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LOW TECHNOLOGY TREE PROPAGATION AND THE RESTORATION OF NATURAL FOREST ECOSYSTEMS

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The loss of forests, and their associated biodiversity, is now a serious issue in many rapidly developing tropical countries. Throughout Northern Thailand for example, large areas of land within national parks and wildlife sanctuaries are deforested and require reforestation. In such protected areas, where the primary objectives are conservation of biodiversity and watershed protection, reforestation should aim to recreate the original forest ecosystems. Recently, many community groups have organised tree planting events to restore forests on degraded land, to mark the Golden Jubilee of His Majesty King Bhumibol Adulyadej. However, such tree planting projects are constrained by lack of knowledge of the propagation and production of the many hundreds of native tree species. Further, there is no identification manual for tree fruits, seeds or seedlings. The Forest Restoration Research Unit (FORRU), a joint initiative between the Royal Forest Department and Chiang Mai University, with sponsorship from Riche Monde (Bangkok) Ltd., was established in November 1994 to determine the most effective methods to complement and to accelerate natural forest regeneration in deforested areas, to increase biodiversity and to protect watersheds. Two of the major tasks of FORRU are to illustrate and describe seedlings at all stages of development for a seedling identification guide, and to develop appropriate nursery methods to propagate such tree species.

Introduction

DEFORESTATION IN SE ASIA

Southeast Asia is losing its forests and associated biodiversity at an alarming rate. The official estimate of current forest cover in Thailand is 134,910 km^2 or 26% of the country, a reduction from 53% in 1961 (Bhumubamon, 1986). These figures do not distinguish between plantations and natural forests and unofficial estimates put Thailand's natural forest cover at less than 20% (Leungaramsri and Rajesh, 1992). Between 1981 and 1990, the annual deforestation rate was 3.3%, the highest rate in SE Asia. In 1989, the government banned commercial logging, in response to floods blamed on deforestation, which devastated parts of Southern Thailand. However, since then, forest destruction has continued, although probably at a reduced rate. In recent years, forested areas have been denuded largely by logging and the expansion of agricultural land (Hirsch, 1990). Consequently, today, secondary forests of differing degrees of disturbance, and completely denuded lands occupy large areas. Even within national parks, large tracts of forest have been severely degraded (Elliott *et al.*, 1989). One option to compensate for continuing destruction is for deforested areas to be converted back into forest, which is able to maintain rural communities, protect watersheds and conserve biodiversity. The need to identify and monitor biodiversity and to preserve and restore ecosystems to conserve them for sustainable use is now widely recognised (Elliott *et al.*, 1996). The Government of Thailand has recognised the need to preserve areas of pristine forest, to set aside large areas for the conservation of biodiversity and to encourage tree planting schemes.

Following the logging ban, the Thai National Forest Policy, which stipulates that 40% of the country should be under forest cover, was adjusted. The target for production forest was reduced from 25% to 15% of the country's area whilst that for conservation forests was increased from 15% to 25%. This policy was implemented by designating many former logging concessions as national parks or wildlife sanctuaries. Such areas now cover about 64,020 km^2 (12.66% of the country), or more than half of the total forest area (Boontawee *et al.*, 1995). Consequently, large parts of many national parks and wildlife sanctuaries were already degraded or deforested before they acquired protected status. Such areas must be reforested, if they are to fulfil their functions of conserving biodiversity and protecting watersheds.

FOREST TYPES IN NORTHERN THAILAND

Monsoon forest is the vegetation of much of the mountains of Northern Thailand, ranging from evergreen forest on the upper slopes, mixed deciduous-evergreen forest at mid-elevations, to deciduous dipterocarp forest on the lower slopes. Recent inventories in Doi Suthep-Pui National Park (DSPNP) in Northern Thailand (Elliott *et al.*, 1989), for example, indicate that its tropical dry forests are among the most diverse in tree species in the world. However, large parts of this region are now severely degraded due to logging and shifting cultivation, and its large vertebrate populations have been severely depleted and some extirpated both within national parks and wildlife sanctuaries and outside protected areas. Consequently, the biodiversity in Northern Thailand, which is extremely rich but poorly known, is now severely threatened.

