NURSERY AND VEGETATIVE PROPAGATION TECHNIQUES FOR GENETIC IMPROVEMENT AND LARGE SCALE ENRICHMENT PLANTING OF DIPTEROCARPS

Moura-Costa, P. H. In: Ecology, conservation and management of Southeast Asian rainforests. Primack, R.B. and Lovejoy, T. (Eds.). Yale University Press, Pp. 116-128, 1996.

INTRODUCTION: ENRICHMENT PLANTING IN THE ULU SEGAMA FOREST RESERVE

A large proportion of the economy of Sabah, East Malaysia, is derived from the logging of dipterocarp forests. In order to maintain the forest products industry and the economic returns derived from this sector, forest regeneration must be managed for sustainable yields. The high densities of natural forest stands in Sabah (Newbery et al. 1992) allow extraction rates of up to 120 m^3 ha^{-1} (Silam Forest Products, timber extraction figures). However, this rate of extraction causes substantial disturbance to the residual stand (Nussbaum et al., this volume; Appanah and Weinland 1990). In some areas, the residual stocking and seedling bank of timber species is much reduced and artificial regeneration must be used (Appanah and Weinland 1990).

Enrichment planting is a technique for promoting artificial regeneration in which seedlings of preferred timber trees are planted in the under storey of existing forests and given preferential treatment to encourage their growth. There is a long history of enrichment planting with dipterocarps (Appanah and Weinland 1993, and references therein), although in some cases survival rates of plants were low and/or growth rates disappointing (Chai 1975; Tang and Wadley 1976; Awang and Sawal 1986; Priasukmana 1989). Lack of plot maintenance during the initial years may contribute substantially to poor performance in these trials (Tang and Wadley 1976; Priasukmana 1989). For instance, most seedling damage and mortality occurs during seedling stage until plants reach 3 m in height (Wyatt-Smith 1963). Seedlings are particularly susceptible to damage by insect borers (Daljeet-Singh 1975; Becker 1983), browsing mammals (Wyatt-Smith 1963; Becker 1985), competing vegetation such as lianas and vines (Chai 1975; Tang and Wadley 1976; Priasukmana 1989), and physiological stress caused by drought (Awang and Sawal 1986) or excessive radiation (Sasaki and Mori 1981). It is therefore essential that maintenance of plots is carried out during this initial phase. Subsequent silvicultural treatments such as liberation thinning are also required to maintain growth rates (Fox and Chai 1982).

These requirements may be met only if a project receives long-term support. For example, a cooperative project between Rakyat Berjaya Sdn Bhd (a subsidiary of Innoprise Corporation, Sdn. Bhd., Yayasan Sabah) and the Face Foundation (Forests Absorbing Carbon-dioxide Emission, the Netherlands) was initiated in the Ulu Segama Forest Reserve (Sabah, Malaysia) with the objective of promoting the rehabilitation of logged forests to absorb CO_2 from the atmosphere. The project involves large-scale enrichment planting of degraded forests using seedlings of dipterocarp trees. The project area comprises 25,000 ha of logged-over dipterocarp forests around the Danum Valley Field Centre, which also supports other research related to forest ecology and regeneration (see Marshall and Swaine 1992). The long-term nature of the RBJ-Face Foundation project (25 years) will allow the maintenance of plots, including four rounds of weeding a year for two years and follow-up silvicultural treatments.

NURSERY FACILITIES AND SOURCES OF PLANT MATERIAL

An inherent difficulty related to the large-scale planting of dipterocarps is availability of planting material. Dipterocarps exhibit mast fruiting, with 1 to 10 years between seeding years (Ashton et al. 1988), and their seeds have brief viability preventing long-term storage (Sasaki 1980). In years when seeding occurs, large numbers of wild propagated seedlings (wildings) are found on the forest floor (Liew and Wong 1973), and can be transferred to the nursery. However, wilding availability depends on the occurrence of seeding years, and is therefore an unreliable source of planting material.

