Available online at www.sciencedirect.com
SCIENCE DIRECT®
ELSEVIER
Bioresource Technology 88 (2003) 33–39
BIORESOURCE TECHNOLOGY

Bamboo as bioresource in Ethiopia: management strategy to improve seedling performance (*Oxytenanthera abyssinica*)

Kassahun Embaye [a,*], Lars Christersson [a], Stig Ledin [b], Martin Weih [a]

[a] *Department of Short Rotation Forestry, Swedish University of Agricultural Sciences, P.O. Box 7016, S-750 07 Uppsala, Sweden*
[b] *Department of Soil Sciences, Swedish University of Agricultural Sciences, P.O. Box 7014, S-750 07 Uppsala, Sweden*

Received 18 February 2002; received in revised form 29 September 2002; accepted 5 October 2002

Abstract

Seedling emergence and subsequent survival and growth are vital for natural forest restoration or plantation establishment by means of seeds. Such information is lacking for the African bamboo species. Two experiments were carried out in a greenhouse to evaluate the influence of seed orientation and sowing depth of the lowland bamboo *Oxytenanthera abyssinica* on seedling emergence, survival and growth. A randomised complete block design was used. Seedling emergence in the seed orientation experiment followed the order embryo-end-up > lay-flat > embryo-end-down. Survival rate after 62 days decreased in the order lay-flat > embryo-end-down > embryo-end-up. Mean seedling height and number of leaves per seedling followed a similar pattern. Seeds sown on top of the soil surface and at 2.5 mm depth achieved faster and higher seedling emergence than those sown at 5 and 10 mm depths. However, mean seedling height and number of leaves per seedling were higher in 5 and 2.5 mm depths than surface and 10 mm depths. There were significant quadratic relationships between sowing depth and seedling height ($p = 0.034$) as well as number of leaves per seedling ($p = 0.032$), both peaking around 5 mm soil depth. Lay-flat orientation, which is the most frequent position in broadcast sowing, is recommended at 5 mm sowing depth for the lowland bamboo based on overall performance in seedling emergence, survival and growth.

Keywords: Bamboo management; Ethiopia; *Oxytenanthera abyssinica*; Seed orientation; Sowing depth; Seedling growth

1. Introduction

The pure natural bamboo forest in Ethiopia is the largest in Africa, over about 1 million ha, and 85% of this area is covered by *Oxytenanthera abyssinica* A. Richard Munro (Embaye, 2000). *O. abyssinica* is an indigenous bamboo to Ethiopia and endemic to tropical Africa. It belongs to the subfamily *Bambusoideae* and family *Poaceae* (Ohrnberger, 1999).

Bamboo forest is a material source for furniture, building, pulp, particleboard, bioenergy, food, forage and medicine. It plays a vital role in environmental amelioration, bio-diversity preservation and soil and water conservation and has waste purification potential (Kelecha, 1980; Ayre-Smith, 1963; Embaye, 2000). Given its fast growth, high soil conservation potential, multiple use and adaptability to low quality sites, bamboo has the capacity to redress most of the deforestation-related problems.

Bamboo naturally propagates both sexually and asexually from seeds and rhizomes. Artificial propagation by vegetative methods includes planting of offsets, culm cuttings, layering, and grafting of rhizome (Uchimura, 1980). However, success with these methods so far has been generally poor (Hasan, 1980). Offsets are relatively better with clump forming species, but they require painstaking work for digging the rhizome out, which entails considerable risk of damage to the roots and buds of the offset and mother plant. Moreover, they are bulky, heavy and difficult to handle and transport (Banik, 1980) and, therefore, are unsuitable for large-scale plantation establishment far away from bamboo forests. Some bamboo species are successfully regenerated using culm cuttings (Liese, 1985). However, raising planting materials of *O. abyssinica* from cuttings has been found difficult (Kigomo and Kamiri, 1987;

* Corresponding author. Tel.: +46-18-672554; fax: +46-18-673440.
E-mail address: kassahun.embaye@lto.slu.se (K. Embaye).