NEED FOR REFORESTATION

Within national parks and wildlife sanctuaries, where the primary objectives are wildlife conservation and watershed protection, reforestation efforts are being directed towards the permanent restoration of the original forest ecosystems, as closely as possible, by accelerating the natural processes of forest regeneration. Rehabilitation and restoration of degraded ecosystems is an extremely important component of *in situ* conservation as identified in the Rio Biodiversity Convention (1992), but research in the biological and social dimensions of these issues has been neglected. In situations where biodiversity has been reduced, local populations are likely to require substantial support in terms of resources and knowledge if they are to participate in the development and implementation of remedial actions. Community forestry programmes have been launched which seek to give local people greater control over local forest resources (Oldfield, 1988). However, such programmes similarly require restoration strategies in order to provide a diverse range of forest products and ecological services for local people (Elliott, 1994).

Tree nursery and propagation technology

REQUIREMENT OF VARIOUS GROUPS FOR NURSERY TECHNOLOGY

In the past few years, there has been a major shift in the types of reforestation projects being carried out in Thailand, away from the establishment of plantations of fast-growing species, such as pines and eucalypts, towards planting a wide range of native forest species. This type of reforestation is sometimes termed "enrichment planting" or "accelerated/assisted natural regeneration". For example, in Northern Thailand, Chiang Mai University (CMU) and the Royal Forest Department of Thailand (RFD) have identified the restoration of the forests of DSPNP as extremely important for two reasons. Firstly, to maintain the high and unique biodiversity of the locale and to promote recovery of threatened species and, secondly, given its close proximity to the second largest urban centre in Thailand, to serve as a regional educational facility for biodiversity conservation, nursery techniques for native species, restoration ecology and sustainable development. The rehabilitation and restoration of degraded ecosystems and the promotion of the recovery of threatened species are essential components for the maintenance of biodiversity through *in situ* conservation, although there has been little recorded systematic study.

In 1993, a major reforestation project was initiated to mark the Golden Jubilee of His Majesty King Bhumibol Adulyadej. The long-term aim of this project is to replant 8273 km^2 of degraded forest land. The project stipulates the use of a wide range of native forest tree species and that restored forests are to be preserved for conservation.

These projects are being undertaken by a diverse range of organisations, including villages, schools, charitable foundations, private companies, religious groups and other non-governmental organisations. However, the implementation of this abrupt change in policy has been constrained by a lack of knowledge of propagation and planting techniques for the wide range of native tree species required. There is no doubt that the effectiveness of forest restoration projects would be considerably improved through the development of native tree propagation technology, and the dissemination of this knowledge.

CURRENT STATE OF NURSERY TECHNOLOGY IN THAILAND

Nursery technology for certain woody species in Thailand is quite advanced, both for conventional propagation and micropropagation. However, this technology has concentrated almost exclusively on exotic and commercial plantation species. Much of the research on conventional propagation has been carried out at the ASEAN-Canada Forest Tree Seed Centre, Muak Lek, Thailand. Their work has, for example, identified cost effective methods for propagating seedlings commercially using novel media such as coconut husk (Kijkar, 1991a). In the case of native species of commercial importance, they have developed seed testing standards for *Dipterocarpus alatus*, *D. intricatus* and *Hopea oderata* (Krishnapillay, 1992) and vegetative propagation techniques for dipterocarps in general (Kantarli, 1993). Vegetative propagation has been extensively studied with exotic eucalypts and acacias, resulting, for example, in the production of a handbook for the propagation of *Eucalyptus camaldulensis* (Kijkar, 1991b). Elsewhere, workers have developed *in vitro* propagation techniques for a very limited number of commercial species, such as bamboo, using micropropagation (Gavinlertvatana, 1992). Plant biotechnology may also offer potential for the storage of seed and vegetative material of forest species through cryopreservation (Blakesley *et al.*, 1996). However, very little work has been carried out with the vast majority of native tree species. Many of the conventional techniques developed for commercial species, such as vegetative propagation of elite trees, would be inappropriate for isolated small-scale forest nurseries, and would not be desirable for many operations.