Nevertheless, seeds and wildings should be used whenever they are available. During the fruiting season, collection must be carried out daily in order to avoid predation by insects or mammals. Seeds must be taken immediately to the nursery for germination. When fresh seeds are used, germination rates of up to 97 % (n = 5,000, SE = 1.2) can be obtained after 2 weeks for Dryobalanops lanceolata, Shorea leprosula and Parashorea malaanonan. Sharp decreases in germination rates were observed when seeds were kept for more than two weeks, with less than 50 % (n = 5,000, SE = 4.2) germination. If seeds are not collected from the forest, they quickly germinate, and the resulting wildings can be cultivated. Wildings are pulled from the forest floor in the most efficient way (one person can collect up to 180 wildings per hour) but this method often damages their root system. Thus, special care must be given during an acclimatization period after transfer to the nursery. Wildings are watered and kept in plastic covered chambers with high humidity, until a new root system is formed. Satisfactory rates of survival have been obtained with this system, eg. 94.4 % (n = 200, SE = 3.2) for Shorea parvifolia and 88.2 % (n = 200, SE = 2.5) for Dryobalanops lanceolata, after a 4 week acclimatization period.

VEGETATIVE PROPAGATION BY CUTTINGS

The use of vegetative propagation by cuttings as an alternative to supply dipterocarp planting stock has been investigated by many researchers (Momose 1978; Hallé and Hanif-Kamil 1981; Srivastava and Penguang Manggil 1981; Smits 1983; Hamzah 1990; Kantarli 1993). However, dipterocarps are considered difficult to root and results are sometimes unsatisfactory (see Momose 1978; Hallé and Hanif-Kamil 1981; Srivastava and Penguang Manggil 1981). Techniques for vegetative propagation of dipterocarps have been developed in Danum Valley Field Centre (Moura-Costa and Lundoh, in press) based on the methods used by Smits (1983) and Leakey et al. (1982, 1983).

Two-node cuttings are taken from the apical shoots of juvenile stockplants, either young seedlings or managed hedge orchards, their leaves are trimmed to approximately 30 cm^2 and their basal ends are dipped in a fungicide solution. No auxins are used since previous experiments showed that IBA, NAA and 2,4-D (at 0.2, 0.8 and 3.0 % w/w) suppress rooting of juvenile cuttings of some dipterocarps (Moura-Costa and Lundoh, in press). Cuttings are rooted in a mist propagator unit covered by a transparent plastic sheet (Plate 1) to increase relative humidity. After roots form (Plate 2), cuttings are potted and kept in plastic covered chambers in the shade house for two weeks during the acclimatization stage, before exposure to normal nursery conditions. Mycorrhizal inoculation is done during potting, by adding soil containing inocula to the soil in the planting bags. Cuttings of D. lanceolata and several Shorea species have been produced using this method. Percentage rooting after 12 weeks is around 87 % (n = 396, SE = 1.6) for D. lanceolata and 65 % (n = 40, SE = 2.4) for Shorea spp.

Hedge orchards with stockplants are being established in Danum Valley Field Centre to guarantee a steady supply of plant material for cutting production. Seedlings are planted in lines in a partially shaded area adjacent to the research nursery and managed to increase the number of orthotropic shoots produced by each plant. Their apical shoot is excised and the stem bent over (Plate 3), in order to break apical dominance and induce the sprouting of dormant stem nodes (Leakey 1983). Up to 15 shoots can be formed by each stockplant monthly.

This method of vegetative propagation is being adapted to minimise the number of operations required for cutting production, and therefore the costs, allowing its use for large-scale production of cuttings in our operational nursery. We conducted an experiment in which cuttings of Dryobalanops lanceolata were set to root directly in 7 x 21 cm poly-bags containing forest top-soil. Percentage rooting after 12 weeks in the mist unit was 83 % (n = 20, SE = 2.3). Further trials are underway to test the rooting of cuttings in the plastic covered chambers used for acclimatization of wildings instead of a mist unit.

MICROPROPAGATION

Tissue culture techniques for in vitro propagation of dipterocarps are also being investigated in collaboration with the Forest Research Centre (Sepilok, Sandakan, Malaysia). The methods used for shoot multiplication of dipterocarps are those of Linington (1991). Experiments for rooting micropropagated dipterocarp plants have been carried out, using Dipterocarpus intricatus plantlets from cultures provided by I. Linington (Kew Gardens, U.K.). By applying 0.8 % IBA talcum formulations to the basal end of the plantlets, 35 % (n = 20) formed roots after 12 weeks in the mist spray sand beds. This method could be improved to attain better multiplication rates in vitro, as well as better percentages of rooting and establishment of plants ex vitro. Successful tissue culture systems would enable the large-scale rapid multiplication of clonal genotypes, with enormous advantages for commercial forestry (Bonga and Durzan 1987). A further improvement would be the study of somatic embryogenesis for artificial seed production (Redenbaugh et al. 1989; Moura-Costa et al., in press), with potential for the mass propagation of tropical trees at a low cost (see Mascarenhas 1988).