0960-8524/03/$ - see front matter
PII: S0960-8524(02)00265-1

Abeels, 1961). On the other hand, although the gregarious flowering cycle of the species is about 20 years (Fanshawe, 1972), it also produces seeds from sporadic out-of-phase flowering in the intervening period (Adlard, 1964). This is not the case with most bamboo species, they flower only once in their life time gregariously and die. New bamboo growth may then emerge again on the site from germinating seeds if the land is left undisturbed and seed predation is not detrimental. For these reasons *O. abyssinica* establishment now does, and will probably also in the future depend on seed rather than vegetative propagules. Knowledge of factors that influence seedling emergence, survival and growth is thus vital for successful establishment and expansion of the species.

Propagation by seed is also the best method both from economic and genetic points of view (Liese, 1985). Seeds are easy and cheap to transport over long distances in quantities large enough for large-scale plantations and seedlings are easier to transport, store and plant than other types of propagation materials. They also possess larger genetic variation than cuttings and offsets, which is essential to withstand environmental changes and outbreaks of pests and diseases. Moreover, bamboos that originate from seed are likely to flower later and thus live longer than those produced by vegetative propagation (Gupta, 1979).

The success of plantation establishment from seed depends largely on the emergence of seedlings after sowing and subsequent survival and growth. Cost of seedling production in a nursery becomes low if most seeds germinate and seedlings grow vigorously. Seed orientation and sowing depth are reported to influence seedling emergence, survival and growth of various species. Thus, Pittman (1965) records enhanced germination and early growth for corn seeds oriented with respect to magnetic lines of force. Differing results are documented on corn yield from seed orientation experiments aimed at directing leaf canopy for more efficient light utilisation (Howe, 1963). Research reports on orientation of seed tip with respect to soil surface are few. Patten and Van-Doren (1970) found substantially higher emergence and seedling growth of corn with embryo-end-up than with embryo-end-down orientation. Bowers and Hayden (1972) also report higher percent and faster rate of seedling emergence for bean seeds with embryo-end-up than embryo-end-down, and lay-flat position had about mean value. In Ethiopia, as is also the case in other developing countries, forest tree seed sowing is frequently done manually by dropping seeds into a hole made with a stick. In such practices, increased success may be gained by placing seeds in a specific orientation with respect to the soil surface.

Sanchez and King (1994) identify sowing depth as one of the most important factors that affect seedling emergence, survival and subsequent onward growth of acacia species from Ethiopia. Al Ashoo and Al Khaffaf (1997) also found sowing depth to have marked effect on germination of many species. Some species require shallow sowing depth, for example, coconut palm, eucalyptus and cycad seeds should be planted just under or level with the medium surface (Anonymous, 1991; Hendromono, 1995). Other species, like *Melocana bacifera*, need to be buried 5–10 cm deep for successful seedling emergence (Beniwal et al., 1996). Knowledge of optimum sowing depth is thus important for successful seedling production, survival and vigorous growth.

The following were the objectives of the present set of experiments. To investigate the influence of *O. abyssinica* seed orientation and sowing depth on seedling emergence, survival and vigour. To find out the optimum sowing depth and seed orientation type that could be recommended for successful seedling production and growth of the species.

2. Methods

2.1. Seed material

Seeds were collected from a gregariously flowered and heavily seeded natural bamboo (*O. abyssinica*) forest at Metekel, Southwest Ethiopia, 11°14′ N and 36°16′ E, in January 1999. The mean annual temperature at the seed provenance is 20 °C with little variation between the months of a year. The mean annual precipitation sum is 1811 mm and about 90% of this falls between May and October with a maximum in August (climate data from Metekel observatory 1987–1997). The seeds were kept in Ethiopia in a cold store at 5 °C until transport to Sweden in May 1999. They were subsequently kept in a cold store until the beginning of the experiments in July 1999.

2.2. Seedling growth conditions

Two experiments were carried out in a greenhouse, where daily mean temperature and relative humidity varied from 11 to 24 °C and 28% to 84%, respectively. The experiment continued for two and half months. In both experiments, defect-free seeds of uniform size and plastic pots of 5 l volume filled with a mixture of sand and peat (ratio 3 sand:1 peat) were used in randomised complete block design. Watering and emergence counting were done daily. The amount of watering was guided by a previous exploratory trial (unpublished data), which showed the susceptibility of *O. abyssinica* seedlings to desiccation at low soil moisture and to suffocation at high soil moisture conditions. For this reason adequate moisture was maintained in the soil to avoid seed desiccation while keeping it below field capacity to ensure adequate oxygen supply. This was done through continuous visual monitoring and addition of moisture when the soil surface tended to dry. Height from soil surface up to the most recently unfolded leaf and number of leaves per seedling counted were recorded weekly. The actual seedling height was calculated by adding the sowing depth to the recorded seedling height from soil surface.