THE FOREST RESTORATION RESEARCH UNIT (FORRU)

In recognising the need to initiate research into forest restoration techniques in Northern Thailand, and the wider region, CMU and RFD jointly founded (in November 1994) the Forest Restoration Research Unit (FORRU), in collaboration with the University of Bath and the Natural History Museum, London. A tree nursery was constructed at the Headquarters of DSPNP, (18° 50' N, 98° 50' E) at about 1,000 m elevation, in a transitional zone between mixed deciduous-evergreen forest and evergreen forest. The nursery aims to propagate a wide range of native forest tree species and to transplant nursery-grown stock into degraded forest.

The FORRU nursery manager, or indeed any nursery operation faced with a request for native tree seedlings, or with a degraded area which requires replanting with native trees, must have access to information to guide decisions on such issues as species selection, propagation techniques and production scheduling. There are, of course, already manuals available which describe basic nursery practices and techniques. However, in addition to these guides, information is required particularly in the local language, which illustrates appropriate nursery techniques for native species under local conditions with local materials. Further, guidance is necessary to indicate the criteria which should be used in the choice of species for replanting, and their identification. It is interesting to note that 626 species of trees have been recorded within DSPNP alone, of which about 400 grow in the habitats and elevation range around the FORRU research unit. Whilst many local people have the skills to identify mature trees and fruit, seedlings are more problematic. The availability of a seedling identification guide is important for many reasons, including (i) the collection of "wildlings" (seedlings which have germinated in the forest) for potting and subsequent growing-on in the nursery and (ii) the assessment of natural regeneration taking place in degraded areas, to avoid destroying tree seedlings already present, and to avoid duplicate planting of these species. Assuming that a target list of so-called "framework species" (species suitable for planting to complement natural seedling establishment) has been compiled (Elliott *et al.*, 1997), the nursery manager will need to plan a production schedule for these species, which must include seed collection dates, seed treatments, pricking out times and growing-on periods. It may be necessary to manipulate the growth rate of seedlings in order to produce a seedling of the correct size for planting at a particular time of the year, such as the start of the monsoon season.

FORRU was initially established because most of the information already discussed is not available for the vast majority of native tree species in Thailand. Consequently, the following specific objectives were identified by FORRU:

1. To develop tools for studying the restoration of natural forest ecosystems, such as tree flowering and fruiting phenology, a seedling identification handbook, seedling herbarium and databases of seed, fruit and seedling morphology.
2. To study the ecological processes of natural forest regeneration to determine ways in which these processes might be accelerated.
3. To identify which tree species are suitable for planting to complement natural seedling establishment (so-called "framework species").
4. To develop appropriate methods to propagate such tree species and to carry out experimental planting trials.

5. To act as a demonstration unit, to produce literature and to teach interested groups about appropriate forest restoration techniques.

Studies of several hundred species have already been performed at FORRU. The approaches taken in the study of fruit and seed phenology and morphology, seed germination and seedling identification are described below. Extracts from a recent account of *Hovenia dulcis* Thunb. (Rhamnaceae) (Kopachon *et al.*, 1996), which was added to the flora of Thailand in 1993 (Maxwell, 1994), are provided as an example.

FRUIT AND SEED PHENOLOGY AND MORPHOLOGY

Phenological studies are carried out primarily to determine the seasonal availability of seeds of a wide range of tree species. Along existing forest trails in DSPNP, marked trees are currently observed with binoculars every three weeks and scored for the presence of flowers, fruits and foliage. A linear scale of 0-4 is used, 4 representing maximum intensity of reproductive activity or canopy cover and 3, 2, and 1 representing 75%, 50% and 25% of the maximum intensity or canopy cover, respectively. Data for each species are plotted as a phenological profile, such as that of *H. dulcis* (Fig. 4.1). Such diagrams allow nursery managers to plan seed collection programmes and to show the relationships between reproductive activity and the presence of leaves.

