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# STAND STRUCTURE, GROWTH AND BIOMASS OF *ARUNDINARIA ALPINA* (HIGHLAND BAMBOO) ALONG TOPOGRAPHIC GRADIENT IN THE CHOKE MOUNTAIN, NORTHWESTERN ETHIOPIA

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**ABSTRACT:** Three landforms were evaluated for their effect on stand structure, growth and yield of *Arundinaria alpina* K. Schum in the Choke Mountain, northwest Ethiopia. Parameters on stand characteristics and soil properties were assessed. The landforms were (1) 5-15% level to sloping land, (2) 40-60% straight slope (ridge) and (3) 40-60% concave slope (valley). Altitude ranged from 2,870 to 2,938 m a.s.l. All parameters on stand characteristics, except the number of plants per hectare and shoot recruitment rate, were higher in the lower slope position (40-60% concave slope). On the other hand, except clay content and soil moisture, chemical soil properties had similar or better status on 5-15% level to sloping land followed by 40-60% straight slope. Significantly bigger diameter (average 8.4 cm) and emerging height culms (average 15 m) with high growth rate (average maximum of 43 cm day$^{-1}$) and high biomass (117 t ha$^{-1}$) were obtained in 40-60% concave slope landform. Hence, it can be concluded that landform is more influential than nutrient availability for performance of *A. alpina* in the Choke Mountain. Consequently, future bamboo afforestation practices are advised to focus primarily on 40-60% concave slope landform. The 40-60% straight slope is the second most important site for expanding *A. alpina*. Moreover, valleys and ridges are not suitable for annual crop production due to their steep slope. Therefore, superior performance of bamboo on these sites can be excellent opportunity for the area and the community.

**Key words/phrases**: Afroalpine bamboo, Landform, Slope.

## INTRODUCTION

An understanding of site characteristics and their productivity is vital in planning and implementing sustainable management of forests and protection of ecological environment. Site characteristics may include topographic features that comprise landforms, slope characteristics and soil conditions (Skovsgaard and Vanclay, 2008). Information about site productivity will have an important implication on the economics, ecology and social aspects of land use (Diebold, 1998) where there is increased

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interest in reforestation of available land for forest production including bamboos.

Topography refers to the configuration of the land surface encompassing major landforms, the position of the site within the landscape, the slope shape, slope gradient and elevation (Graney, 1989; FAO, 2006). These topographic features are often associated with site quality. Landform refers to any physical feature on the earth's surface that has been formed by natural processes and has a distinct shape or morphology (FAO, 2006) and dominantly differentiated by its dominant slope. It is largely defined by its surface form and location in the landscape as part of the terrain (Turner *et al*., 2001). They affect the flow of many quantities including energy and matter through a landscape and affect ecosystem processes such as site productivity, biomass decomposition, and nitrogen cycling (Turner *et al*., 2001).

Consequently, many studies reported that topographic variables influence plant performance, distribution and stand structure (Chen, 2000; Wei *et al*., 2008; Homeier *et al*., 2010). Chen (2000) classified productivity (site-class) of bamboo stands in China based on their topography. Under his classification, clay pan soil on valley-land had a better site-class (diameter 8-10 cm) than on slopes (diameter 6-8 cm) and table land (diameter <6 cm). Similar findings were also reported in southern Ecuador (Homeier *et al*., 2010). One factor for the difference in productivity along topographic gradient was concluded to be creation of small-scale mosaic of edaphically different habitats because of the existence of steep altitudinal and topographic gradients in a rather limited area (Lu *et al*., 2006). Aigang *et al*. (2006) has indicated the significant effects of landforms on temperature.

Bamboo plantations in the Choke Mountain, one of the topographically diversified alpine mountains in the country, are found under different landforms that range from upper slopes down to the valleys. The level to sloping land (5-15% slope) in the area is preferred mainly for annual crop production including potato that requires deep soil. Ridges (straight slope up to 60%) and valleys (concave slope up to 60%) are used for tree planting including highland bamboo. However, information on site characteristics of bamboo forests and their productivity is lacking in Ethiopia in general and the Choke Mountain in particular.

In this study, three landforms were investigated for their effect on stand structure, growth characteristics and biomass of *A. alpina* (English name: Afroalpine bamboo, Mountain bamboo; common name: highland bamboo;

other scientific names: *Yushania alpina* and *Sinarundinaria alpina*). Data on these variables were also compared with the soil physical and chemical characteristics of the landforms. Thus, the objectives of the study were to (1) determine the variation in bamboo stand structure (stocking, age-class composition, plant size) and growth (height growth rate, recruitment rate) among landforms, (2) quantify biomass accumulation among landforms, and (3) investigate the underlying physico-chemical soil properties of the landforms and describe their effect on plant performance.

## MATERIALS AND METHODS

### Study site and plot selection

The landscape that extends from up the ridge down to the valley bottom of Geltima-Gank watershed was stratified into three landforms based on slope gradient and shape and its position along the gradient. The soil description guideline by FAO (2006) was used while defining the landforms. Accordingly, the landforms were categorized as (1) 5-15% level to sloping land located at the middle part of the watershed, (2) 40-60% straight slope (ridge) located at the upper part of the watershed and (3) 40-60% concave slope (valley) found at the bottom of the watershed. Altitude ranged from 2,870 to 2,938 m a.s.l (Fig. 1, Table 1).