CLONAL PROPAGATION AND GENETIC IMPROVEMENT OF DIPTEROCARPS

Previous trials of enrichment planting have used trees from natural populations, consisting of a wide range of genotypes with different growth rates. Vegetative propagation can be used to produce clones, reducing genetic variability of planting stock and permitting better controlled studies of growth and development of dipterocarps in enrichment planting and the establishment of stands with more homogeneous growth rates. A further advantage of using vegetative propagation is the possibility of genetic improvement of planting stock. An example of the benefits of using selection and cloning in forestry is the 3-fold increases in biomass production of Eucalyptus achieved in Aracruz Celulose, Brazil (Campinhos and Ikemori 1983). To our knowledge, no work has ever been done on genetic improvement of dipterocarps; substantial gains are expected from selection and cloning of superior genotypes. The advantages and disadvantages to clonal populations of forest trees are discussed below.

Problems of selection and propagation of adult trees

Clonal forestry is typically based on the phenotypic selection of superior trees followed by vegetative propagation (Hartmann et al. 1990). However, selection based on mature trees has several problems. Firstly, plant material from adult trees is physiologically mature and often more difficult to root, as has been demonstrated for dipterocarps (Smits et al. 1990). The use of mature material for vegetative propagation might have been the reason for an overall low percentage of rooting achieved by Momose (1978) and Hallé and Hanif-Kamil (1981). All cuttings Momose prepared from mature tissues failed to root. On the other hand, high percentages of rooting were observed when juvenile material was used by Smits (1983) and Hamzah (1990). Therefore, mature material taken from adult trees needs to be rejuvenated in order to improve rooting ability (see Hackett 1985). Grafting mature scions onto juvenile rootstocks (Martin and Quillet 1974) or serial cuttings (Black 1972) are possible methods. An alternative is to induce the production of juvenile tissue from mature trees (Hackett 1985). However, most dipterocarp trees do not coppice and methods involving the manipulation of the whole tree, eg. severe pruning (Mazalewsky and Hackett 1979), are not feasible.

Secondly, the selection of plus trees in the forest relies on the phenotypic characteristics of the individual selected. However, the phenotypes of mature trees in natural forests are strongly influenced by different environmental factors which can affect the expression of their genotypes (see Namkoong et al. 1980). Furthermore, the recruitment of dipterocarp trees from the seedling bank in the forest is not necessarily linked to genotypic characteristics. According to the process of gap regeneration dynamics described by Whitmore (1984), seedlings of dipterocarps stay in the understorey for long periods and are liberated when gaps form in the canopy. The random process of gap formation does not benefit the best genotypes but those which happen to be present in the gap at that particular moment. Therefore, selection of mature trees is not reliable and must be confirmed by carrying out clonal trials, which are impractical due to the slow growth of dipterocarps.

Selection at the seedling stage: apical dominance in juvenile material

Correlations between juvenile characteristics and desirable genetic traits of mature trees would allow the selection of plants at an early stage, circumventing some of the problems mentioned above. The use of apical dominance of seedlings as a selection factor was suggested by Ladipo, Leakey and Grace (1991), who found a positive correlation between this factor and height of *Triplochiton scleroxylon* trees after five years. The strong negative correlation between increase in total branch length and height increment observed in *D. lanceolata* seedlings (Moura-Costa et al., in press) suggests that this method may be applicable for dipterocarps. Strong apical dominance is also a desirable characteristic in Ulu Segama Forest Reserve, where up to 40 % of dipterocarp seedlings planted suffered damage to their apical meristems from browsing mammals or stem boring insects (L. Lundoh and M. Pinard, unpublished results). Plants with strong apical dominance produce a single replacement shoot, thus retaining a good stem form. Since apical dominance can be expressed at the seedling stage, selection of superior genotypes can be done in the nursery. This reduces the effect of environmental variability and provides juvenile material suitable for clonal propagation by the methods described above. The "Predictive Test For Apical Dominance" (Ladipo et al. 1991) was applied to seedlings of *Dryobalanops lanceolata*. The degree of apical dominance obtained after decapitation of 350 seedlings was highly variable, creating scope for selection (Moura-Costa, unpublished results). A proportion of the plants were decapitated a second time to test whether this characteristic is consistently expressed, i.e. genetically controlled. Subsequent assessments have been carried out in order to determine how quickly plants regain apical dominance. Trials are being conducted to test for a correlation between re-establishment of apical dominance and height increment of trees grown in the field.