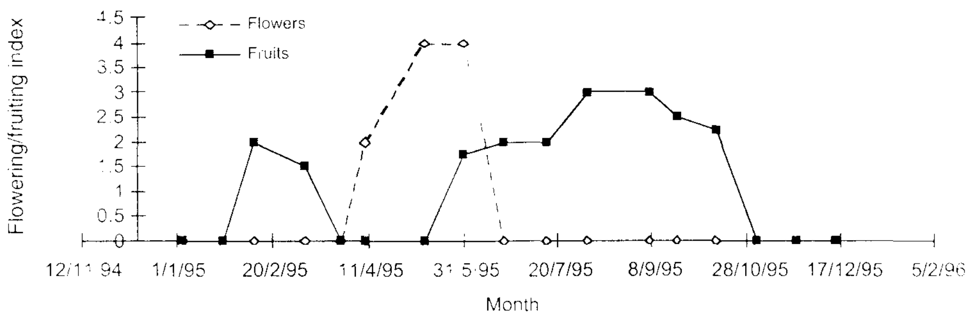

Figure 4.1 Phenological profile of the flowers and fruits of *Hovenia dulcis*. See text for explanation of scoring system (n=3).

A dried voucher specimen is made of every tree from which seeds are collected, and data on location, habitat, girth, height and bark characteristics are also recorded. Voucher specimens are stored at CMU Biology Department Herbarium. Fruit and seed characteristics are also recorded (Section 1) (Kopachon *et al.*, 1996) and are entered into a database that will act as an identification aid, as well as provide the means to reveal relationships between seed/fruit morphology and germination success rate or phenology.

1. Fruit and seed characteristics of *H. dulcis*

Fruits of *H. dulcis* are capsules, produced in cymes. The pedicels are very thin and curving for 2-3 mm immediately above each fruit, but further along, together with other axes, they become swollen and fleshy (almost as wide as the fruits themselves), green when the fruits are unripe, turning red-brown or black as the fruits ripen (Fig. 4.2A). The fruits (Fig. 4.2A-D) are roughly spherical capsules, which split open along internal walls (septicidally dehiscent), 6.9-8.5 mm long, 6.0-7.4 mm wide, and 6.0-7.7 mm thick (mean $\pm$ SDs: 7.87 $\pm$ 0.39, 6.99 $\pm$ 0.34 and 6.87 $\pm$ 0.41 mm, respectively, n = 20). They are three-lobed, lime-green and moist when unripe, turning brown or black and drying out upon ripening. There is usually one seed in each lobe. Each capsule has a small cup at its base (derived from the old calyx) and a small scar at its apex (derived from the style). Both the exocarp and endocarp are thin (Fig. 4.2C,D). At maturity, the outer layer gradually disintegrates and flakes off, exposing the cream-coloured inner layer. The three locules of the inner layer of the fruit wall then separate and dangle on irregular threads from the fruit stalk; the fibres in the wall of each segment spread apart slightly, becoming basket-like. It is unclear whether the seeds fall out of each segment or must be removed by seed dispersers.

Seeds (Fig. 4.2E,G) are smooth, glossy, turning from light brown to dark brown and then black as the fruit ripens. Each seed is shaped like a one-third segment of a sphere, 5.0-6.0 mm long, 4.8-5.8 mm wide and 2.2-2.6 mm thick (mean $\pm$SDs: 5.57 $\pm$ 0.41, 5.37 $\pm$ 0.21 and 2.36 $\pm$ 0.24 mm, respectively, n = 20). The hilum has a shallow rim around it. The embryo is composed of a small rudimentary plumule and two large cotyledons. There is a thin layer of endosperm around the embryo. The seed coat is formed of two prominent layers: the outer one is clear to cream-coloured, forming a hard protective covering around the seed; the inner one is softer and brown to black, giving the seed its colour. Seeds dried overnight at 90°C had a mean dry weight ($\pm$ SD) of 27.8 $\pm$ 3.75 mg (n = 20) and a mean moisture content ($\pm$ SD) of 19.1% $\pm$ 4.4% (n = 20).