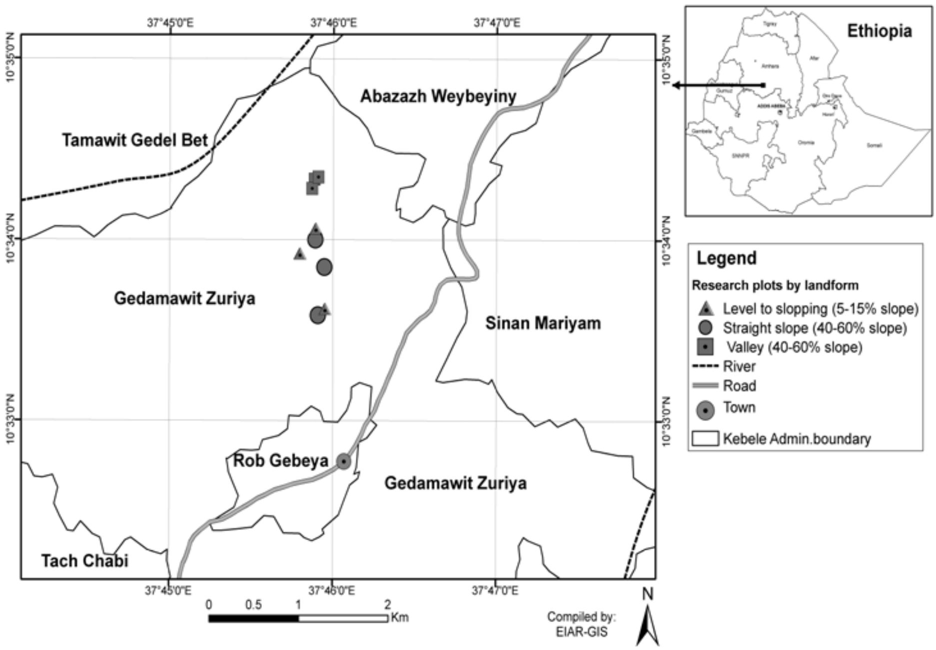


Fig.1. Geltima-Gank study site of Gedamawit peasant association, Sinan district, East Gojam Zone, Ethiopia. Plots under the three landforms are marked by different markers.

Three privately owned stands that had wider area (at least 100 $m^2$) and been used employing selective harvesting of old culms annually by landowners were selected from each landform. The minimum age of the selected stands was 30 years (discussion with the forest owners). One sample plot of size 5 m x 10 m was then delineated from each stand.

Table 1. Characteristics of sample plots under three landforms.

| S.N. | Landform | Plot | Slope (%) | Elevation (m a.s.l.) |
|---|---|---|---|---|
| 1.1 | Steep land (straight slope) | 1 | 40 | 2,909 |
| 1.2 | Steep land (straight slope) | 2 | 67 | 2,937 |
| 1.3 | Steep land (straight slope) | 3 | 55 | 2,938 |
| 2.1 | Level–sloping land | 1 | 5 | 2,900 |
| 2.2 | Level–sloping land | 2 | 10 | 2,906 |
| 2.3 | Level–sloping land | 3 | 14 | 2,923 |
| 3.1 | Steep land (concave slope) | 1 | 62 | 2,878 |
| 3.2 | Steep land (concave slope) | 2 | 40 | 2,870 |
| 3.3 | Steep land (concave slope) | 3 | 62 | 2,890 |

## Climate

Mean annual rainfall of the area is 1,447 mm (20 years average, National Meteorological Agency, 2010). Average temperature is 20.9°C (extrapolated from nearby stations using LocClim 2.0). The main rainy season extends from June to September (shooting season of bamboo) and the high temperature months extend from January to April (Fig. 2).

## TIFRO landrace of *Arundinaria alpina*

*Arundinaria alpina* bamboo stands investigated under this study were of TIFRO landrace. TIFRO is one of the dominantly growing and important landrace in the study area. This landrace grows in wider topographic and soil conditions and performs well. The name TIFRO (Amharic, meaning “having nails”) is given because it has adventitious roots throughout all the culm nodes. It has light green stem the first year and gets darker afterwards. As compared to other landraces of the area, rhizome neck of this landrace is significantly longer hence number of stems per unit area is smaller but growth and biomass are higher because of its bigger diameter and height.

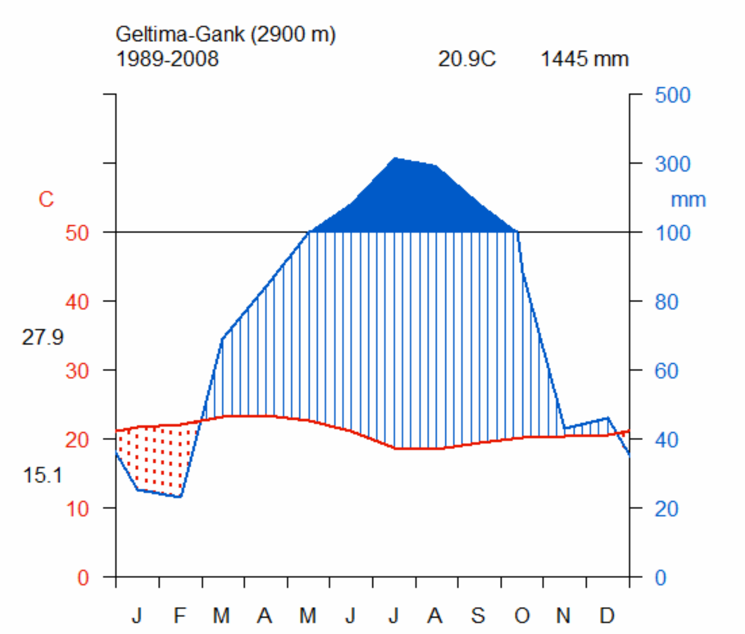


Fig. 2. Klima-diagram showing total monthly precipitation and mean monthly temperature of the study site. Temperature data used to develop this figure was extrapolated from many similar nearby meteorological stations using the software LocClim 2.0 while rainfall data was what is actually collected from Rebu Gebeya Meteorological Station of the National Meteorological Agency.

## Age determination and diameter measurement

After the plots were demarcated, age determination of each plant was done. Permanent markers were used to write age of the plants on culms. Age was determined following a manual (Ronald, 2005) and local experience. The highly appreciable indigenous knowledge on age identification within bamboo farmers was used. According to the manual and local experience, the main criteria for age determination were internode colour, internode cover, internode epiphytes, culm sheaths, sheath ring at node, and branches. The single shooting season in a year (June-September) also made contrasting easier. Diameter at breast height (DBH) of each plant was measured with Vernier Caliper. The minimum diameter considered in the study was ≥2.5 cm.

## Height growth measurement

Ten newly coming shoots were selected from each plot. Height growth was measured every four days interval using graduated bamboo culms and clinometer. The measurement was continued throughout the active growing period, starting from shoot emergence (30 July 2009) till the start of sheathing off (28 September 2009). Because crown obstruction made measuring the last growth after the start of sheathing off difficult, measurement was limited only up to this stage.