ECOLOGICAL CONSIDERATIONS OF CLONAL PROPAGATION FOR FORESTRY

The use of clonal material for forestry is a cause of some controversy. Although timber yields can be substantially improved (Campinhos and Ikemori 1983), the risks of susceptibility to outbreaks of diseases or pests are usually higher in clonal stands than in sexually propagated populations. Therefore, selection intensity should be modest, allowing the use of a large number of clones to guarantee a diverse genetic base in the planted stands.

A second concern is the characteristics of the rooting system of plants derived from cuttings. Cutting-derived plants do not produce tap roots and consequently it has been suggested that they are more susceptible to wind throw or droughts. However, cuttings are able to produce a large root plate from which axillary sinker roots often develop (Leakey 1987). Furthermore, there is evidence that most dipterocarp trees do not form deep tap roots (Baillie and Mamit 1983), but shallow lateral roots from which vertical sinkers develop. The same pattern of root systems can be expected for wildings. After collection in the forest, the tap root of wildings is often pruned to promote the development of adventitious roots. Although old plantations of dipterocarps planted with cuttings do not exist, there are plots planted with dipterocarp wildings dating back to 1935 (eg. Tan et al. 1987) which do not appear to suffer from any of the problems related to a poor root system discussed above.

CONCLUSIONS

Advances in vegetative propagation and nursery techniques have improved the reliability of supply and the quality of dipterocarp planting material. The development of efficient tissue culture techniques might provide enormous benefits for dipterocarp propagation but further studies are still required to increase multiplication rates in vitro and percentages of rooting ex vitro. Whichever propagation system is used, it is important that costs of production are kept low, since planting stock accounts for a substantial share of the costs of enrichment planting.

Genetically superior planting stock is urgently needed to improve growth rates of planted stands and to increase the attractiveness of enrichment planting as a tool for the management of logged rainforests. If a correlation between apical dominance and growth rates of dipterocarp trees is confirmed, it can be used for a simple selection procedure. Clonal populations of fast growing genotypes can be established in a short period of time, improving the quality of planted stands and reducing the time required for rehabilitation of logged forests by enrichment planting.

ACKNOWLEDGEMENTS

This work was possible through the support of Innoprise Corporation Sdn. Bhd., Malaysia, and the Face Foundation, Netherlands. The author is grateful to the Danum Valley Research and Training Programme, the Forestry Department of Sabah for use of their tissue culture facilities, and I. Linington for supplying the in vitro cultures of dipterocarps used for this study. I would also like to thank B. Howlett, R. Nussbaum and J. Willott for their comments on an early version of the manuscript.

REFERENCES

Appanah, S. and Weinland, G. 1990. Will the management systems for hill dipterocarp forests stand up ? Journal of Tropical Forest Science 3: 149-158.

------. 1993. Planting quality timber trees in Peninsular Malaysia - a review. Malaysian Forest Record No. 38. Forest Research Institute Malaysia, Kepong. 221.

Ashton, P.S., Givnish, T.J. and Appanah, S. 1988. Staggered flowering in the Dipterocarpaceae: New insights into floral induction and the evolution of mast fruiting in the aseasonal tropics. The American Naturalist 132: 44-66.

Awang, K. and Sawal, P. 1986. Initial performance of three indigenous species used in an enrichment planting of hill dipterocarp forest. In Y. Hadi, K. Awang, N.M. Majid and S. Mohamed (eds.), Proceedings of the Workshop on Impact of Man's Activities on Upland Forest Ecosystem. Universiti Pertanian Malaysia, Selangor, pp. 41-65.

Baillie, I.C. and Mamit, J.D. 1983. Observations on rooting in mixed dipterocarp forest, Central Sarawak. The Malaysian Forester 46: 369-374.

Becker, P. 1983. Effects of insect herbivory and artificial defoliation on survival of Shorea seedlings. In S.L. Sutton, T.C. Whitmore and A.C. Chadwick (eds.), Tropical Rainforest Ecology and Management. Blackwell Scientific Publications, Oxford, pp. 241-252.