2.2.1. Experiment 1: Seed orientation

O. abyssinica seeds are creamy-brown, hard, sulcate down one side, cylindrical, slightly tapering to the tip bearing persistent stigma (Fanshawe, 1972). The embryo is located at the thick end of the seed. In this experiment, each block consisted of 30 pots in which ten seeds were sown at random, at 2 mm soil depth, in each of the three orientations: embryo-end-up (thick-end-up), embryo-end-down (thick-end-down) and lay-flat (horizontal): all replicated four times, i.e., 10 seeds × 3 orientations × 4 blocks (= 120 pots).

2.2.2. Experiment 2: Sowing depth

Each block consisted of 20 pots in which five seeds were sown in a lay-flat orientation at each of the four sowing depths: (1) 0 mm (surface) (2) 2.5 mm (3) 5.0 mm and (4) 10.0 mm: replicated four times, i.e., 5 seeds × 4 soil depths × 4 blocks (= 80 pots).

2.3. Data processing

The SPSS statistical software package (Release 10.1, SPSS Inc., Chicago, IL) was used to analyse the sets of data. Block means of the different treatments were applied for all ANOVA calculations.

3. Results

3.1. Experiment 1: Seed orientation

More than half of the seeds emerged as seedlings within two weeks in all seed orientation treatments. Cumulative emergence (%) was highest in embryo-end-up and lowest in embryo-end-down orientations most of the time (Fig. 1). A similar pattern emerged when the seedling emergence was calculated on a daily basis (data not shown).

After 62 days, seedling survival was 80% for lay-flat orientation, 60% for embryo-end-up and 65% for embryo-end-down. Thus, the embryo-end-up orientation that had excelled in emergence speed and cumulative emergence in the first two weeks had the lowest survival rate at age 62 days. Some of the seedlings died while others emerged from seeds that had not germinated in the first two weeks. The overall germination percentage after 62 days was between 75% and 95%.

The mean number of leaves per seedling significantly varied among seed orientations (one-way ANOVA,

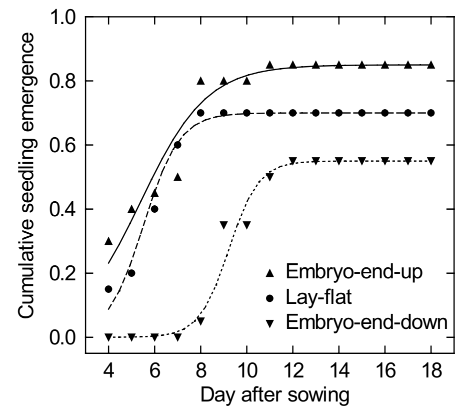

Fig. 1. Cumulative seedling emergence (quantity fraction) from bamboo seed that was sown in three different orientations. The curves were fitted according to logistic regression procedures ($r^2 \geqslant 0.88$, $p < 0.001$).

$p = 0.011$, $df_{\text{error}} = 9$). Embryo-end-up produced significantly lower leaf quantities than the embryo-end-down (ANOVA, Tukey test $p = 0.046$) and lay-flat (ANOVA, Tukey test $p = 0.011$) treatments. The lay-flat orientation attained the longest mean seedling length and had also the largest number of leaves per seedling, whereas the embryo-end-up orientation performed worst in both traits (Fig. 2). Mean seedling height increment rate was consistently high in the lay-flat and low in the embryo-end-up orientations (Fig. 3). In all cases the height increment rates were still on the increase at age 62 days.