## Biomass data collection

Plants were grouped into three age classes as <1, 1-3, >3 years of age and DBH data list was prepared for each age group. Then two plants were randomly selected from the DBH data list of each age group and plot. Selected plants were extracted out, their height measured after felling, sorted in to four components as rhizome, stem, branch and leaf and then their weight measured immediately. Subsamples (15-50 g for leaf and branch and 100-300 g for stem and rhizome) were then taken from each component for dry to fresh weight ratio determination. Subsamples from stems were taken from the second internode of the bottom, middle and top parts, after dividing the culm into three equal parts. The subsamples were then dried in an oven till constant weight at 103°C. Component dry weight and total dry weight were determined using the dry/fresh weight ratio of subsamples.

## Biomass estimation functions

Regression functions were developed employing sample biomass data collected for each age group under this study. Age group was found to be a more influential factor than landform in developing functions hence an independent function was developed for each age group. DBH was found to be the only predicting variable at $R^2$=0.91–0.99 and SE=0.28–0.43 for total dry weight and $R^2$=0.87–0.99 and SE=0.24–0.46 for aboveground total dry weight (see the functions below). Total plant dry weight and aboveground total dry weight of each plant under each plot and age group was then estimated using the developed functions.

TDW (<1 year) = exp (0.202*DBH) $R^2$=0.914, SE=0.431

TDW (1-3 years) = exp (0.310*DBH) $R^2$=0.984, SE=0.297

TDW (>3 years) = exp (0.320*DBH) $R^2$=0.988, SE=0.320

where TDW represents total dry weight and DBH represents diameter at breast height.

AGTDW (>3 years) = exp (0.30*DBH) $R^2$=0.99, SE=0.239

AGTDW (<1 year) = exp (0.172*DBH) $R^2$=0.87, SE=0.463

AGTDW (1-3 years) = exp (0.289*DBH) $R^2$=0.87, SE=0.463

where AGTDW represents aboveground total dry weight and DBH represents diameter at breast height.

## Soil physico-chemical property analysis

Three composite soil samples were taken from three depths (0-20 cm, 20-40 cm and 40-60 cm) from each plot (a total of 27 composite samples). Physical and chemical properties were determined at the National Soil Testing Laboratory of the Ministry of Agriculture, Addis Ababa, Ethiopia. The oven drying method (SAA, 1977) was used to determine soil moisture content. Particle size fractions were determined by hydrometer after dispersion in a mixer with sodium hexametaphosphate (Bouyoucos, 1962). Soil pH was measured with a combination electrode in a 1:2.5 soil: water suspension. EC was determined using conductivity metre. Organic carbon was determined by dichromate oxidation (Walkley and Black, 1934). The total N content was analyzed by the Kjeldahl digestion using $CuSO_4$ and selenium powder as catalysts. Soil cation exchange capacity (CEC) and exchangeable bases were measured by using ammonium acetate extraction method at pH 7. Calcium and magnesium were determined by atomic absorption spectrophotometry, while sodium and potassium by flame emission spectrophotometry. Available P was analyzed according to the standard method described by Olsen *et al*. (1954).

## Data analysis

After data was summarized, analysis was made employing the different functions of PASW Statistics 18. The normality of distribution of observations and homogeneity of variances was checked. Univariate Analysis of the General Linear Model (one-way ANOVA and two-way ANOVA) was then used. Tukey's Honest Significance Difference (HSD) test was used when statistically significant difference ($p<0.05$) was observed. Curve-fit features of the regression function were used for determination of best-fit allometric growth and biomass models. Sigma Plot version 10 was used to present the analyzed data in different graphs.

# RESULTS

## Stand density, age structure and plant size

The 5-15% level-sloping landform had significantly higher stand density (20,467 plants $ha^{-1}$) than the 40-60% straight slope (11,300 plants $ha^{-1}$) and 40-60% concave slope (10,667 plants $ha^{-1}$) landforms (Fig. 3).

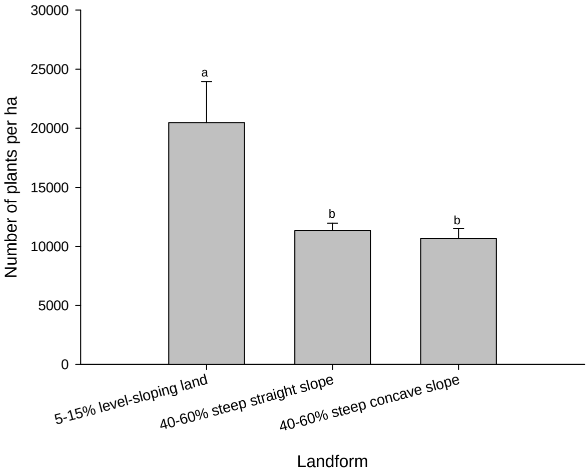


Fig. 3. Number of plants per hectare under three landforms (n=3; p=0.05).

However, the number of plants per hectare did not vary among plants of the three age-groups (Table 2). From the same table, the ratio of <1: 1-3: >3 year old plants for 40-60% concave slope, 40-60% straight slope and 5-15% level-sloping land were 2:4:5, 3:4:5 and 6:7:7, respectively.

Table 2. Number of stems of different ages under the three landforms (Mean ± SE; n=3).

| | Number of stems per hectare | | | |
|---|---|---|---|---|
| **Age (years)** | **40-60% concave slope** | **40-60% straight slope** | **5-15% level-sloping land** | **Total** |
| <1 | 1,533 ± 291 | 2,800 ± 1,102 | 6,400 ± 721 | 10,633 ± 4,318 |
| 1-3 | 3,733 ± 67 | 4,067 ± 882 | 7,200 ± 1,732 | 14,800 ± 3,208 |
| >3 | 5,400 ± 1,039 | 4,667 ± 1,288 | 7,333 ± 1,593 | 17,000 ± 2,230 |
| Total | 10,667 ± 3,359 | 11,300 ± 1,570 | 20,467 ± 733 | 14,144 ± 1,913 |

Significantly higher (p=0.000) mean DBH (8.4 cm) and height (15.2 m) values were found from 40-60% concave slope followed by 40-60% straight slope (DBH=6.0 cm and height=10.7 m) and 5-15% level-sloping land (DBH=5.0 cm and height=9.6 m) (Table 3). The maximum DBH and height values on 40-60% concave slope were 9.2 cm and 18 m, respectively. The 40-60% straight slope and 5-15% level-sloping land had maximum DBH 8.6 and 6.2 cm and maximum height of 13.0 and 12.7 m, respectively.