SEED GERMINATION

Seed germination experiments currently aim to identify which tree species germinate easily without any special treatment. Germination is a very important criterion in the selection of framework species. Seeds are removed from fruits and planted in modular plastic trays under two shade treatments; partial shade (40% of full sunlight, similar to the quantity of light in partially regenerating gaps) and deep shade (less than 1% full sunlight, similar to the quantity of light under an evergreen forest canopy). For the partial shade treatment, seed trays are placed on top of concrete benches, under a transparent plastic roof, whilst for the deep shade treatment, trays are placed underneath benches, screened around the sides with black plastic shade netting. Section 2 presents the general format in which seed germination results are reported (Kopachon *et al.*, 1996).

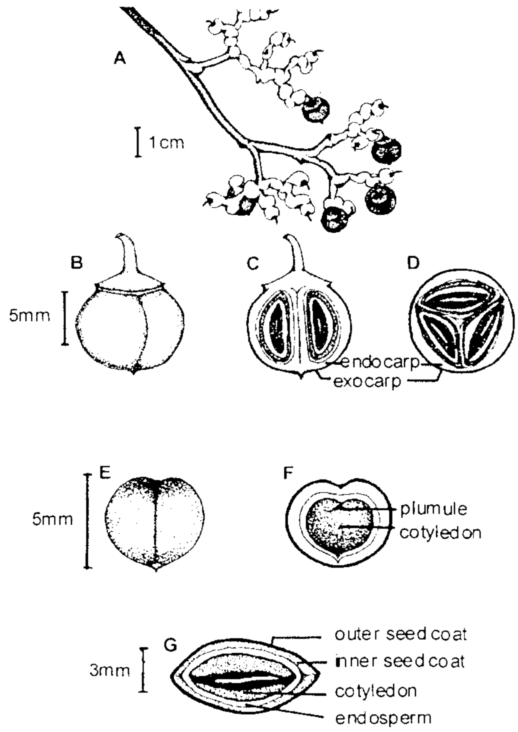

Figure 4.2 Fruits and seeds of *Hovenia dulcis*: A. Cyme, note the thickened fruit stalks, which are characteristic of the species and are believed to have medicinal properties. B. Fruit. C. Longitudinal section through a fruit. D. Transverse section through a fruit, E. Seed, F. Longitudinal section through a seed. G. Transverse section through seed (drawings by K. Suriya and G. Pakaad).

2. Germination of *H. dulcis*

Ripe fruits of *H. dulcis* were collected from the ground below a single tree, 25 m tall with a dbh of 64 cm, 1,075 m above sea level on 20th December 1994. Seeds were removed from the fruits and planted on 24th December at the FORRU nursery, under the two shade treatments. The first seed germinated 17 days after planting in partial shade and after 24 days in deep shade. Seeds continued germinating up to 115 days from the planting date (Fig. 4.3). The final germination percentage was significantly higher ($p<0.05$, chi-square test) in partial shade (50% ± SD 21.2%) than in deep shade (28% ± SD 12.2%). In addition, for those seeds that germinated, the number of days between sowing and germination did not differ significantly between treatments ($p = 0.69$, Kolmogorov-Smirnoff 2-sample test, Sokal and Rohlf, 1981). Fifty per cent of all seeds that germinated had done so 45 days after sowing in both treatments.

