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Morphology and biomass variations of *Arundinaria alpina* landraces in the Choke Mountain, northwestern Ethiopia

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Abstract: A study on the rhizome morphology, growth and biomass of four *Arundinaria alpina* landraces was made in the Choke Mountain, northwestern Ethiopia. Three 10 m x 10 m sample plots were randomly selected from each landrace from a church forest of age >50 years. A total of 72 plants, six plants from each plot, were used to characterize the morphology and develop biomass functions. The result indicated that the rhizome proper of all landraces was nearly vertically positioned and exhibits sympodial branching pattern. Landraces showed statistically significant difference in rhizome neck length (mean value 8.5 - 17.3 cm), diameter and number of internodes of the rhizome neck and of the rhizome proper. Number of plants per hectare of the landraces was also significantly different with mean values ranging from 11,467 - 15,800. Average values of diameter and height of culms of the landraces ranged from 3.7–5.3 cm and 7–11 m, respectively. The highest biomass per ha of the landraces was estimated at 74 t ha^{-1}. Higher stand density associated with shorter rhizome neck and emerging height might contribute to higher shoot mortality rate but also to higher biomass in the high biomass yielding landrace.

Keywords: Afro-alpine, mortality, rhizome, stand structure, *Yushania alpina*

INTRODUCTION

Silvicultural management, productivity and utilization of bamboos depend on the basic nature of the species and hence a better understanding of their morphology is an important concern in bamboo production. Their growth habit, particularly the manner in which the underground rhizome and aboveground parts develop leading to the formation of harvestable products affect growth and biomass of bamboos. McClure (1966) classified bamboos into two main groups, based on their rhizome branching pattern- the sympodial and the monopodial. Taxonomists also reserved the terms pachymorph and leptomorph to describe morphology of the two aforementioned basic rhizome types (Dransfield and Widjaja, 1995). In sympodial branching, each new rhizome turns upward and develops into a culm and becomes dominant (Recht and Wetterwald, 1994). The rhizomes are short, thick, and usually curved upwards. The

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rhizome is a part of the modified branch of a monopodial bamboo plant (Liese, 1998).

It looks like a thin horizontal underground culm, extending horizontally for long distance, except that it bears roots at every node. It is uniformly thin, long with well separated nodes, and usually stays underground, with erect culms or further horizontal rhizomes branching off at intervals (Qisheng *et al*., 2001).

Arundinaria alpina, common name Afro-alpine bamboo or highland bamboo, was reported to exhibit sympodial branching pattern and robust clumping rhizome type (Breitenbach, 1963; Phillips, 1995; Kigomo, 2007). On the contrary, the same species was also reported to exhibit monopodial branching pattern (Embaye *et al*., 2005; Seyoum, 2005) and leptomorphic rhizome type (Were, 1988). Wimbush (1945) described that *A. alpina* occurs gregariously-growing together (not in clumps) within mountain forests in tropical Africa. One cause for inconsistency in naming the rhizome morphology and culm spacing of *A. alpina* might arise either from the inconsistent naming of the plant by bamboo taxonomists (Watanabe *et al*., 1994; Stapleton, 1998) or by actual variations within different landraces of the species.

A report in the Kew Bulletin by Chi-son and Renvoize (1989) indicated that, from classification made based principally on the vegetative state, *Arundinaria* is transferred into another genus *Sinarundinaria* hence its new name *Sinarundinaria alpina*. The authors added that rhizome of *Sinarundinaria* is sympodial, with short or long necks. From the list of recently corrected names of bamboos by Ohrnberger (1999) the new name of *A. alpina* is *Yushania alpina*. Because of the existing inconsistencies in naming the species and lack of clarity in its taxonomic classification (Phillips, 1995), the old name, *A. alpina* is used in this paper.

Different reports indicated that there are different highland bamboo landraces (assumed varieties) mainly varying in their growth characteristics, morphological attributes and wood working properties (LUSO, 1997; SIM, 2002). The reports stressed that there should be scientific research to confirm if the variation is because of environmental variations or species or varietal difference. In the Choke Mountain, four assumed varieties differing in their morphological characteristics, utilization, regeneration and management need have been cultivated, for more than a century (group discussion and field survey before the start of this research). For perennial crops and crops with vegetative reproduction like bamboos, the term landrace is used when the crop has been cultivated and reproduced in the area for more than 60 years (Calvet-Mir *et al*., 2011). Thus the assumed varieties can be called as landraces.

Therefore, this study emanates from the inconsistency in naming of the rhizome morphology in different reports on the one hand and the observed differences in the field on the other. Under this study, rhizome morphological characteristics, stand structure, recruitment and biomass of four *A. alpina* landraces cultivated in the Choke

Mountain were investigated. The objectives of the study were to: (1) investigate rhizome characteristics (2) examine stand structure (stocking, age, diameter, height) and (3) determine recruitment rate and biomass of four *A. alpina* landraces.