Table 3. Diameter and height of plants per plot of the three landforms (n=9; p=0.000).

| Landform | Maximum DBH (cm) | Mean DBH (cm) | Maximum height (m) | Mean height (m) |
|---|---|---|---|---|
| 5-15% level-sloping land | 6.2 | $5.0 \pm 0.2^c$ | 12.7 | $9.6 \pm 0.4^b$ |
| 40-60% straight slope | 8.6 | $6.0 \pm 0.4^b$ | 13.0 | $10.7 \pm 0.6^b$ |
| 40-60% concave slope | 9.2 | $8.4 \pm 0.2^a$ | 18.0 | $15.2 \pm 0.5^a$ |

## Growth and recruitment

### Height growth rate

Generally, from the growth curves (Figs. 4 and 5) it was observed that except for the first three measurements of 5-15% level-sloping and 40-60% straight slope landforms, height growth was continuously increasing up to 13 September 2009, and then slowed down. The 40-60% concave landform had significantly higher growth rate (p=0.000) than other landforms throughout the growth period. Average growth rate of this landform for all the measurement periods was 23 cm day$^{-1}$ (maximum value 43 cm day$^{-1}$ at the 13$^{th}$ measurement - 16 September 2009). Average height growth rates of the 40-60% straight slope and 5-15% level-sloping land were 34 and 25 cm day$^{-1}$, with corresponding average values of 17 and 15 cm day$^{-1}$, respectively.

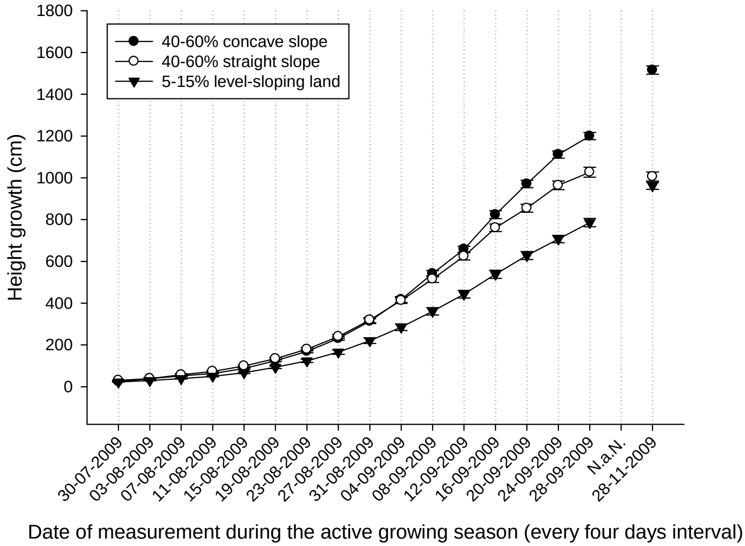


Fig. 4. Height growth of newly growing bamboo culms calculated from data collected at four days interval during active growing period on different landforms. Marks indicated on 28-11-2009 on the figure show average heights of mature plants of the respective landraces of the studied stands. N.a.N indicates that measurement of height growth in the two months period was not taken.

The growth rates were also regressed against the measurement periods (dates of measurement). The fitted curves indicated exponential growth rates for the different landforms during the measurement period. The functions for the different landraces were as follows:

40-60% concave slope:

GR (measurement period) = exp (0.299*measurement period) $R^2$=0.94, SE=0.758

40-60% straight slope:

GR (measurement period) = exp (0.282*measurement period) $R^2$= 0.94, SE=0.664

5-15% level-sloping land:

GR (measurement period) = exp (0.268*measurement period) $R^2$=0.91, SE=0.779

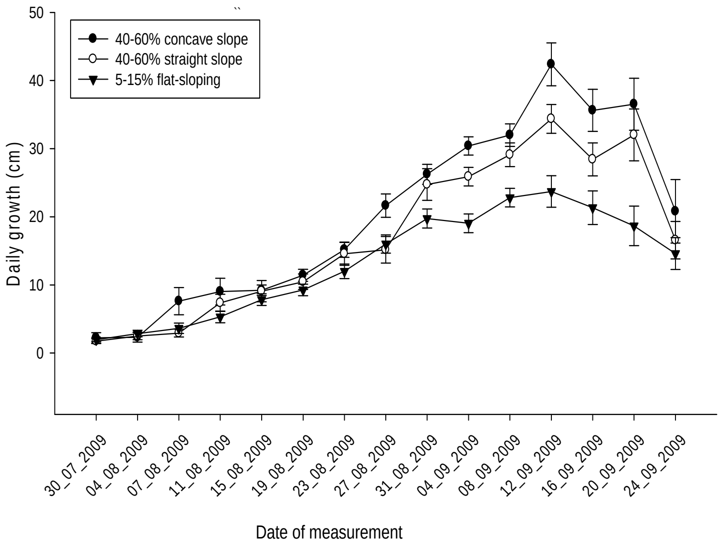


Fig. 5. Daily growth rates of newly growing bamboo culm calculated from data collected at four days interval during active growing period on different landforms.

## Recruitment rate

Recruitment rate was determined as the ratio of recruited shoots to the total shoots emerged during the shooting season. Recruitment rate for landform 5-15% level-sloping land (87%) was significantly higher (p=0.006) than 40-60% concave slope (65%) and 40-60% straight slope (72%) (Fig. 6).

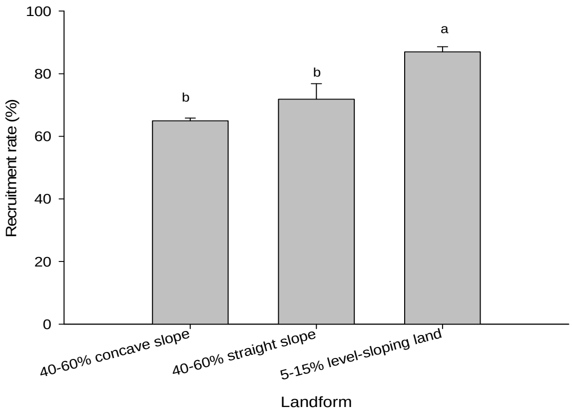


Fig. 6. Recruitment rate of stands under three landforms.