3.2. Experiment 2: Sowing depth

Seedling emergence speed and cumulative percentage of seeds sown on the surface and at 2.5 mm depths were consistently higher than of seeds sown at 5 and 10 mm depths (Fig. 4). Similarly, seeds sown on the surface and at 2.5 mm depth attained their maximum mean daily seedling emergence percentage within 11 days, whereas 5 and 10 mm depths took longer, i.e., 14 and 16 days,

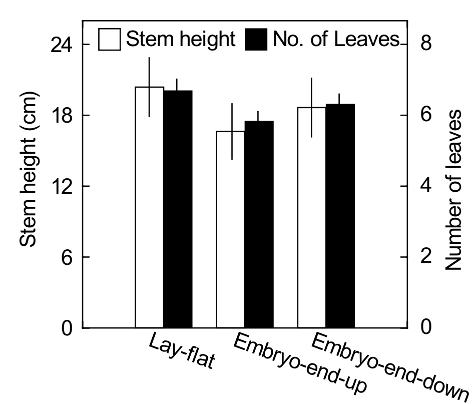

Fig. 2. Mean (±1 SE) length (cm) and number of leaves of bamboo seedlings at age 62 days for plants grown from seed that was sown in three different orientations. $n = 16$, 12 and 13 for lay-flat, embryo-end-up and embryo-end-down, respectively.

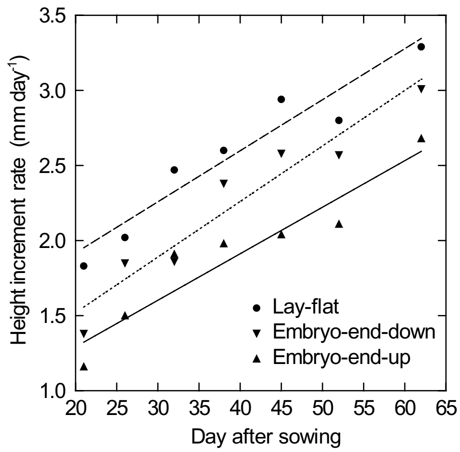

Fig. 3. Mean daily height increment (mm) of bamboo seedlings grown from seed that was sown in three different orientations. The fitted lines indicate significant linear regressions ($r^2 \geqslant 0.91$, $p < 0.001$, $n = 7$).

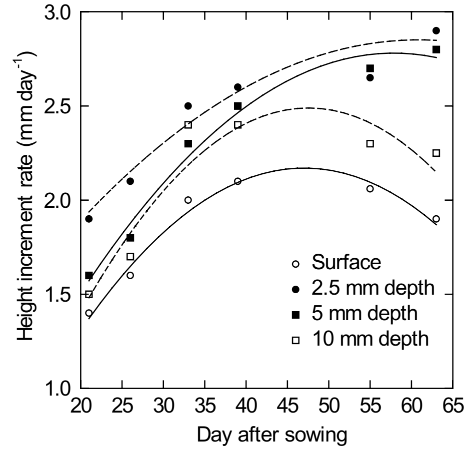

Fig. 5. Mean daily height increment (mm) of bamboo seedlings grown from seed that was sown at various depths. The curves were fitted using quadratic regression procedures ($r^2 \geqslant 0.89$, $p \leqslant 0.039$, $n = 6$).

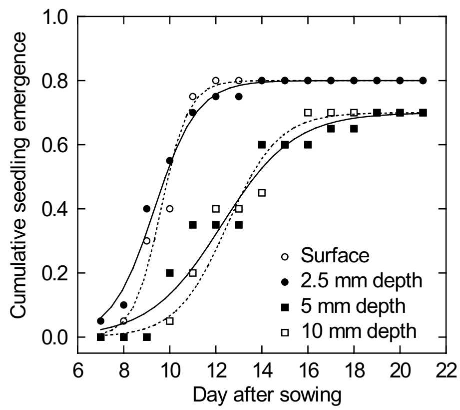

Fig. 4. Cumulative seedling emergence (quantity fraction) of bamboo seed that was sown at various depths. The curves were fitted according to logistic regression procedures ($r^2 \geqslant 0.84$, $p < 0.001$, $n = 16$).