MATERIALS AND METHODS

Selection of landraces and sample plots

Reconnaissance survey of the area and group discussion with communities were made ahead of selecting the landraces. Though there were variations in naming the landraces and also variation of the landraces themselves, only three dominantly growing and one landrace having high preference for handicrafts were selected for this study. The four landraces (local varieties) selected were locally called *Tifro, Welele, Wonde* and *Enkotekot* (Fig. 1). Based on prior agreement and memorandum of understanding with the community and leaders of the Ethiopian Orthodox Church, three 10 m x 10 m sample plots were randomly selected from each landrace from a church forest of age >50 years. The first plots of each landrace were laid 10 m away from two sides of the stands and the consecutive plots at each 40 m distance within the forest.

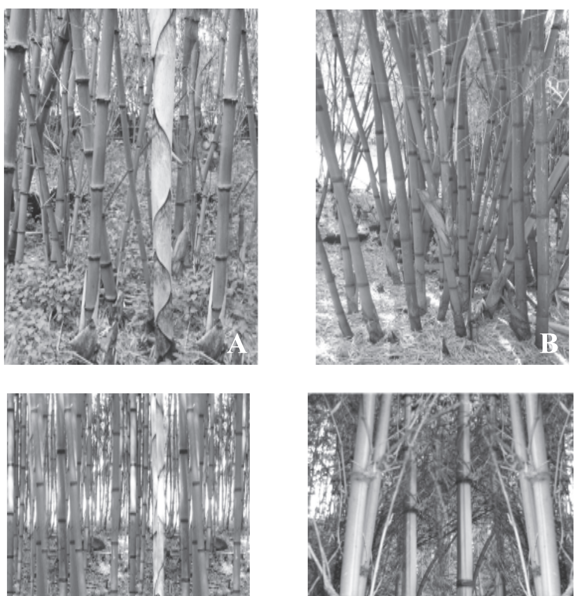

Figure 1. Mature stands of *A. alpina* landraces in the Choke Mountain: (A) *Tifro,* (B) *Welele*, (C) *Wonde* and (D) *Enkotekot* landraces. Note the spacing between plants, culm color and shape of the nodal region

Age determination and diameter measurement

Because individuals in the studied *A. alpina* bamboo stand are usually well separated and distributed in an area basis, not in clumps, the term "plant" is used in this paper to refer to individuals (comprising both belowground and aboveground parts); whilst culm is used to refer only to the aboveground stem of individual plant.

After the plots were demarcated, age determination of each and every 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 color, internode cover (white flour on the surface of culms), internode epiphytes or lichens that grow on culms, culm sheaths, sheath ring at node, and branches. Internodes of <1 year culms are often covered with tiny white hairs, called 'flour' which falls of within 1–2 years and culms >2 years have no 'flour' left. Culms of <2 years have no internode epiphytes while in >2 year culms lichen and epiphytes are found. Almost all culm sheaths are intact in <1 year culms, and begin to fall off until none are left within 1-2 years. Culms of >2 year have no culm sheaths. Culms of <1 year have whole sheath ring or part of it is persistent, while in 1–2 year old culms, the remaining sheath ring becomes harder, and then falls off. Culms of <1 year have no secondary branches. Existing branches of 1–2 year culms feel soft. Secondary branches start growing after 2 years. The branches are lightly colored and not tough in <1 year culms, while they become tougher and turn to yellow-green or dark afterwards. Diameter at breast height (DBH) i.e. diameter at 1.3 m above ground, of each and every plant whose age was determined in advance was then measured with a Vernier Caliper. The minimum diameter of plants that were considered to be at their full grown stage was $\geq$2.5 cm, hence diameter of all plants having $\geq$2.5 cm was measured and data summarized.

Rhizome morphology characterization

Two plants were randomly selected from each age-group and plot (a total of 72 plants) were excavated-out. The different plant parts were measured and counted. Quantified parameters include length of rhizome neck, number of internodes of the rhizome neck, thickness of the rhizome neck, length of rhizome proper, number of internodes of the rhizome proper, thickness of rhizome proper, thickness of the attached culm and number of elongated rhizome necks attached to rhizome. Description of the rhizome before and after excavating-out from the soil was made in the field. Description of parts of the rhizome is as described in McClure (1966).

Assessment of shoot mortality

Assessment on the number of emerged and died (aborted) shoots from each plot was conducted every four days interval starting from the emergence of about 50% of the expected shoots at the end of July. Thus, the total number of shoots emerged and the total number of shoots died was determined after confirming the completion of shoot emergence. Completion of shoot emergence was prolonged up to the 25 August 2009.