## Biomass

Estimates for total dry weight (TDW) per plant and aboveground total dry weight (AGTDW) were significantly different among landforms (Fig. 8). However, estimates made on per hectare basis were not statistically different (Fig. 7) among landforms that might be because of compensation of the higher number of plants of small size in the 5-15% level-sloping land by bigger size but smaller number of plants in other landforms. Though not statistically different, the 40-60% concave slope had 30% and 82% higher TDW than the 5-15% level-sloping and 40-60% straight slope landforms, respectively. AGTDW followed similar trend to TDW. AGTDW for 5-15% level-sloping, 40-60% straight slope and 40-60% concave slope were 99±23.7, 56±6.6 and 80±19.9 t $ha^{-1}$, respectively. TDW and AGTDW were also statistically varied among age-groups. However, values of the interaction between landform and age-groups were not significant for all the fresh and dry weight per plant and per hectare basis estimates.

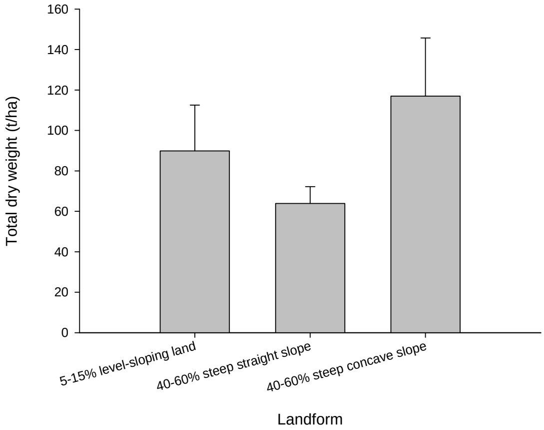


Fig. 7. Biomass per ha of bamboo plants under three landforms (n=3).

Biomass per plant for <1 year old plants was less than half that of the 1-3 and >3 years old plants (Fig. 8). However, diameter and height were not different among the different age-groups as bamboos do not increase in size after shoot elongation that happens in 2-3 months time.

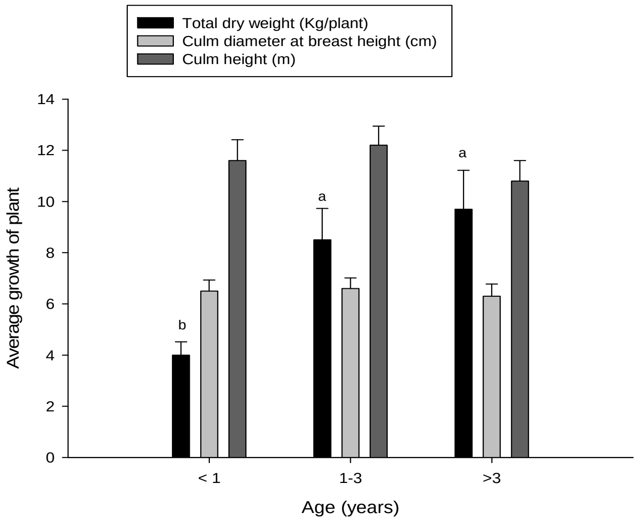


Fig. 8. Diameter, height and biomass of plants under three age-groups of the studied plots (n=9, Tukey's HSD test).

## Biomass partitioning among plant parts

Allocation to plant parts was not statistically different among landforms. The proportion of allocation to culm was 65, 67 and 69% for 40-60% concave slope, 40-60% straight slope and 5-15% level-sloping landforms, respectively. The values for rhizome, branch and leaf parts of the respective landforms were 17, 17 and 14; 13, 9 and 12; and 5, 6 and 5%, respectively (Fig. 9). Accordingly, the proportion of allocation to aboveground and belowground plant parts were 79-89% and 13-17%, respectively, resulting in the belowground to aboveground ratio of 0.15 for 5-15% level-sloping landforms and 0.20 for the other two landforms.

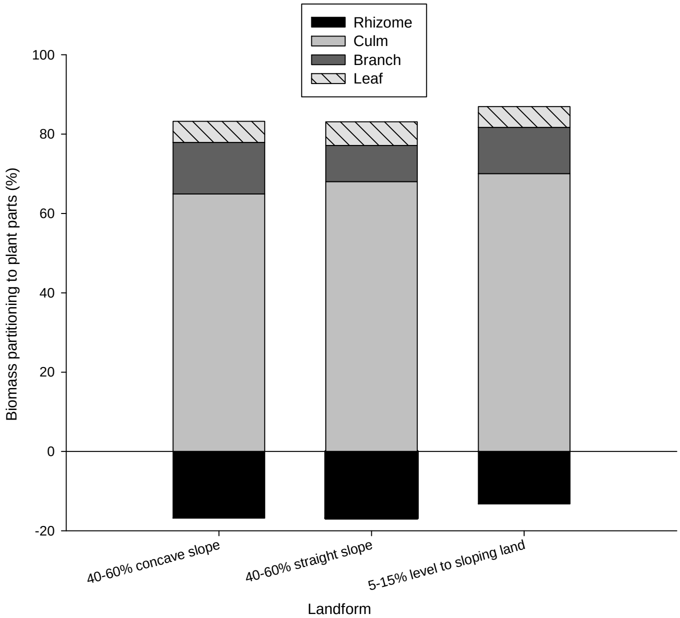


Fig. 9. Biomass partitioning (% of total) of *Arundinaria alpina* among the different parts under three landforms (n=54).

## Soil physical properties

The 5-15% level-sloping landform had statistically lower sand (38%) but higher silt content (39%) as compared to the 40-60% steep straight slope. The 40-60% concave slope had also lower silt content (23%) but statistically higher clay content (41%) as compared to the 40-60% straight slope landform (Table 4). Soil texture class was found to be clay for 40-60% concave slope and clay-loam for the other landforms.

## Soil chemical properties

The difference in pH of the three landforms was statistically different (p=0.05). The 5-15% level-sloping landform had the highest value (6.26) followed by the 40-60% steep straight slope landform (6.03). The least pH value (5.92) was determined for the 40-60% concave slope landform (Table 5).

