2.9	4.4±0.09^{ab}	6.9	8.5
3	2.9	4.1±0.16^{ab}	6.5	7.5
4	2.6	3.7±0.16^{b}	6.5	7.0
5	2.9	4.3±0.16^{ab}	6.5	8.0
6	2.9	4.5±0.12^{a}	6.7	8.7
7	3.1	4.3±0.19^{ab}	6.7	8.0
8	3.1	4.2±0.26^{ab}	6.6	8.3
Compost (main plot)				
0 t/ha	3.0	4.3+0.1	6.7	7.9
12 t/ha	2.8	4.2+0.1	6.6	8.2

Treatments (1) Removing old stumps, (2) soil loosening +Removing old stumps +, (3) selective thinning +Removing old stumps, (4) soil loosening + selective thinning +Removing old stumps, (5) soil loosening, (6) soil loosening + selective thinning, (7) Selective tinning and (8) Control. Bars with same letter are not statistically different; N.S.= none significant difference; N=8; Alpha <0.05, Duncan MRT.

Size (diameter and height) of recruited bamboo culms 5 months after establishment was generally small and variation between treatments was insignificant. The statistically insignificant difference might be associated with the performance of underground shoot growth that happened simultaneously or immediately after shoot-culm growth of the previous year (2008). Underground shoot growth that covers a period in which rhizome bud in soil grows up to the soil surface is highly influenced by bamboo stand condition of the sprouting time (Jianghua 2005). However plant size increased in the 2010 shooting season and showed significant variation among treatments.

Combined analysis of the two factor split plot ANOVA indicated that DBH and height significantly vary between the 2009 and 2010 shooting seasons (Table 4 A and B). The 2010 DBH and height values were significantly higher than the 2009 shooting season. Mean DBH values were also statistically significant among silvicultural treatments and among the interaction of Organic fertilizer x Silvicultural treatment.

Table 4. ANOVA of combined analysis of 2009 and 2010 DBH measurements (A) and height measurements (B) as affected by silvicultural management techniques and organic fertilizer application

A

Source	df	Mean Square	F-value	Prob.
Year	1	42.135	380.40	<0.0001
Organic fertilizer	1	0.375	3.39	0.0702
Year x Organic fertilizer	1	0.004	0.03	0.8546
Error	4	0.121		
Silvicultural treatment	7	0.474	4.28	0.0006
Year x Silvicultural treatment	7	0.113	1.02	0.4277
Organic fertilizer x Silvicultural treatment	7	0.349	3.15	0.0062
Year x Organic fertilizer x Silvicultural treatment	7	0.084	0.7397	
Error	56	0.114		
Total	95			

B

Source	**df**	**Mean Square**	**F-value**	**Prob.**
Year	1	48.337	63.42	<0.0001
Organic fertilizer	1	0.608	0.80	0.3750
Year x Organic fertilizer	1	0.380	0.50	0.4826
Error	4	1.273		
Silvicultural treatment	7	1.366	1.79	0.1032
Year x Silvicultural treatment	7	0.599	0.79	0.6011
Organic fertilizer x Silvicultural treatment	7	1.076	1.41	0.215
Year x Organic fertilizer x Silvicultural treatment	7	0.661	0.8252	
Error	56	0.800		
Total	95			

Culm production across years and climate pattern

The culm production (number of recruited culms) trend of the mismanaged stand both treated and control plots, had big variation from year to year. The two shooting seasons (2009 and 2010) after treatment application and the preceding year (Table 1) had significant difference in culm production. Culm production of the 2010 growing season was the least (Fig. 3) as compared to the 2009 and also to 2007 and 2008 recruitments. This year, all the stands including outside the experimental area and under private and church holdings demonstrated very marginal shooting.