Biomass data collection

The 72 plants that were randomly selected for rhizome characterization were also used for biomass data collection. Height was measured after excavating out plants and each plant was sorted into four components *viz.* rhizome, culm, branch and leaf. Total component fresh weight of each part was measured. Accordingly, the total fresh weight (TFW) of plants was determined by aggregating component fresh weights. Subsamples were then taken from each component for determination of dry to fresh weight ratio. Subsamples from culms were taken from the second internode of the bottom, middle and top parts, after dividing the culm in to three equal parts. The subsamples were then dried in an oven, at 85°C, till constant weight was reached. Component dry weight and total dry weight (TDW) were determined using the dry/fresh weight ratios of subsamples.

Biomass estimation functions

Biomass functions were developed using the regression curve-fit function of Predictive Analysis Software (PASW) Statistics 18. Exponential functions gave the higher R^2 and smaller SE and DBH was found to be best predictor variable for plant total dry weight (TDW) and aboveground total dry weight (AGTDW). Grouping plants into age-groups gave rise to more precice functions hence one function was selected for each age-group for both the landraces considered and used in estimating its corresponding biomass.The following were the selected functions for the three age-groups.

TDW (<1 *year*) = exp (0.185*DBH) R^2=0.835, SE=0.444
TDW (1-3 *years*) = exp (0.3004*DBH) R^2=0.965, SE=0.324
DW (>3 *years*) = exp (0.323*DBH) R^2=0.950, SE = 0.366

Similarly, the exponential functions selected for estimating AGTDW of plants of the different age-groups in each plot had the following formula:

AGTDW (<1 year) = exp (0.147*DBH) R^2=0.749, SE=0.461
AGTDW (1-3 years) = exp (0.267*DBH) R^2=0.9430, SE=0.371
AGTDW (>3 years) = exp (0.278*DBH) R^2=0.930, SE=0.377

Biomass Estimation

Biomass estimation was made employing the functions developed for the three age-groups of plants from the three landraces. The general formula for biomass of each age-group in each plot was:

$$TDWj = \sum_{i=1}^{n}(\exp\ (Bi*DBHi))$$

$$AGTDWj = \sum_{i=1}^{n}(\exp\ (Bi*DBHi))$$

where j=the j^th^ age-group, i= the i^th^ plant in age-group j, B_i*=coefficient of the predictor variable DBH.*

Data Analysis

Analysis was made employing the different functions of PASW Statistics 18. Univarate Analysis of the General Linear Model (One-Way-ANOVA and two-way-ANOVA) was used. Tukey's Honest Significance Difference (HSD) test was used when statistically significant difference ($p \leq 0.05$) observed. Curve-fit features of the regression function were used for determination of best-fit allometric biomass functions. Sigma Plot version 10 was used to present the analyzed data in different graphs.

RESULTS

Description of the rhizome

The rhizome proper of all landraces was nearly vertically positioned. It harbored many horizontally elongated rhizome necks slotted into two vertically arranged columns (Fig. 2). It was thicker than the rhizome neck but thinner than the attached culm. Unlike the leptomorphic rhizome illustrated by McClure (1966), rhizome of *A. alpina* landraces did not penetrate horizontally through the soil. The rhizome neck was basal to the rhizome proper.

Figure 2. Parts of the rhizome (photo taken from an old *A. alpina* plant, but still attached to the rhizome system, of *Welele* landrace during the field work in March, 2009)

Elongated rhizome necks were also observed above the soil in the same pattern as they were in the soil. However, rhizome necks above the ground and nearer to the culm base were shorter than those nearer to rhizome neck inside the soil. The rhizome necks above the ground were also curved downward probably with a purpose of anchoring the plant or because of geotropism. Rhizome necks (the collective feet) were not haphazardly distributed over the rhizome proper, but rather arranged along two sides in angular fashion leaving about 2/3 of the circumference of the rhizome proper to their mother side (Fig. 3). The portion of the circumference of the rhizome proper within the two colonizing sides was about 1/3. Hence a rhizome colonizes forward with in 1/3 of its circumference. The rhizome had a true rhizome neck.