Table 4. Texture and moisture content of soil under three landforms.

| | **Landform** | | | | | **Soil depth (cm)** | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Texture, Moisture content** | **40-60% concave slope** | **40-60% straight slope** | **5-15% level-sloping** | **F-value** | **p-value** | **0-20** | **20-40** | **40-60** | **F-value** | **p-value** |
| Sand (%) | 22.78 (1.78)[b] | 34.22 (3.90)[a] | 23.44 (2.44)[b] | 5.089 | 0.014 | 31.11 (3.61) | 26.00 (3.46) | 23.33 (2.39) | 1.525 | 0.238 |
| Silt (%) | 36.22 (1.90) | 34.89 (1.60) | 37.56 (0.65) | 0.809 | 0.457 | 35.33 (1.33) | 35.56 (1.14) | 37.78 (1.87) | 0.833 | 0.447 |
| Clay (%) | 41.00 (2.06)[a] | 30.89 (3.72)[b] | 39.00 (2.79)[ab] | 3.332 | 0.053 | 33.56 (2.85) | 38.44 (3.43) | 38.89 (3.30) | 0.853 | 0.439 |
| MC (%) | 23.80 (0.96)[a] | 22.12 (0.50)[ab] | 20.30 (0.68)[b] | 5.590 | 0.010 | 22.00 (0.95) | 21.92 (0.77) | 22.30 (0.95) | 0.051 | 0.951 |
| Texture class | Clay | Clay-loam | Clay-loam | – | – | – | – | – | – | – |

MC=Moisture Content

Table 5. pH and EC of soil under three landforms and along three soil depths.

| | **Landform** | | | | | **Soil depth (cm)** | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| **Soil property** | **40-60% concave slope** | **40-60% straight slope** | **5-15% level-sloping** | **F-value** | **p-value** | **0-20** | **20-40** | **40-60** | **F-value** | **p-value** |
| pH_$H_2O$ | 5.92 (0.04)[b] | 6.03 (0.12)[ab] | 6.26 (0.08)[a] | 3.54 | 0.045 | 6.07 (0.09) | 6.056 (0.11) | 6.09 (0.11) | 0.27 | 0.973 |
| EC | 0.12 (0.02) | 0.107 (0.01) | 0.13 (0.02) | 0.599 | 0.557 | 0.17 (0.01)[a] | 0.106 (0.01)[b] | 0.08 (0.01)[b] | 27.07 | 0.000 |

Mean (n=9)± standard error. Different letters within one column indicate significant differences (p<0.05, Tukey's HSD test); NS=mean values in the row are not statistically significant

The three important soil fertility parameters namely total nitrogen, organic carbon and their ratios (C:N ratio) did not show significant difference among the three landforms. The values for total nitrogen were 0.393, 0.387 and 0.383 for the 5-15% level-sloping, 40-60% straight slope and 40-60% concave slope landforms, respectively (Table 6). The corresponding values for organic carbon were 4.247, 3.963 and 3.89%, respectively. Available phosphorus, potassium and magnesium showed significant difference among landforms. The highest available P value (49.47 ppm) was found on the 5-15% level-sloping landform and followed by the 40-60% straight slope (9.67 ppm). The least value (3.45 ppm) was found on the 40-60% concave slope. The concentration of cations was in the following order: Ca+ > Mg+ > K+ > Na+. The highest K (2.39 Cmol (+)/kg) was found on the 40-60% straight slope, followed by the 40-60% concave slope (1.67 Cmol (+)/kg) and 5-15% level-sloping landform (0.64 Cmol (+)/kg).

Table 6. Soil chemical properties under three landforms.

| Landform | Unit | 5-15% level-sloping land | 40-60% straight slope | 40-60% concave slope | F-value | p-value |
|---|---|---|---|---|---|---|
| N | % | 0.39 ± 0.05[ns] | 0.39 ± 0.30 | 0.38 ± 0.03 | 0.014 | 0.986 |
| C | % | 3.96 ± 0.57 [ns] | 4.25 ± 0.44 | 3.89 ± 0.43 | 0.152 | 0.860 |
| C:N | Ratio | 9.89 ± 0.59 [ns] | 10.83 ± 0.26 | 9.96 ± 0.40 | 1.412 | 0.263 |
| Av. P | Ppm | 86.19 ± 21.96[a] | 79.74 ± 31.49[ab] | 4.87 ± 0.97[b] | 4.156 | 0.028 |
| Na | Cmol/kg | 0.23 ± 0.02 [ns] | 0.39 ± 0.06 | 0.31 ± 0.06 | 0.780 | 0.470 |
| K | Cmol/kg | 0.64 ± 0.11[b] | 2.39 ± 0.26[a] | 1.67 ± 0.57[ab] | 5.847 | 0.009 |
| Ca | Cmol/kg | 22.27 ± 0.76[ns] | 21.33 ± 0.30 | 20.59 ± 3.17 | 0.350 | 0.709 |
| Mg | Cmol/kg | 6.72 ± 0.41[a] | 5.23 ± 0.27[ab] | 4.93 ± 0.65[b] | 4.180 | 0.028 |
| CEC | Cmol/kg | 42.73 ± 0.75[ns] | 40.35 ± 1.68 | 42.12 ± 3.54 | 0.288 | 0.752 |
| Base Sat. | % | 69.78 ± 1.32[ns] | 68.67 ± 2.25 | 62.23 ± 4.77 | 1.634 | 0.216 |

Mean (n=9)± standard error. Different letters within one row indicate significant differences (p<0.05, Tukey's HSD test); NS=mean values in the row are not statistically significant

Total N at top 0-20 cm was significantly higher (0.492%) than at the middle 20-40 cm (0.370%) and bottom 40-60 cm (0.30%) depths. The trend was also similar for organic carbon. Values for organic carbon at 0-20 cm depth (5.41%) were significantly higher than the 20-40 (3.775%) and 40-60 cm (2.913%) depths. The C:N ratio for 0-20 cm depth was significantly higher (11.19) followed by 20-40 cm depth (10.14). The value for 40-60 cm depth was the lowest (9.44). However, the values for available P, base cations and base saturation did not show significant difference along soil depth (Table 7).