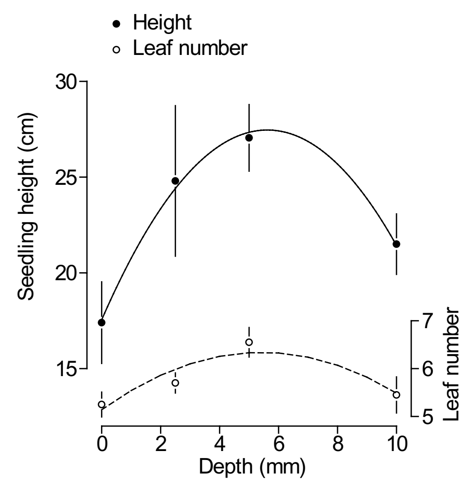

Fig. 6. Mean (±1 SE) height and number of leaves of bamboo seedlings at age 62 days as related to the sowing depth of seeds. Quadratic regressions $y = -0.31x^2 + 3.53x + 17.55$, $r^2 = 0.41$, $p = 0.034$, $n = 16$ (seedling height, cm) and $y = -0.04x^2 + 0.44x + 5.14$, $r^2 = 0.41$, $p = 0.032$, $n = 16$ (number of leaves per seedling).

respectively (data not shown). The mean daily seedling emergence of seeds sown on the surface and at 2.5 mm depth were consistently higher than those of seeds sown at 5 and 10 mm depths, throughout the 21 days. At age 63 days, seeds sown at surface and 2.5 mm depth showed considerably higher seedling survival (80–85%) than 5 and 10 mm depths (65–70%).

The height increment per day firstly increased and later levelled off with increasing seedling age in all depth treatments (quadratic regression was the best fit with $p = 0.000$, Fig. 5). Height increment rate varied significantly between the surface and 2.5 mm depth (repeated measure ANOVA, Tukey test, $p = 0.034$, $df_{\text{error}} = 52$). The differences in height growth were more pronounced as the seedlings aged over 39 days, i.e., when the seedlings entered the fastest growth rate phase in their developmental stage. Seedling height and number of leaves increased with the sowing depth until an optimum at about 5 mm and decreased thereafter (Fig. 6).

4. Discussion

More than half of the sown seeds emerged as seedlings within two weeks in both experiments (Figs. 1 and 4). This is a fast seedling emergence speed when seen against the fact that the seeds had been stored for more than 3 months and were sown without any pre-treatment, which may indicate the absence of dormancy and the capacity of the seeds to imbibe water and germinate readily. The overall seedling emergence was above 75% in both seed orientation and sowing depth experiments. This is a very high value with respect to the generally short viability and low germination rate of bamboo seeds reported by many researchers (Liese, 1985; Banik, 1985).

Among the three seed orientations tested here, embryo-end-up orientation revealed the fastest emergence speed and showed the highest cumulative seedling emergence; in terms of depth, seeds sown at and near the surface performed best in both traits. The fast and high seedling emergence percent of embryo-end-up orientation is in agreement with the results reported by Prasad and Nautiyal (1995) for *Bauhinia retusa* Ham. Ex Roxb., Bowers and Hayden (1972) for bean (*Phaseolus vulgaris* L.), and Masilamani and Dharmalingam (1998) for teak (*Tectona grandis*). The better seedling emergence speed and cumulative seedling emergence at and near the surface is in conformity with the general trend of increasing seedling emergence with decreasing sowing depth reported by many researchers (Iji et al., 1993; Yorinori et al., 1996; Arya and Singh, 1996; Hendromono, 1995). High resistance presented by the overlying soil layer against the emergence force and insufficient supply of oxygen at deep depths due to soil saturation could be the reasons for the relatively slow emergence speed and low cumulative emergence percent of the embryo-end-down orientation and 10 mm sowing depth. Some seedlings are strong enough to penetrate hard and even very hard layers, but juvenile bamboo seedlings are inherently weak at the nodes owing to exceedingly small undifferentiated cells that make up the node (Liese and Weiner, 1996). Light was probably not the causal factor as the seeds germinated equally well in light and dark conditions (unpublished data). As a rule of thumb, seeds should not be sown deeper than 1 to 2 times their diameter (Anonymous, 2000). The mean diameter of the *O. abyssinica* seeds used here was about 2 mm. The embryo-end-up and lay-flat orientations and the 2.5 mm sowing depth are within twice this range and, thus, the rule of thumb is in line with our results. Fanshawe (1972) also recommends light soil cover, frequent watering and shading for *O. abyssinica* seeds to obtain high seedling emergence, survival and vigour.