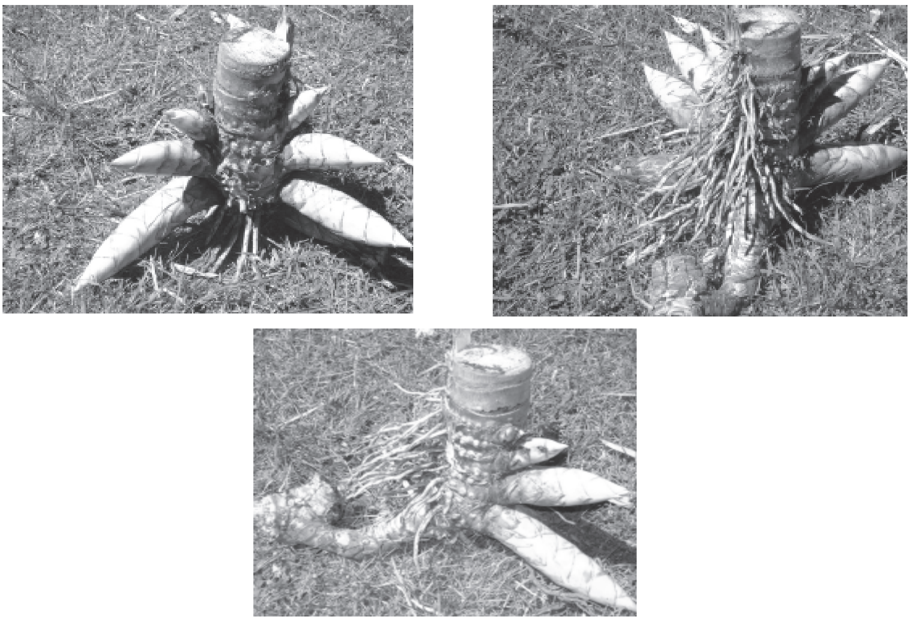

Figure 3. Appearance of rhizome morphology of a <1 year old *A. alpina* plant, after detached from the rhizome system and excavated-out from the soil (the three views are shown).

Characteristics of morphological parameters

All the measured rhizome parameters showed statistically different results among the four *A. alpina* landraces. The rhizomes were taken from three age-groups (<1, 1-3 and >3 years). Age had no significant effect in any of the rhizome characteristics of the four landraces.

The rhizome neck

One of the very important characteristics of the rhizome that determine the stocking and distribution of plants in bamboo stands was the rhizome neck (the spacer). Length of rhizome neck of *Tifro* landrace (17.3 ±1.75 cm) was significantly higher ($p \leq 0.001$)

than *Wonde* (12.4 ± 1.58 cm), *Welele* (11.0 ±1.30 cm) and *Enkotekot* (8.5 ±0.91 cm) (Fig. 4). Diameter of rhizome neck of *Tifro* (4.1 ± 0.22 cm), *Wonde* (3.8 ± 0.31 cm) and *Welele* (3.7 ±0.31 cm) were significantly higher ($p \leq 0.05$) than *Enkotekot* landrace (2.7 ± 0.25 cm). Similarly, the number of internodes of the rhizome neck of *Tifro* landrace (16 ± 1) was significantly higher ($p \leq 0.05$) than *Welele* (8 ± 1) and *Enkotekot* (10 ± 1) landraces. The value for *Wonde* landrace (14 ± 2) was not statistically different from *Tifro* and *Enkotekot* but higher than *Welele* landrace.

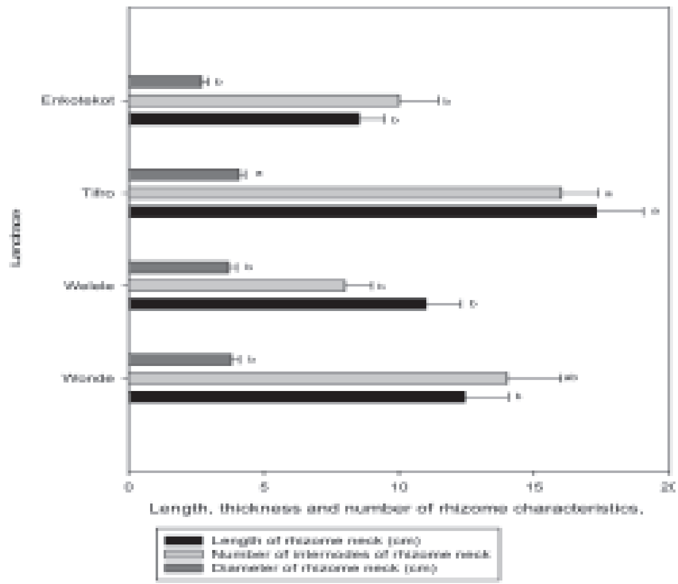

Figure 4. Characteristics of the rhizome neck of different *A. alpina* landraces (n=18, $p \leq 0.05$, Tukey's HSD Post-hoc test)

The rhizome proper and its appendages

Length of rhizome proper of *Wonde* (19.6 cm), *Welele* (23.1 cm) and *Tifro* (20.5 cm) was significantly higher ($p \leq 0.05$) than that of *Enkotekot* (15.3 cm) (Table 1). Diameter

Table 1. Characteristics of rhizome proper of the different *A. alpina* landraces (n=18, $p \leq 0.05$, Tukey's HSD Post-hoc test)