Table 7. Soil chemical properties along soil depth.

| Soil property | Unit | Soil depth (cm) 0-20 cm | 20-40 cm | 40-60 cm | F-value | p-value |
|---|---|---|---|---|---|---|
| N | % | 0.49 (0.04)[a] | 0.37 (0.02)[b] | 0.30 (0.03)[b] | 11.568 | 0.000 |
| C | % | 5.41 (0.31)[a] | 3.77 (0.31)[b] | 2.91 (0.34)[b] | 15.707 | 0.000 |
| C:N | Ratio | 11.10 (0.30)[a] | 10.14 (0.46)[ab] | 9.44 (0.40)[b] | 4.481 | 0.022 |
| Av. P | Ppm | 59.00 (21.32) | 56.80 (27.73) | 55.00 (27.60) | 0.006 | 0.994 |
| Na | Cmol/kg | 0.30 (0.06)[ns] | 0.33 (0.06) | 0.31 (0.06) | 0.184 | 0.833 |
| K | Cmol/kg | 1.75 (0.41)[ns] | 1.46 (0.40) | 1.53 (0.55) | 0.090 | 0.914 |
| Ca | Cmol/kg | 22.63 (2.01)[ns] | 20.96 (2.43) | 20.62 (1.92) | 0.827 | 0.449 |
| Mg | Cmol/kg | 5.62 (0.50)[ns] | 5.51 (0.57) | 5.74 (0.56) | 0.043 | 0.958 |
| CEC | Cmol/kg | 42.77 (2.24)[ns] | 42.66 (2.57) | 41.32 (2.36) | 0.480 | 0.625 |
| Base Sat. | % | 69.38 (3.23)[ns] | 64.22 (3.71) | 66.33 (2.95) | 0.887 | 0.425 |

Mean (n=9)± standard error. Different letters within one row indicate significant differences (p<0.05, Tukey's HSD test); NS=mean values in the row are not statistically significant

# DISCUSSION

## Stand structure

The standing culm density recorded for the three landforms (11,000-20,000 plants ha$^{-1}$) under this study was higher than what is reported from Masha natural bamboo forests (8,840 plants ha$^{-1}$) by Kassahun Embaye (2003) but closer to what Wimbush (1945) noted from an undisturbed bamboo crop of *Arundinaria alpina* (10,000-17,000 plants ha$^{-1}$). This value is still higher than what is reported as rational density (3,000 plants ha$^{-1}$) for *Phyllostachys pubescens*, a monopodial bamboo extensively cultivated in China (Yegen, 1992), and 8,018 plants ha$^{-1}$ for natural stands of *Gigantochloa scortechinii*, a widely distributed sympodial bamboo, in Malaysia (Othman, 1994). The higher density of plants of *A. alpina* may principally be associated with the nature and colonization pattern of its rhizome. It produces shoots that are almost evenly distributed in the stand. Besides, it produces more as it is selectively harvested every year.

In general, the ratio of the number of the three age-groups of the plants (<1, 1-3 and >3 years) of the three landforms was 3:4:4 (calculated from Table 2). This proportion showed that the forest is in a recommendable age structure as compared to the proportion reported by Kassahun Embaye *et al.* (2005), from Masha natural bamboo forest (<1 year 13%, 1-3 years 24% and >3 years 63%). The rational age structure of plants in all the landforms was impressing. As the farmers in the Choke Mountain selectively harvest older culms every year, the rational age structure and its productivity could be maintained.

Average values of DBH 5-8 cm (maximum 9.9 cm), height 10-15 m (maximum 20 m), total dry weight 5-12.5 kg plant$^{-1}$ and total fresh weight 13-32 kg plant$^{-1}$ are comparable to what is reported by LUSO (1997) for the same species, by Jinhe (2000) for *Phyllostachys pubescens* and by Azmy *et al*. (2004) for *Gigantochloa scortechinii*. DBH of *P. pubescens* bamboo ranges from 6-18 cm and height over 20 m (Jinhe, 2000). The maximum diameter and height of *G. scortechinii*, with fertilizer application was 7.7 cm (5 to 7 cm) and 18 m (most culms 11 to 14 m), respectively (Azmy *et al*., 2004). The lower values in DBH and height under the 5-15% slope than other landforms in this study may be associated with the generally negative relationships between plant size and plant density (Tateno and Takeda, 2003) and the effect of the underlying soil and topographic conditions.

**Shoot recruitment, height growth rate and biomass**

Mortality of emerging shoots for the three landforms ranged from 13% (for 5-15% level-sloping land) to 35% (for 40-60% concave slope), i.e. recruitment rate of 65-87%. This value is within the range, 9-69% depending on eco-physiological conditions, reported for natural mortality of emerging shoots (Banik, 1997). During the period of rapid growth of new shoots, limited availability of required nutrients that are absorbed directly from the soil or carbohydrate originate from current photosynthesis and stored photosynthates in older (≥1 year old) plants may result in food shortage (Li *et al*., 1998; Kleinhenz and Midmore, 2001). Clump congestion, soil moisture, and genetic make-up of each species and clump may also affect natural mortality rate of emerging shoots (Banik, 1997). The higher mortality rate of emerging shoots determined in this assessment implies that management practices that can maximize shoot recruitment rate may be critical for the 40-60% concave slope.

Average height growth rate of *A. alpina* measured during the two months rainy season on the three landforms ranged from 15-23 cm day$^{-1}$ (with average maximum value ranging from 25-43 cm day$^{-1}$). This value was similar to what is reported for the daily growth rate of *Dendrocalamus giganteus* (10-30 cm, but reaches 58 cm day$^{-1}$) (Banik, 1997) and *Bambusa arnhemica* (peak elongation rates of 15-30 cm day$^{-1}$) in Australia (Franklin, 2005) and *Bambusa bambos* (five month average 30 cm day$^{-1}$) in India (Shanmughavel and Francis, 1996). Besides soil and topographic factors, competition for light in valley areas (Tateno and Takeda, 2003) may be one of the factors that resulted in higher height growth rate in the 40-60%

concave slope landform.

Despite the higher shoot mortality rate and lower number of plants per hectare, the 40-60% concave slope showed higher biomass (117±28.8 t ha$^{-1}$) as compared to 5-15% level-sloping landform (90±22.6 t ha$^{-1}$) and 40-60% straight slope landform (64±8.3 t ha$^{-1}$) (Table 3, Fig. 7). This finding does not agree with what is reported by Zhang *et al*. (1996) in which slope and biomass had negative relationships in six locations in China. This study indicated that besides slope gradient, shape of the slope influences productivity of bamboos The total dry weight and aboveground total dry weights found in this study were higher than what was reported by LUSO (1997) (51 t ha$^{-1}$ total aboveground biomass) from Masha natural bamboo forest but within what Wimbush (1945) noted (100 ton air-dry weight of culms) and 110 t ha$^{-1}$ total aboveground biomass estimates of Kassahun Embaye (2003). Nevertheless, this value is lower than what is reported from northeast India (122 t ha$^{-1}$ aboveground stand biomass) for *Bambusa cacharensis*, *Bambusa vulgaris* and *Bambusa balcooa* (Nath *et al*., 2009).