------. 1985. Catastrophic mortality of Shorea leprosula juveniles in a small gap. The Malaysian Forester 48: 263-265.

Black, D.K. 1972. The influence of shoot origin on the rooting of Douglas-fir stem cuttings. Proceedings of the International Plant Propagation Society 22: 142-159.

Bonga, J.M. and Durzan, D.J. (eds.). 1987. Cell and Tissue Culture in Forestry. Martinus Nijhoff Publishers, Dordrecht. 272.

Campinhos, E.Jr. and Ikemori, Y.K. 1983. Mass production of Eucalyptus spp. by rooting cuttings. Silvicultura 8: 770-775.

Chai, D.N.P. 1975. Enrichment planting in Sabah. The Malaysian Forester 38: 271-277.

Daljeet-Singh, K. 1975. A preliminary survey of insect attack on seedlings and saplings in Bukit Belata Forest Reserve. The Malaysian Forester 38: 14-16.

Fox, J.E.D. and Chai, N.P. 1982. Refinement of the regenerating stand of a Parashorea tomentella/Eusideroxylon zwageri type of lowland dipterocarp forest in Sabah - a problem in silvicultural management. The Malaysian Forester 45: 133-183.

Hackett, W.P. 1985. Juvenility, maturation and rejuvenation in woody plants. Horticultural Reviews 7: 109-155.

Hallé, F. and Hanif-Kamil 1981. Vegetative propagation of dipterocarps by stem cuttings and air-layering. The Malaysian Forester 44: 314-318.

Hamzah, A. 1990. A note on the rooting of Shorea bracteolata stem cuttings. Journal of Tropical Forest Science 3: 187-188.

Hartmann, H.T., Kester, D.E. and Davies F.T. 1990. Plant Propagation. Principles and Practices. Fifth edition. Prentice-Hall International Editions, New Jersey. 645.

Kantarli, M. 1993. Vegetative propagation by cuttings in ASEAN region. Review Paper No. 1. ASEAN-Canada Forest Tree Seed Centre Project, Saraburi, Thailand. 58.

Ladipo, D.O., Leakey, R.R.B. and Grace, J. 1991. Clonal variation in a four-year-old plantation of Triplochiton scleroxylon K. Schum. and its relation to the Predictive Test for branching habit. Silvae Genetica 40: 130-135.

Leakey, R.R.B. 1983. Stockplant factors affecting root initiation in cuttings of Tryplochiton scleroxylon K. Schumm., an indigenous hardwood of West Africa. Journal of Horticultural Science 58: 277-290.

------. 1987. Clonal forestry in the tropics - A review of the developments, strategies and opportunities. Commonwealth Forestry Reviews 66: 61-75.

Leakey, R.R.B., Chapman, V.R. and Longman, K.A. 1982. Physiological studies for tree improvement and conservation. Factors affecting root initiation in cuttings of Triplochiton scleroxylon K. Schum. Forest Ecology and Management 4: 53-66.

Liew, T.C. and Wong, F.O. 1973. Density, recruitment, mortality and growth of dipterocarp seedlings in virgin and logged-over forests in Sabah. The Malaysian Forester 36: 3-15.

Linington, I.M. 1991. In vitro propagation of Dipterocarpus alatus and Dipterocarpus intricatus. Plant Cell, Tissue and Organ Culture 27: 81-88.

Marshall, A.G., and Swaine, M.D. (eds.). 1992. Tropical Rain Forest: Disturbance and Recovery. Proceedings of a Royal Society Discussion Meeting. Philosophical Transactions of the Royal Society of London 335: 323-447.

Martin, B. and Quillet, G. 1974. Bouturage des arbres forestiers au Congo. Resultats des essais effectues a Pointe-Noire de 1969 a 1973. Rajeunissement des arbres plus et constitution du parc a bois. Bois et Forets des Tropiques 157: 21-40.

Mascarenhas, A.F., Khuspe, S.S., Nadgauda, R.S., Gupta, P.K., and Khan. B.M. 1988. Potential of cell culture in plantation forestry programs. In J.W. Hanover and P.E. Keathley (eds.), Genetic Manipulation of Woody Plants. Plenum Press, New York, pp.398-412.

Momose, Y. 1978. Vegetative propagation of Malaysian trees. The Malaysian Forester 41: 219-223.