Landrace	Length of rhizome proper (cm)	Diameter of rhizome proper (cm)	Diameter of attached culm (cm)	Number of internodes of rhizome proper	Number of elongated rhizome necks
Wonde	19.6^{a}	14.6^{a}	7.0^{a}	13^{a}	7 (2, 10)
Welele	23.1^{a}	14.7^{a}	6.6^{a}	13^{a}	7 (3, 9)
Tifro	20.5^{a}	15.1^{a}	7.3^{a}	12^{ab}	7 (3, 11)
Enkotekot	15.3^{b}	11.0^{b}	4.9^{b}	10^{b}	6 (2, 11)

Numbers in brackets under the last column indicate minimum and maximum values, respectively.

of rhizome proper and diameter of the attached culm followed similar trend. The values were 14.6, 14.7, 15.1 and 11.0 cm for thickness of rhizome proper and 7.0, 6.6, 7.3 and 4.9 cm for thickness of the attached culm for *Wonde*, *Welele*, *Tifro* and *Enkotekot* landraces, respectively. *Wonde* and *Welele* landraces had significantly higher number of internodes ($p \leq 0.05$) in their rhizome proper than *Enkotekot* landrace. The value for *Tifro* landrace was not statistically different from other landraces. The number of rhizome necks per rhizome proper had not shown any significant difference among the four landraces. The values were 6.0 for *Enkotekot* and 7.0 for the other landraces. The maximum number of elongated necks ranges from 9–11 for all landraces.

Stand density

Number of plants per ha of *Enkotekot* landrace (15800 ± 1411) was significantly higher ($p \leq 0.05$) than *Wonde* landrace (11467 ± 689 but not that of *Tifro* (14,200 ± 1442) or *Welele* (14767 ± 176) landraces (Fig. 5).

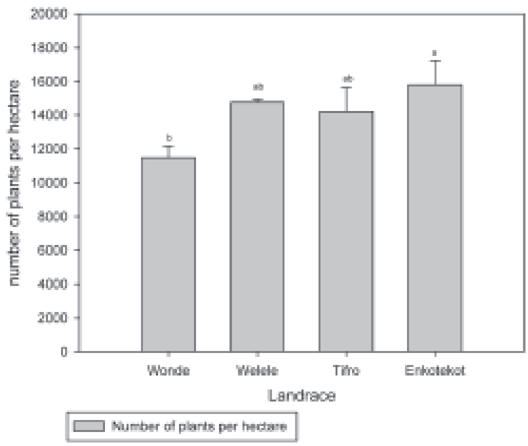

Figure 5. Number of plants per hectare of the four *A. alpina* landraces ($p \leq 0.05$) Duncan MRT, n=3)

Age structure

In general, plants of >3 years constituted 44% followed by 1–3 years old (33%) and <1 year-old plants (22%) forming a 3:2:1 ratio (Table 2). Number of plants per ha was not statistically different among age-groups for *Tifro* and *Wonde* landraces. The values were 2133 ± 348, 4600 ± 252 and 4700 ± 1233 for *Wonde* and 4467 ± 338, 5267 ± 1017 and 4467 ± 742 for *Tifro* landraces for <1, 1–3 and >3 year-old culms, respectively. Unlike that of *Wonde* and *Tifro* landraces, the number of plants of age >3 were significantly higher than <1 and 1–3 years- old plants in *Welele* and *Enkotekot* landraces (Table 3-3). The number of plants per ha were1733 ± 186, 4967 ± 328 and 8100 ± 240 for *Welele* landrace, 4100 ± 781, 4100 ± 600 and 7600 ± 529 for *Enkotekot* landrace

Table 2. Number of plants per hectare of the four *A. alpina* landraces under three age- groups (n=3, mean ±SE)

Age-group	Landrace				Overall average	%
	Wende	*Welele*	*Tifro*	*Enkotekot*		
< 1 year	2133±348	1733±186[c]	4467±338	4100±781[b]	3108±411	22
1–3 years	4600±252	4967±328[b]	5267±1017	4100±600[b]	4733±297	34
≥ 3 years	4700±1233	8100±240[a]	4467±742	7600±529[a]	6217±592	44
Total	11467±689	14767±176	14200±1442	15800±1411	4686(331)	100

Cell values differing by a letter in the superscript in a column are significantly different at $p \leq 0.05$

for <1, 1–3 and >3 year-old plants, respectively. The significantly lower number of <1 year-old plants in *Welele* landrace might be associated with the lower shoot recruitment in the 2009 shooting season that inturn might be caused by food shortage associated with the congested rhizome nature of the landrace.

Growth characteristics

Both growth characteristics namely culm diameter at breast height (DBH), culm height and total biomass per plant showed significant differences ($p \leq 0.001$) among the four landraces. Significantly higher DBH values were obtained from *Tifro* (5.3 cm), *Wonde* (5.3 cm) and *Welele* (4.9 cm) than *Enkotekot* landrace (3.7 cm) (Table 3). A similar trend was observed for height ($p \leq 0.001$) with values 10.6, 10.6, 10.1 and 7.1 m for *Wonde*, *Welele*, *Tifro* and *Enkotekot* landraces, respectively.