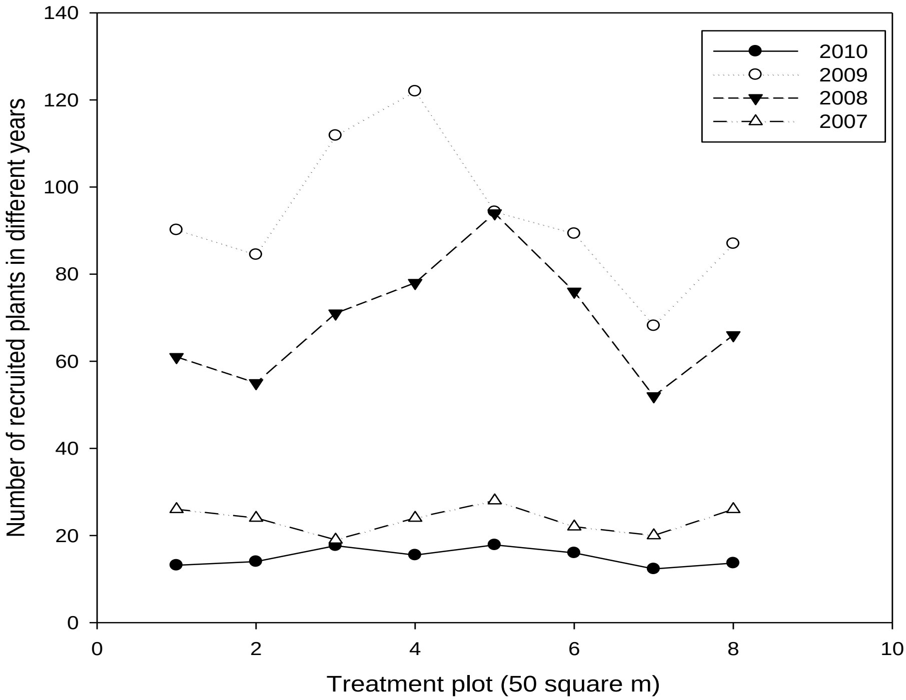

Figure 3: Number of recruitments of the studied plots across years. Recruitments of 2007 and 2008 are before application of treatments (as indicated in Table 1) but recruitments of 2009 and 2010 and after application of treatments

However, growth in diameter and height of the studied mismanaged stand, including the control plot, showed an increasing trend (Fig. 4) across years. Diameter and height of the control plot increased from 2.62 cm and 4.63 m before application of treatments, to 4.18 cm and height of 8.30 m 18 months after treatment application, respectively.

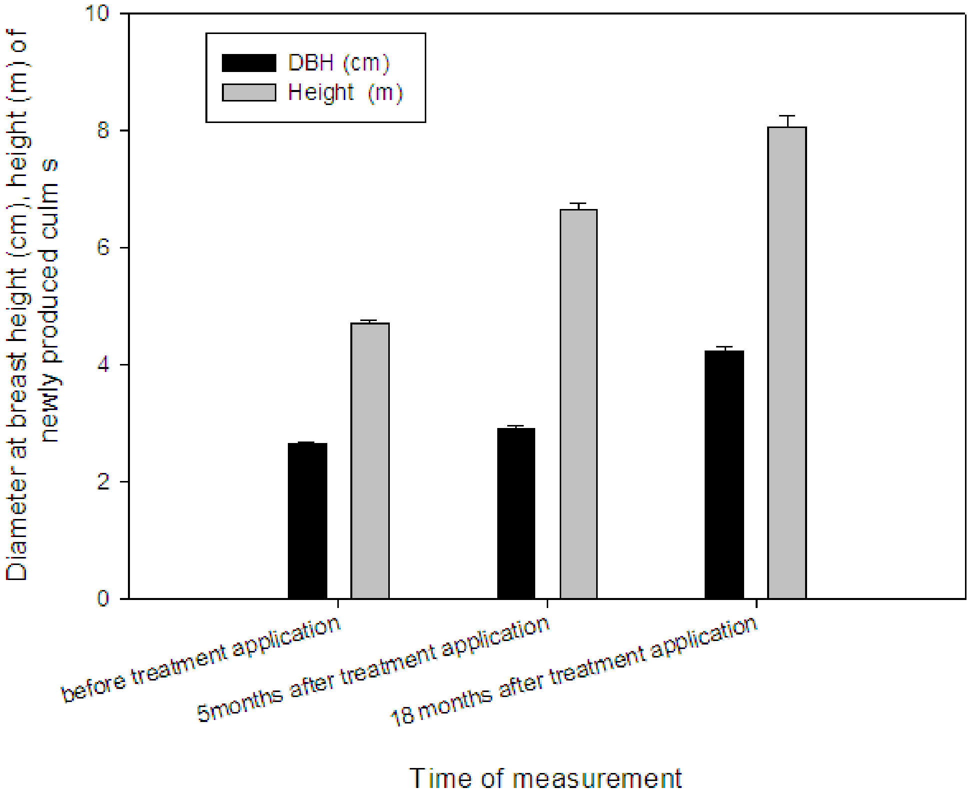

Figure 4: Diameter and height growth of newly recruited shoots across years

The total rainfall of the years 2008, 2009 and 2010 was 1275, 1185, 1476 mm, respectively. From distribution point of view, only two months (February and March) of 2008 had no any rain (Fig. 5). This year, the distribution followed a sigmoid pattern, the highest being in August (271 mm) and July (259 mm). The rainfall distribution of 2009 had more irregularities and shorter shooting season. Unlike other years, May 2009 was dry and rainfall in September was marginally low (only 68 mm). The year 2010 had the highest rain fall distributed throughout the 12 months in a sigmoid pattern, maximum in July (340 mm) and August (277 mm).