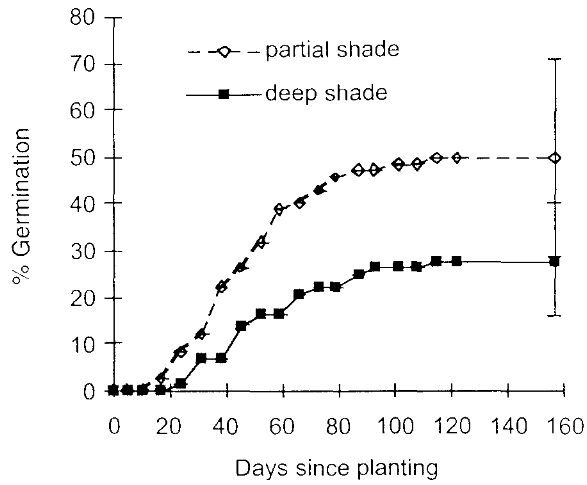

Figure 4.3 Germination curves of *Hovenia dulcis* seeds in partial and deep shade at the FORRU nursery, Doi Suthep-Pui National Park 1.050 m above sea level. Bars indicate standard error of the final germination percentages (n=3).

Knowledge of likely seed germination rates has obvious applications to the preparation of seedling production schedules for each species. It enables nursery managers to calculate the number of fruits which need to be collected to produce a required number of seedlings. Furthermore, the germination experiments are providing information on the length of seed dormancy, so that nursery managers know the period they may have to wait before seedlings are produced.

SEEDLING IDENTIFICATION MANUAL

One of the aims of the germination experiments is to produce seedlings for illustration and description for an identification manual of the forest tree seedlings of Northern Thailand. Seedlings of known age are harvested from the germination experiments at different stages of development. They are photographed, drawn (Figs. 4.4 and 4.5) and prepared as dried herbarium

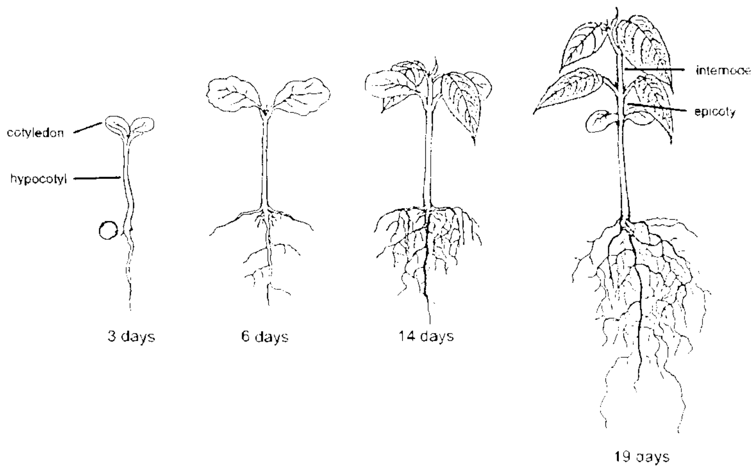

Figure 4.4 Seedlings of *Hovenia dulcis* aged 3-19 days (*CMU Biology Department Herbarium, Suriya s18b1 h1*) (drawing by K. Suriya).

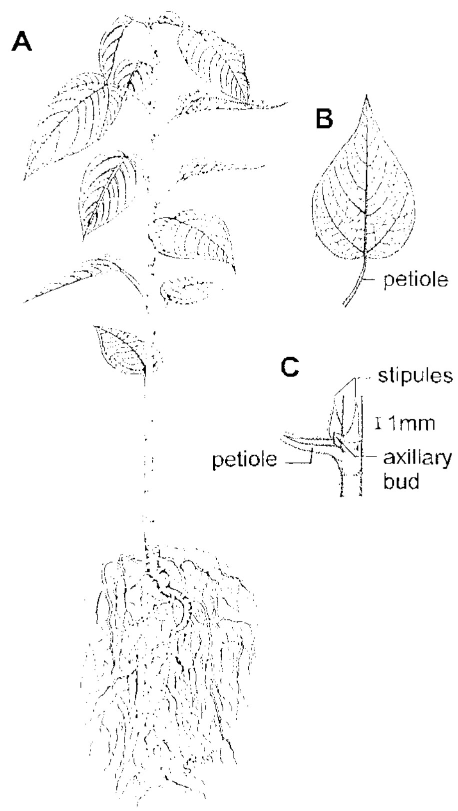

Figure 4.5 A. A seedling of *Hovenia dulcis* aged 183 days, B. Leaf venation, C. Stipules and axillary bud (*Suriya s18b1h2*) (drawing by K. Suriya).

specimens stored at CMU Biology Department Herbarium. Seedling specimens are stored in the same folders as the voucher specimens of the parent trees from which they originated. Detailed descriptions are also prepared in the format presented in Section 3 (Kopachon *et al.*, 1996).