Substantial differences were found in seedling survival rate, mean seedling length and number of leaves per seedling among seed orientations and sowing depths (Figs. 1 and 2). Although embryo-end-up orientation showed the fastest emergence speed and highest emergence percent among the differing seed orientations in the first two weeks, it was the least in seedling survival rate, height growth and number of leaves per seedling at age 62 days. This may be explained by the emergence of the coleoptile above the soil surface while the radicle was less developed to support the plant to withstand the variable conditions above the soil surface. Water potential, temperature, oxygen and other factors vary more on the soil surface than inside the soil layer (Allen and Meyer, 1998). The greenhouse was not shaded. Rapid water loss from the soil surface due to high temperature had possibly caused dehydration-induced damage on the juvenile seedling, although this was not visually apparent. Jonson (1994) suggests that evaporation caused by high surface temperature may intensify seedling water deficit, drought-induced mortality and loss of growth vigour, so, even very temporary droughts could be catastrophic (Kozlowski et al., 1991). Subsequent re-hydration upon watering may have helped repair and restitution of normal function and structure, although this may have resulted in low vigour. Rapid loss of moisture from the soil surface might also have favoured fast root growth of seedlings from shallow sown seeds at the expense of shoot growth (Cheung et al., 1985). Moreover, juvenile seedlings are entirely dependent on food supply from the seed in their early phase of development. The growing embryo of some grass seeds is known to produce growth substances such as gibberelin, which move through the scutelum to induce enzyme synthesis by the aleurone layer of the seed to breakdown the starch in the endosperm into sugar (Hill, 1980). The movement of enzymes, growth substances and food could have been influenced differently by the various seed orientations.

The mean seedling height was above 17 cm at age 63 days in all seed orientation types and sowing depths. Growth would be expected to continue up to about 110 days age (Ueda, 1960). This is probably a faster growth than the 25 cm mean seedling height reported for the same species by Kigomo and Kamiri (1987) in an open nursery in Kenya after 1 year. This is an adequate size for planting out in the field. Thus, *O. abyssinica* seeds should be sown about 3 months before the onset of the rain season for planting in the same year to obviate costs of keeping seedlings in the nursery.

Lay-flat and embryo-end-down orientations had significantly higher number of leaves per seedling than embryo-end-up. Likewise, 5 mm depth had significantly higher number of leaves per seedling than surface. This information is vital due to its far-reaching consequences in subsequent shoot recruitment and growth. The growth differences observed among seed orientation types and sowing depths would be expected to increase substantially in the subsequent progenies, as the vigour of new bamboo shoots depends entirely on the food stored in the rhizome by their mother plants (Uchimura, 1980). Thus, height and number of leaves of current shoots depend on the conditions experienced in the preceding growth season. Bamboo plants growing on the same area are physiologically integrated through the rhizome system, and resources and growth substances are exchanged among interconnected ramets (Marshall, 1990). Recruitment and growth of new shoots in bamboo is carbohydrate-dependent and photosynthetic capacity of mother plants is crucial for the wellbeing and unrestrained growth of their new shoots elongating from their rhizome buds (Li et al., 2000). Thus, bamboo seedling vigour is a determinant of subsequent shoot growth. In bamboo, the whole shoot growth occurs in a single flush and is pre-determined early in the ontogeny (embryonic state) and cannot be improved by favourable conditions experienced later (Li et al., 2000). Therefore, factors that influence seedling emergence and growth have to be optimised from the outset before the onset of shoot growth to ensure unlimited potential growth. Our research showed that seed orientation and sowing depth are among these factors.

Mean daily seedling height increment of surface and 10 mm depths had ceased after 55 days while the other depths and orientation types were still on the increase. This was possibly due to the susceptibility of bamboo seeds to intermittent desiccation on the soil surface and to inadequate oxygen supply due to saturation when buried deep. Mean seedling height increment differences were more conspicuous after 55 days in sowing depths (Fig. 5) i.e., when they entered the fast growth phase in their development stage. Bamboo growth is slow at the beginning, but gradually gains speed up until it attains maximum size for its age and site and slows down thereafter (Ueda, 1960). Sympodial bamboos of the clump forming ones reach their maximum potential diameter and height in a maximum of 110–120 days (Ueda, 1960). Ideally, bamboo seedling performance comparisons should, therefore, include the whole range of development up to height growth culmination for full appreciation of the differences. In addition, in this study interaction effects between seed orientation and sowing depth cannot be ruled out. However, the separate nature of the pieces of experiments did not allow the interaction to be assessed. This should be considered in future experiments.