Table 3. Diameter and height of plants per plot of the four landraces (n=12; $p \leq 0.05$)

Landrace	Maximum DBH (cm)	Mean DBH (cm)	Maximum height (m)	Mean height (m)
Wonde	6.7±0.2	5.3±0.1[a]	12.7	10.6±0.34[a]
Welele	6.5±0.1	4.9± 0.1[a]	12.7	10.6±0.34[a]
Tifro	8.7±0.2	5.3±0.3[a]	13.9	10.1±0.51[a]
Enkotekot	5.9±0.3	3.7±0.1[b]	9.0	7.1±0.28[b]

Cell values differing by a letter in the superscript in a column are significantly different at $p \leq 0.05$

Recruitment rate

The number of emerged shoots per plot was not statistically different ($p=0.05$) among landraces. The values were 97, 67, 90 and 82 for *Wonde*, *Welele*, *Tifro* and *Enkotekot* landraces, respectively. However, the number of aborted shoots was statistically different ($p \leq 0.05$). The highest mortality (58 per plot or 58%) was recorded from *Wonde* landrace, followed by *Welele* (40 per/plot or 60%), and *Tifro* landrace (26 per plot or 29%). Statistically lower mortality (13 per plot or 16%) was recorded from *Enkotekot* landrace. Accordingly, the recruitment of *Enkotekot* and *Tifro* landraces (84 and 73%, respectively) was significantly higher ($p \leq 0.001$) than *Wonde* and *Welele* landraces (42 and 41%, respectively) (Fig. 6).

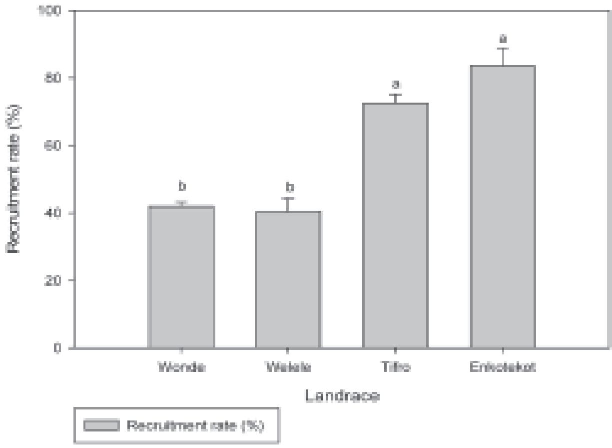

Figure 6. Recruitment rate of four *A. alpina* landraces

Biomass accumulation per plant and unit area

Biomass of each plant in each plot was estimated using biomass functions developed for the purpose. TDW and AGTDW were generated from plot estimates. Values for per plant basis estimates were generated from the randomly selected sample plants used for biomass estimation functions. Value for total fresh weight (TFW) and aboveground total fresh weight (AGTFW) were estimated only on per plant basis. All parameters showed significant variation among landraces and among age-groups ($p \leq 0.001$) but not among the interactions of these factors ($p \leq 0.001$). The values of the fresh and dry weights of sample plants randomly selected from the four landracesand three age-groups are presented in Table 4 and 5.

Table 4. Fresh and dry weight of the randomly selected plants from each landrace for biomass study (n=18)

Landrace	TFW (kg plant^{-1})	AGTFW (kg plant^{-1})	TDW (kg plant^{-1})	AGTDW (kg plant^{-1})
Wonde	15.022	11.832	4.617	3.914
Welele	15.267	11.305	5.436	4.487
Tifro	16.547	13.316	5.811	4.846
Enkotekot	8.012	5.510	2.583	1.893

Table 5. Fresh and dry weight of the randomly selected plants from each age-group for biomass study (n=24)

Age-group	TFW (kg plant^{-1})	AGTFW (kg plant^{-1})	TDW (kg plant^{-1})	AGTDW (kg plant^{-1})
< 1 year	12.633	9.597	2.964	2.445
1–3 years	15.8	12.17	5.696	4.748
> 3 years	12.703	9.706	5.175	4.70

Total plant dry weight per ha was statistically significant among landraces ($p \leq 0.05$. *Welele* landrace has the highest value (74±8.1 t ha^{-1}) followed by *Tifro* (69 ± 11.7 t ha^{-1}) and *Wonde* (59±7.0 t ha^{-1}). The value for *Enkotekot* landrace was significantly lower (45 ± 3.6 t ha^{-1}) than the other three landraces (Fig. 7). Aboveground total dry weight also followed the same trend to total above ground biomass. The values for *Welele (*60±5.9 t ha^{-1}), *Tifro* (55± 8.7 t ha^{-1}) and *Wonde* (48±5.4 t ha^{-1}) were significantly higher than for that of *Enkotekot* landrace (39± 3.1 t ha^{-1}).