3. Seedling description

SEEDLINGS: Cotyledons are held above the soil (epigeal) and are free of the seed coat (phanerocotylar).
ROOTS: Primary root slender, fibrous, white to light brown, developing into a thick tap root. Secondary roots few, slender, sparsely branching, cream-coloured.
STEMS: Hypocotyl 3-6 cm long, light green with orange-brown longitudinal striations; densely covered with minute white hairs. Epicotyl 8-12 mm long, light green, covered in white hairs. Internodes: first internode 6-11 mm long, later internodes to 42 mm long; youngest parts light green, covered in white or light brown hairs; older parts a darker shade of green-brown, with prominent lenticels, especially on the lower part. Stems of larger seedlings erect, slender. Axillary buds minute, green with brown apex, conical, hairy, about 1 mm in diameter.
COTYLEDONS: Opposite, two, hairless, persistent until expansion of the 11th leaf. Blades green, thin, orbicular, with entire margins, rounded to somewhat truncate at apex, rounded at base; 13-14 mm in diameter (when mature). Venation pinnate, obscure, with two basal veins. Petioles 3-4 mm long, covered in fine white hairs.
LEAVES: Opposite at first node, spiral at later nodes. Blades at first node thin, darker green above than below, ovate, acuminate at apex, truncate at base, finely toothed along margins, 22-35 mm long x 14-17 mm wide; simple, fine, white hairs sparse on blades above, absent on blades below, dense on midrib above and below and somewhat dense on other veins below. Blades at later nodes ovate, but somewhat broader at higher nodes than at lower nodes, up to 122 mm long x 85 mm wide, otherwise similar to blades at first node. Venation pinnate; primary and secondary veins below lighter green than the blade, prominently raised; primary basal veins two, opposite; secondary veins 4-6 on each side of midnerve, alternate; all lateral veins curved, mostly free-ending, sometimes weakly looped.
PETIOLES: Very hairy; 6-8 mm long and 0.2-0.4 mm thick at first node, to 50 mm long and 2 mm thick at later nodes; green with light brown hairs. Stipules thin, ovate-lanceolate, acuminate at the apex; about 1 mm long at first node, to 4 mm long at later nodes; densely covered in fine white hairs; sometimes persisting after leaves are shed at early nodes, but usually falling soon after leaves mature at later nodes, leaving tiny scars.

BRANCHES: Not formed on seedlings less than 60 cm tall; first produced at 68 cm above ground level (about node 24), then in each of the next four consecutive leaf axils; spiral around stem; extending soon after the subtending leaf matures.

Conclusions

In order to operate a successful nursery for native tree seedling production, information and technology must be available, from species selection and identification through to production scheduling for each species. Further, this information must be accessible to local people. In the short time that it has been in operation, FORRU has developed useful methods for studying a large number of native forest tree species. One of the key objectives of the unit is to identify framework species; species which are suitable for planting in deforested gaps to accelerate re-establishment of canopy cover, increase biodiversity of regenerating forest and hasten the succession towards primary forest. The seed germination trials have enabled identification of primary forest species which germinate readily in partial shade with no special treatments, grow well in containers under nursery conditions and which are not commonly found establishing naturally in deforested gaps (data not shown). Future work will focus on improving propagation techniques for the mass production of vigorous, healthy seedlings of approximately 30 framework species. Seeds will be collected and sown in every month of the year. Research will be carried out into the control of growth rates of the container-grown stock to allow planting of all species at the same time, at the beginning of the monsoon season. Planting experiments will investigate the effectiveness of various simple planting treatments (e.g. artificial shade, mulching, fertilisers) on seedling performance.

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