5. Conclusion

The fact that the seeds germinated without any pretreatment after long storage time (7 months) indicates that *O. abyssinica* has orthodox seeds, which can be stored for months at low temperature and moisture content without losing germination power and growth vigour. Seed orientation and sowing depth do affect seedling emergence, survival and growth. *O. abyssinica* seeds should be sown at shallow depth (about 5 mm) in lay-flat orientation, which is the most common position in broadcast sown seeds and thus practical and economical as less effort is required to orient the seeds in that position. *O. abyssinica* seeds are susceptible to desiccation and suffocation (data of a pilot study preceding the experiments, not shown). Watering frequency and intensity should always be adjusted to keep the soil moist at all times and below field capacity to ensure adequate oxygen supply. Bamboo seedling vigour could have far-reaching consequences in subsequent shoot recruitment and growth, since new bamboo shoots are nourished by older culms through the physiologically integrated root–rhizome system (Li et al., 2000). Research should be started to elucidate this by empirical evidence.

Acknowledgements

We thank Drs. Demel Teketay and Girma Balcha for providing us space in the Ethiopian Tree Seed Center cold store for keeping the seeds until transport to Sweden. We also acknowledge the valuable comments of Prof. Staffan Karlsson on the draft article. The project was fully funded by the Swedish International Development Agency (SIDA), as part of the Swedish support to the forestry education in Ethiopia.

References

Abeels, P., 1961. The propagation of bamboos. Bull. Agri. Congo 52, 591–598.

Adlard, P.G., 1964. Regeneration of common bamboo (*Oxytenanthera abyssinica* (A. Rich) Munro). Forest Report Silviculture Res. Station Dedza 5, 13–19.

Al Ashoo, J.A., Al Khaffaf, R.S., 1997. Effect of sowing depth and covering medium on the germination and germination energy of *Cedrus libani* Loud seeds. Dirasat Agric. Sci. 24, 112–118.

Allen, P.S., Meyer, S.E., 1998. Ecological aspects of seed dormancy loss. Seed Sci. Res. 8, 183–191.

Anonymous, 1991. Propagation of landscape plants. Available from <http://edis.ifas.ufl.edu/BODY_MG108>.

Anonymous, 2000. Natural regeneration and direct seeding. Available from <http:/www.netc.net.au/felix/felix5.html>.

Arya, H.R., Singh, K.P., 1996. Germination of elm (*Ulmus laevigata* Royle) as affected by depth of sowing. Indian Forester 122, 432–433.

Ayre-Smith, R.A., 1963. The use of bamboo as cattle feed. E. Afr. Agrc. For. J. 29, 50–51.

Banik, R.L., 1980. Propagation of bamboos by clonal methods and by seed. In: Lesslard, G., Chouinard, A. (Eds.), Bamboo Research in Asia. IDRC, Ottawa Canada, pp. 139–150.

Banik, R.L., 1985. Techniques of bamboo propagation with special reference to pre-rooted and pre-rhizomed branch cuttings and tissue culture. Available from <http://www.inbar.int/publication/txt/INBAR_PR_03.htm>.

Beniwal, B.S., Dhawan, V.K., Joshi, S.R., 1996. Standardisation of nursery techniques of *Meloccana bacifera* (syn. *M. bambusoides*). Van Vigyan 34 (3), 81–83.

Bowers, S.A., Hayden, C.W., 1972. Influence of seed orientation on bean seedling emergence. Agronomy J. 64, 736.

Cheung, Y.Y., Cooper, S.G., Hansken, J.J., Cheung, Y.C., 1985. Research on raising of *Phyllostachys pubescens* seedlings. In: Rao, A.N., Dhanarajan, G., Sastry, C.B. (Eds.), Research on Bamboos. IDRC, Ottawa, Canada, pp. 76–92.

Embaye, K., 2000. The indigenous bamboo forests of Ethiopia: an overview. Ambio 29, 518–521.