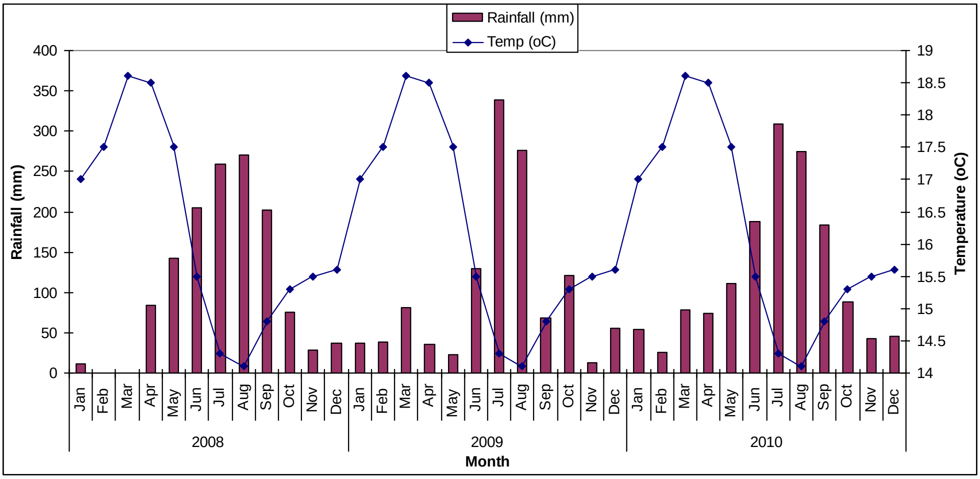

Figure 5: Climate of the study area during the study period, including the previous year (2008)

Culm recruitment and rainfall amount of the shooting seasons (June, July and August) of 2008, 2009 and 2010 had weak correlation (r=0.084).This indicates that reduced number of culm recruitment in 2010 was not because of problems related to moisture deficit. The possible reasons for the dramatic decline may be because of higher population of old leaves that are not photosynthetically efficient (off-year). Bamboo is subjected to an integral system of growth phase that depends upon the age structure of plant leaves (Jianghua et al. 1990; Kleinhenz and Midmore 2001).The extent of available photosynthetically active leaves (photosynthetic carbon fixation) in a particular growing season is the basic determinant for shoot emergence and recruitment (Quantai et al. 1993). *A. alpina* is in the sympodial bamboos group (Phillips, 1995) hence age and photosynthetic efficiency of leaves in the studied bamboo stand should be variable. The life span of leaves of sympodial bamboos extends up to six years with average value 2-5 years (Franklin 2005; Kleinhenz and Midmore 2001; Li et al. 1998). So far, there is no information on leaf lifespan of *A. alpina*. Further study on this aspect may describe its on-year and off-year more precisely and come up with silvicultural methods of regulating culm production of the species.

Despite the on-off year culm production during the study period, the significant difference among treatments and variation in the control plot across years and the increasing trend in diameter and height, indicated that beyond silvicultural management problems, problems of stand protection from livestock interference and encroachment are important yield limiting factors in the study area. Comparison of culm production of 2007 (before treatment), that also had intermittent protection from livestock and human encroachment, with the 2009 culm production showed that silvicultural management and protection can maximize culm yield of communal bamboo stands by 158-589%.

Conclusion and Recommendation

So far in the history of *A. alpina* stand management in Ethiopia, silvicultural management practices of matured stands have not been tried. This study showed that mismanaged bamboo stands can be rehabilitated by employing combined silvicultural practices. Because of the combined management problems of improper harvesting and soil compaction, soil and plant management practices resulted in high number of emerged shoots, low shoot mortality and bigger size culms that are important attributes of silvicultural management. Our study indicated that soil loosening combined with removal of old stumps and selective thinning of old culms increases culm yield by 37% (two years average). Culm recruitment during the first year was 40% higher and shoot mortality 61% lower than the control plot. Culm diameter showed increasing trend across the two seasons after establishment. The study also indicated that beyond silvicultural management problems, problems of stand protection from livestock interference and encroachment are important yield limiting factors. The number of recruited culms for the control plot was higher than the previous year recruitments, indicating problems other than silvicultural management. With improved management, including protection of the stand from interference and encroachment, culm yield of communal bamboo stands can be maximized to 158-589% more than the present yield. Further research on fertilizer application may come up still with more number and bigger sized shoots per growing season.

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