The increment or biomass of less than 1 year plants investigated in this study ranged from 6-26 t ha$^{-1}$. This value is higher than what was reported from Masha natural *A. alpina* bamboo forest (8.6 t ha$^{-1}$) by LUSO (1997) and for a semi-natural lowland stand of *Phyllostachys pubescens* (7.7 t ha$^{-1}$ per year) in Zhejiang Province, China by Qiu *et al*. (1992). But it is lower than what is reported by Shanmughavel and Francis (1996) for *Bambusa bambos* grown with fertilizer and irrigation having an equivalent average aboveground productivity of 47 t ha$^{-1}$ per year in southern India.

In light of the above, it may be concluded that TIFRO landrace stands of the Choke Mountains have comparable yield and productivity with high yielding sympodial bamboos like *Bambusa bambos* that is widely planted in India and with giant monopodial bamboos such as *P. pubescens*, the extensively planted species in China (Scurlock *et al*., 2000).

The relative contribution of various components to the standing state of biomass was in the order of culm > rhizome > branch > leaf. Similar trend for the aboveground biomass was reported from Siwalik bamboo forest in the Garhwal Himalaya, India (Joshi *et al*., 1991). Allocation to the belowground plant part was higher for landforms having steep slopes (Fig. 3). This is expected, as the plants tend to allocate more on their belowground part as their survival strategy under steep lands. Scrapping of the rhizome along the slope requires more biomass allocation on the underground plant parts.

## Soil physico-chemical properties

In general, the total N (0.38-0.39%) and organic C (3.89-4.25) contents determined under this study (Table 6) are slightly lower than what is reported by Fantaw Yimer (2007) from the Bale Mountain protected forests (N: 0.59%; OC: 5.31%) but higher than what is reported by Taye Khfa (2011) from wild coffee forest soils of southeastern and southwestern Ethiopia (N: 0.18-0.24, OC 1.27-2.83). The C:N ratios under all the landforms lie within the typical C:N ratio (9-12) described by Batjes and Dijkshoorn (1999). The P, K, and Ca values were higher than what is reported by Kassahun Embaye *et al*. (2005) from Masha natural bamboo stand in southwest Ethiopia (N: 0.64%; P: 0.002%; K: 0.017%; Ca: 0.07%; pH: 4.6).

The concentration of total N and organic C has similar status for the three landforms. However, higher available P (86.19 ppm) and Mg (6.72 Cmol $kg^{-1}$) concentration than the other landforms were recorded on the 5-15% level-sloping land. The soil texture class of the 40-60% concave slope was clay, with higher moisture content (23.80%) and of the other two landforms clay-loam, with lower moisture content. The 40-60% concave slope landform (valley) is found at the lower part of the watershed in the complex landscape setup of the Choke Mountain and is hence expected to have more clay and improved hydrological condition. On the other hand, it is steep in slope and hence had good drainage. Since the concave slope is characterized by bidirectional steep slopes, its role in obstructing direct sunlight, at least for some hours every day, might cause reduction in evapo-transpiration and hence higher moisture of the soil (Table 4). On the contrary, the level land, though seasonally water logged, is exposed to longer sunlight hours hence there might be more evapo-transpiration than in other landforms. In bamboo growth and physiology, factors related to moisture regime (moisture content and drainage) were found to be more affecting than nutrient status (Cirtain *et al*., 2004), hence higher plant size and biomass on the 40-60% concave slope could be associated with the higher moisture-holding capacity of the clay textured soil and steep slope that enhance good drainage.

## CONCLUSION AND RECOMMENDATION

In this study, the effect of topographical variables mainly slope gradient and shape (slope position) and the underlying soil physico-chemical properties on the stand structure, growth rate and biomass was investigated by selecting three landforms. Shoot recruitment rate of 65-87% and standing culm density of 11,000-20,000 were found in the studied landforms. Higher values were recorded for these two parameters for the 5-15% level-sloping land whereas bigger diameter (average 8.4 cm) and emerging height culms (average 15 m), highest growth rates (average maximum of 43 cm $day^{-1}$) and higher biomass (117 t $ha^{-1}$) were obtained in 40-60% concave slope. On the other hand, except the two soil physical properties, namely, clay content and soil moisture, soil chemical properties had similar or better status on the 5-15% level to sloping land followed by the 40-60% straight slope.

Hence, it can be concluded that topography and soil physical properties (soil texture and moisture content) are more influential than nutrient availability for the performance of *A. alpina* (TIFRO landrace) in the Choke Mountain. Topography may also affect stand density. The lower impedance against rhizome growth on level-sloping land as compared to steep slopes might result in higher shoot recruitment but smaller plant size. Consequently, future bamboo afforestation works are advised to focus primarily on the higher site quality landform, 40-60% concave slope (valley) that harbours clay soil with higher moisture content and good drainage because of its steep slope. The 40-60% straight slope (ridges) are the second most important sites for expanding TIFRO landrace production in the area. Moreover, valleys and ridges are not suitable for annual crop production due to their steep slope. Soil and water conservation activities are highly encouraged in such sites, hence superior performance of bamboo on these sites is an excellent opportunity for the area. Level-sloping lands are highly preferred for annual crop production that is the mainstay of the community.

Ratio of the three age-groups of the plants (<1, 1-3 and >3 years) of the three landforms was 3:4:4. This age structure, developed by selective harvesting, is impressing and recommendable. As the farmers in the Choke Mountain selectively harvest older culms every year, the rational age structure and its productivity could be maintained. But improving the recruitment rate through application of management practices on the 40-60% concave slope may be critical.

Unlike different reports that recommend afforestation of sympodial bamboo on level land, planting *A. alpina*, TIFRO landrace on steep slopes will not have any problem in relation to soil erosion; rather, the scrambling rhizomes could make the distribution of plants in the afforestation site uniform thereby favouring soil and water conservation. Hence, besides timber production, the use of *A. alpina* for soil and water conservation purposes on steep lands can have tremendous significance.

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