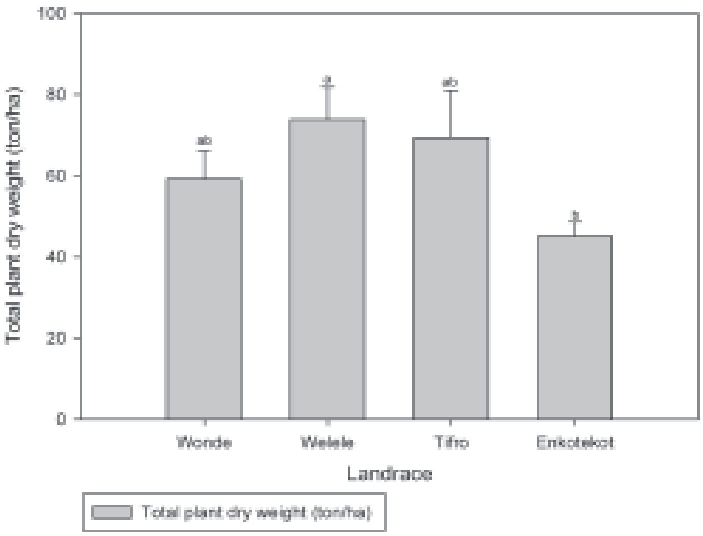

Figure 7. Total plant dry weight per hectare of four *A. alpina* landraces (n=3; $p \leq 0.05$; Duncan MRT)

Biomass partitioning among plant parts

The order of biomass allocation to plant parts was found to be culm > rhizome > branch > leaf (Fig. 8). The highest biomass allocation was allocation to culm (66, 67 and 65 and 55%) followed by rhizome (15, 17, 17 and 21%) and branch (13, 11, 11 and 14%) for *Wonde*, *Welele*, *Tifro* and *Enkotekot* landraces, respectively. The least allocation was to leaf with values 5, 5, 7 and 9% for the respective landraces. The relatively higher allocation to branches by *Wonde* as compared to *Welele* and *Tifro* landraces might cause shading problem due to unfavorable eco-physiological conditions.

DISCUSSION

Rhizome morphology

Our investigation showed that rhizome branching pattern of *A. alpina* is sympodial, and is in agreement with Meredith (2001) and Kigomo (2007) but is different from

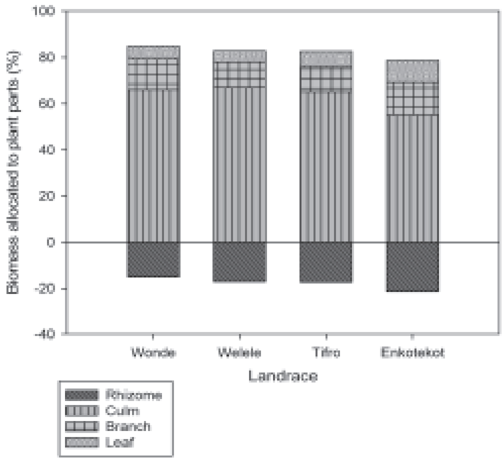

Figure 8. Biomass partitioning of four *A. alpina* landraces to four plant parts (n=24)

the reports of Embaye *et al.* (2005) and Seyoum (2005). The rhizome proper was longer than the rhizome neck and thicker than the attached culm for all the landraces. Unlike rhizomes of monopodial bamboos described by McClure (1966), rhizome proper of the species was nearly vertically oriented, not horizontally positioned (Figs. 2 and 3). The rhizome proper was also attached to collective rhizome necks meant for production of successive rhizomes and shoots (those around the base of the rhizome proper) and probably for support purposes (those on the upper part of the rhizome proper).

In this study, *A. alpina* bamboo landraces grown under similar soil and climatic conditions for the past more than 50 years showed statistically significant difference in size of their rhizome characteristics. The average length of rhizome neck (17.3 cm, max 30 cm), diameter of rhizome neck (4.1 cm, max 5.3 cm) and the number of internodes of the rhizome neck (mean 16 and max 24) for *Tifro* landrace were significantly higher than other landraces (Fig. 4). PROTA (1989) describes *A. alpina* as an evergreen bamboo with short rhizome up to 10 cm thick. But values of rhizome neck length and length of rhizome proper of *A. alpina* landraces reported in this study are higher than the above value.