Fanshawe, D.B., 1972. Bamboo *Oxytenanthera abyssinica*—its ecology, silviculture and utilisation. Kirka 8 (2), 157–166.

Gupta, R.K., 1979. Bamboo plantations on denuded soils. Indian Farming 29 (2), 3–5.

Hasan, S.M., 1980. Lessons from past studies on propagation of bamboos. In: Lessard, G., Chouinard, A. (Eds.), Bamboo Research in Asia. IDRC, Ottawa, Canada, pp. 99–122.

Hendromono, T.W., 1995. Using peat as a germination medium for seeds of *Eucalyptus deglupta* Blume. Bulletin Penelitian Hutan 584, 11–18.

Hill, T.A., 1980. Endogenous plant growth substances. Studies in Biology, second ed. Edward Arnold, London.

Howe, O.W., 1963. Oriented corn yields less under irrigation. Crops Soils 15 (4), 20.

Iji, P.A., Tarawali, G., Baba, M., 1993. The influence of stage of development and sowing depth on seed quality and seedling emergence of *Gliricidia sepium*. Seed Sci. Technol. 21, 197–202.

Jonson, W.C., 1994. Woodland expansion in the Platte river, Nebraska: patterns and causes. Ecol. Monogr. 16, 45–84.

Kelecha, W., 1980. The Bamboo Potential of Ethiopia. Forestry and Wildlife Conservation and Development Authority, Addis Ababa, Ethiopia. Monograph, pp. 14.

Kigomo, B., Kamari, 1987. Studies in propagation and establishment of *Oxytenanthera abyssinica, Bambusa vulgaris* and *Arundinaria alpina* in medium altitude site in Kenya. Kenya J. Sci. (B) 8 (1–2), 5–13.

Kozlowski, T.T., Kramer, P.J., Pallardy, S.G., 1991. The Physiological Ecology of Woody Plants. Academic Press, New York.

Li, R., Werger, M.J.A., de Kroon, H., During, H.J., Zhong, Z.C., 2000. Interactions between shoot age structure, nutrient availability and physiological integration in the giant bamboo *Phyllostachys pubescens*. Plant Biol. 2, 437–446.

Liese, W., 1985. Bamboos—Biology, Silvics, Properties and Utilisation. GTZ Eschborn, Germany.

Liese, W., Weiner, G., 1996. Aging of bamboo culms: a review. In: Rao, I.V.R., Sastry, C.B. (Eds.), Bamboo, People and the Environment. INBAR Technical Report 8 (1), pp 132–148.

Marshall, C., 1990. Source-sink relations of interconnected ramets. In: Van Groenendael, J., de Kroon, H. (Eds.), Clonal Growth in Plants, Regulation and Function. SPB Academic Publishing, Hague, pp. 23–41.

Masilamani, P., Dharmalingam, C., 1998. Effect of orientation of drupe placement and depth of sowing on germination and vigour of teak. Adv. Plant Sci. 11 (2), 205–209.

Ohrnberger, D., 1999. The Bamboos of the World. Elsevier, Amsterdam.

Patten, G.P., Van-Doren Jr., D.M., 1970. Effect of seed orientation on emergence and growth of corn. Agronomy J. 62, 592–595.

Prasad, P., Nautiyal, A.R., 1995. Influence of seed orientation on seedling emergence in *Bauhinia retusa* Ham. Ex Roxb. Seed Sci. Technol. 23, 861–864.

Pittman, U.J., 1965. Magnetism and plant growth III Effect on germination and early growth of corn and beans. Can. J. Plant Sci. 45, 549–555.

Sanchez, B.F., King, G.W., 1994. Ecological factors affecting the early development of seedlings of three acacia species from Ethiopia. S. Afr. J. Plant Soil 11, 147–148.

Uchimura, E., 1980. Bamboo cultivation. In: Lessard, G., Chouinard, A. (Eds.), IDRC, Ottawa Canada, pp. 151–160.

Ueda, K., 1960. Studies on the physiology of bamboo. Bull. Kyoto University: Forests 30, 1–69.

Yorinori, N.A., Sada, S.Y., Pissaia, A., 1996. The effect of depth of sowing and early ageing of popcorn (*Zea mays*) seed upon the percentage of plant emergence. Revista do Sector de Ciencia Agraias 15 (2), 173–178.