Moura-Costa, P.H. and Lundoh, L. In press. A method for vegetative propagation of Dryobalanops lanceolata (Dipterocarpaceae) by cuttings. Journal of Tropical Forest Science.

Moura-Costa, P.H. and Lundoh, L. In press. The effects of auxins (IBA, NAA and 2,4-D) on rooting of Dryobalanops lanceolata (kapur, Dipterocarpaceae) cuttings. Journal of Tropical Forest Science.

Moura-Costa, P.H., Lundoh, L., and Uren, S.C. In press. Effects of nitrogen and light on growth, development and nitrogen metabolism of Dryobalanops lanceolata Burck (Dipterocarpaceae) wildings grown in nursery. Forest Ecology and Management.

Moura-Costa, P.H., Viana, A.M. and Mantell, S.H. In press. In vitro plantlet regeneration of Ocotea catharinensis, an endangered Brazilian hardwood forest tree. Plant Cell, Tissue and Organ Culture.

Namkoong, G., Barnes, R.D. and Burley, J. 1980. A philosophy of breeding strategy for tropical forest trees. Tropical Forestry Papers No. 16. Commonwealth Forestry Institute, Oxford. 67.

Newbery, D.McC., Campbell, E.J.F., Lee, Y.F., Ridsdale, C.E. and Still, M.J. 1992. Primary lowland dipterocarp forest at Danum Valley, Sabah, Malaysia: structure, relative abundance and family composition. Philosophical Transactions of the Royal Society of London 335: 341-356.

Priasukmana, S. 1989. Planting experiments of dipterocarps in East Kalimantan. In I. Soerianegara, S.S. Tjitrosomo, R.C. Umaly and I. Umboh (eds.), Fourth Round-table Conference on Dipterocarps. Biotrop Special Publication No. 41, Bogor, pp. 417-424.

Redenbaugh, K. and Ruzin, S.E. 1989. Artificial seed production and forestry. In V. Dhavan (ed.), Applications of Biotechnology in Forestry and Horticulture. Plenum Publ. Corp., New York, pp. 57-71.

Sasaki, S. 1980. Storage and germination of dipterocarp seeds. Malayan Forester 43: 290-308.

Sasaki, S. and Mori, T. 1981. Growth responses of dipterocarp seedlings to light. The Malaysian Forester 44: 319-345.

Smits, W.T.M. 1983. Vegetative propagation of Shorea cf. obtusa and Agathis dammara by means of leaf-cuttings and stem-cuttings. The Malaysian Forester 46: 175-185.

Smits, W.T.M., Yasman, I., Leppe, D. and Noor, M. 1990. Summary of results concerning vegetative propagation of Dipterocarpaceae in Kalimantan, Indonesia. In G.L. Gibson, A.R. Griffin and A.C. Matheson (eds.), Breeding Tropical Trees: Population Structure and Genetic Improvement Strategies in Clonal and Seedling Forestry. Proceedings of the IUFRO Conference, Pattaya, Thailand. Oxford Forestry Institute, Oxford, pp. 449-450.

Srivastava, P.B.L. and Penguang Manggil 1981. Vegetative propagation of some dipterocarps by cuttings. The Malaysian Forester 44: 301-313.

Tan, SS., Primack, R., Ernest, O.K. and Lee, H.S. 1987. The silviculture of dipterocarp trees in Sarawak, Malaysia. III. Plantation forest. The Malaysian Forester 50: 148-116.

Tang, H.T. and Wadley, H. 1976. Report on the survival and development survey of areas reforested by line-planting in Selangor. FRI Research Pamphlet No. 67, Forest Research Institute Malaysia, Kepong. 105.

Whitmore, T.C. 1984. Tropical Rain Forests of the Far East. Clarendon Press, Oxford. 352.

Wyatt-Smith, J. 1963. Enrichment planting. In Manual of Malayan silviculture for inland forest, Part III, Chapter 6. Malayan Forest Records No 23, Forest Department, Kuala Lumpur, Pp. 6: 1-15.

Plate 1. Inside view of a closed chamber mist propagator used in Danum Valley Field Centre, loaded with cuttings of different dipterocarp species.

Plate 2. A two-node cutting of Dryobalanops lanceolata beginning to form roots, after 8 weeks in the propagation unit.

Plate 3. A Shorea parvifolia plant used in our hedge orchard. Plants are bent and their apical shoots removed. Note orthotropic shoots formed along the stem.