Stand structure

Bamboo stand structure is mainly concerned with the number of plants per unit area and the age composition (age structure). These parameters are important aspects in investigating bamboo stand dynamics and yield. The average standing culm density of the four landraces ranged from 14,200 to 15,800 plants ha^{-1} (Table 2). This value is by far higher than the rational density of *Phyllostachys pubescens* (a monopodial bamboo) stands in China (3000 plants ha^{-1}) (Yegen, 1992) and natural stands of

Gigantochloa scortechinii (a sympodial bamboo) in Malaysia (8018 plants ha^{-1}) (Othman, 1994) but within what Wimbush (1945) noted from an undisturbed bamboo crop of *Arundinaria alpina* (10,000-17,000 plants ha^{-1}). The higher density of plants of *A. alpina* seems principally associated with the nature and colonization pattern of its rhizome. It has rhizome necks of variable length that are attached to the nearly vertically positioned rhizome proper; those towards the base of the rhizome proper are longer than those near the culm base (Figs. 2 and 3). The rhizome necks are longer than that of many clumping species that have no genuine rhizome neck hence it produces many shoots that are almost evenly distributed in the stand (Fig. 1). The higher standing culm density for *Welele* and *Enkotekot* landraces is expected as it has shorter rhizome necks (Fig. 4) hence more shoots flourish around a mother plant within a smaller area than other landraces. The lower standing culm density in *Wonde* and higher values in *Tifro* landraces might be associated with their shoot mortality rates (Fig. 6).

The ratios of the number of plants per hectare of the four landraces under three age-groups (<1, 1–3 and >3 years) were 2:4:4, 1:3:5, 3:3:3 and 3:3:5 for *Wonde*, *Welele*, *Tifro* and *Enkotekote* landraces (extrapolated from Table 2), respectively. The number of plant per ha for *Welele* landrace was similar to *Tifro* (Fig. 5) but the number of <1 year old plants was lower in proportion and dominance of old age plants was evident in this landrace. *Tifro* landrace exhibited silviculturaly recommendable age structure followed by *Enkotekot* and *Wonde* landraces but *Wonde* had still lower number of<1 year-old culms next to *Welele* that might be explained by its high shoot mortality rate (58%).

Shoot recruitment and biomass

Shoot mortality of *A. alpina* landraces ranged from 16-60% depending on the landraces (Fig. 6). This value is within the range of natural mortality of emerging shoots, i.e. 9–69% depending on eco-physiological conditions such as soil moisture, food shortage, clump congestion and genetic make-up of each clump or species (Banik, 1997). In *A. alpina* shooting and development of the shoot-culm system is limited only within the high moisture available period (June to September). Rapid elongation of culms by intercalary expansion during a single “grand period of growth” is the most demanding part of the growth process (Li *et al.,* 1998). Hence because of the limitations of the different eco-physiological conditions, shoot mortality may have resulted. The higher biomass allocation of *Wonde* landrace to branches might cause high rainfall interception loss from plants especially during the main rainy season. Rainfall interception is directly related to the degree of canopy cover (Jackson, 2000) that may affect soil temperature, light and soil moisture (Ritter *et al.*, 2005). The congested rhizome nature of *Welele* landrace (Fig. 4) might cause food shortage. 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 *Wonde* and *Welele* landraces.

Biomass of the landraces ranged from 45 to 74 tonne ha^{-1} for total dry weight and 39-60 tonne ha^{-1} for above ground total dry weight (Fig. 7). As compared to results from other bamboo species and even to biomass of *Tifro* landrace determined from 40-60% concave slope in the same area (total dry weight 117 tonne ha^{-1} and aboveground total dry weight 99 tonne ha^{-1}) determined by Yigardu and Masresha (2011, unpublished) biomass of the landraces is low. It is highly influenced by site factors and lack of proper management.

CONCLUSION

The four landraces of *A. alpina* demonstrated sympodial rhizome branching pattern and pachymorph rhizome type with nearly vertically positioned rhizome proper. However, unlike many other pachymorphic bamboos that form impenetrable clumps (closely spaced culms), *A. alpina* landraces had true rhizome neck, length 9 to 17 cm long with maximum value of 30 cm, that makes them have diffuse culm spacing. Characteristics of the rhizome neck and rhizome proper vary depending on landrace type. Landraces also vary in standing culm density (14,200–15,800 plants ha^{-1}), recruitment rate (40–84%) and biomass (45–74 tonne ha^{-1} for total dry weight and 39–60 tonne ha^{-1} for above ground total dry weight). Length of the rhizome neck, position of the rhizome proper and carbon allocation to branches were observed to influence recruitment rate and standing culm density hence age structure of stands. The effect becomes evident during the later ages after harvest i.e. at the 3rd and 4th years, as the church harvests the stand every 3 to 4 years. During these later ages, competition for food in short rhizome-necked landrace (*Welele*) and lack of optimum moisture and temperature due to rain water and heat interception by the relatively more branches of *Wonde* landrace might reduce recruitment of new shoots and biomass of <1 year old plants. This implies that there is need to manage the bamboo stands based on the belowground and aboveground competitions prevailing in the stands. Therefore, developing a harvesting system that maintains the age structure and a silvicultural system that promotes recruitment and biomass is critically needed. Generally biomass of bamboo stands of the different landraces is negatively influenced by lack of proper management.

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