APPROPRIATE TREE SPECIES AND TECHNIQUES FOR DIRECT SEEDING FOR FOREST RESTORATION IN CHIANG MAI AND LAMPHUN PROVINCES

PANITNARD TUNJAI

MASTER OF SCIENCE
IN BIOLOGY

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17 August 2005

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Panitnard Tunjai
17 August 2005

Thesis Title Appropriate Tree Species and Techniques for Direct Seeding for Forest Restoration in Chiang Mai and Lamphun Provinces.

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ABSTRACT

Most forest restoration projects involve planting nursery-raised tree seedlings, but this is a highly labour- and capital-intensive method. Seed collection, raising seedlings in a nursery, planting and maintaining planted saplings until they can establish and become independent all require substantial labour inputs. So, direct seeding is an alternative method that might reduce the cost of forest restoration. This research was designed to test the hypothesis that appropriate species and techniques of direct seeding can give more efficient results and cost less than planting nursery-raised seedlings for forest restoration in northern Thailand.

Direct seeding was tested in both a highland and a lowland site. Tree species selected for study in the highlands were *Aquilaria crassna* Pierre ex Lec. (Thymelaceae), *Balakata baccata* (Roxb.) Esser. (Euphorbiaceae), *Carallia brachiata* (Lour.) Merr. (Rhizophoraceae), *Eugenia fruticosa* DC. (Myrtaceae), *Sarcosperma arboreum* Bth. (Sapotaceae) and *Spondias axillaris* Roxb (Anacardiaceae). Those selected for testing at the lowland site were *Afzelia xylocarpa* (Kurz) Craib (Leguminosae, Caesalpinioideae), *Artocarpus lakoocha* Roxb. (Moraceae), *Casearia grewiifolia* Vent. var. *grewiifolia* (Flacourtiaceae), *Eugenia cumini* (L.) Druce (Myrtaceae), *Schleichera oleosa* (Lour.) Oken (Sapindaceae) and *Trewia nudiflora* L.

(Euphorbiaceae). Germination tests were carried out, both in the nursery and in the field. This study used two methods to break seed dormancy, accelerate seed germination and thus reduce the amount of time available for seed predation: i) soaking in water (48 hrs) and ii) scarification. In addition, weeding was carried out every 2 months in the field.

Seed pre-treatments (plus soil from mother tree) had little effect on some species, significantly increasing the survival percentage for none and significantly reducing it only for *B. baccata* in the field. The reasons for this were probably seedling predation and desiccation.

Weed control had different effects on different species, significantly increasing the survival per cent for only *C. brachiata* and significantly reducing it for *A. crassna*, *B. baccata* and *S. axillaris*. It had little effect on *A. xylocarpa* and *S. oleosa*. The reasons for this were probably seedling desiccation which affected each species differently depending on their characteristics.

Comparison of seedling growth in the second year made use of an experiment that had been established in the previous year by direct seeding *Gmelina arborea* Roxb. (Verbenaceae), *Melia toosendan* Sieb. & Zucc. (Meliaceae), *Oroxylum indicum* (L.) Kurz (Bignoniaceae), *Prunus cerasoides* D. Don (Rosaceae), *Sarcosperma arboreum* Bth. (Sapotaceae) and *Spondias axillaris* Roxb (Anacardiaceae). Nursery raised plants from the same seed batches were planted next to the direct seeded plants and monitored for a year. Direct seeded *G. arborea*, *M. toosendan* and *P. cerasoides* grew significantly better with higher mean RCD, height and crown width and had higher survival per cent compared with raised-nursery seedlings, during second year of growth in the field ($p<0.05$).

Weed competition was not a serious problem in the first year after sowing. It had no effect on germination per cent, MLD and growth performance of most of the species in this study. Some species appeared to be nurtured and supported by surrounding vegetation, which might protect them from strong sunlight and high temperatures.

Treatments used to increase germination per cent and reduce MLD had variable and inconsistent effects. Therefore, more research to develop more reliable treatments to accelerate germination are required.

Calculations of costs showed that establishment of direct seeded trees can reduce costs by about 50%, compared with planting nursery-raised seedlings. The calculation was based on a stocking density of 500 trees per rai. Direct seeding may suitable for forest restoration projects with low budgets but systematic planning will be needed.

ชื่อเรื่องวิทยานิพนธ์	ชนิดพืชและเทคนิคการปลูกด้วยเมล็ดโดยตรงที่เหมาะสมเพื่อการฟื้นฟูป่าในจังหวัดเชียงใหม่และจังหวัดลำพูน
ผู้เขียน	นางสาวพนิตนาถ ทันใจ
ปริญญา	วิทยาศาสตรมหาบัณฑิต (ชีววิทยา)

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บทคัดย่อ

โครงการฟื้นฟูป่านิยมใช้การปลูกต้นกล้าจากเรือนเพาะชำ ซึ่งมีค่าใช้จ่ายสูงสำหรับแรงงานการเก็บเมล็ด การดูแลต้นกล้าในเรือนเพาะชำ การขนย้ายต้นกล้าไปยังพื้นที่ปลูก การเตรียมพื้นที่และการปลูกตลอดจนการควบคุมวัชพืชและการใส่ปุ๋ยจนต้นกล้าสามารถรอดชีวิตได้ในสภาพธรรมชาติ การปลูกด้วยเมล็ดโดยตรงจึงอาจเป็นทางเลือกสำหรับลดงบประมาณการฟื้นฟูป่าและการศึกษานี้มีวัตถุประสงค์เพื่อหาชนิดพรรณพืชและเทคนิคสำหรับการปลูกด้วยเมล็ดโดยตรงที่เหมาะสมในภาคเหนือของประเทศไทย

แปลงทดลองสำหรับพื้นที่สูงและพื้นที่ราบอยู่ในจังหวัดเชียงใหม่และจังหวัดลำพูนตามลำดับพรรณพืชที่ศึกษาในพื้นที่สูง คือ *Aquilaria crassna* Pierre ex Lec. (Thymelaceae)(กฤษณา) *Balakata baccata* (Roxb.) Esser. (Euphorbiaceae)(สลีนก) *Carallia brachiata* (Lour.) Merr. (Rhizophoraceae)(เฉียงพร้านางแอ) *Eugenia fruticosa* DC. (Myrtaceae)(หว้าขี้กวาง) *Sarcosperma arboreum* Bth. (Sapotaceae)(มะยาง) และ *Spondias axillaris* Roxb (Anacardiaceae)(มะกัก) ส่วนพรรณพืชที่ศึกษาในพื้นที่ราบ คือ *Afzelia xylocarpa* (Kurz) Craib (Leguminosae, Caesalpinioideae)(มะค่าโมง) *Artocarpus lakoocha* Roxb. (Moraceae)(หาด) *Casearia grewiifolia* Vent. var. *grewiifolia* (Flacourtiaceae)(กรวยป่า) *Eugenia cumini* (L.) Druce (Myrtaceae)(หว้าขี้แพะ) *Schleichera oleosa* (Lour.) Oken (Sapindaceae)(ตะคร้อ) และ *Trewia nudiflora* L. (Euphorbiaceae)(มะฝ่อ) มีการทดลองเกี่ยวกับการงอกทั้งในสภาพเรือนเพาะชำและสภาพ

ธรรมชาติ เทคนิคการเตรียมเมล็ดก่อนปลูกที่ใช้ คือ การแช่เมล็ดในน้ำเป็นเวลา 48 ชั่วโมงและทำรอยแผลที่เปลือกหุ้มเมล็ดเพื่อเพิ่มเปอร์เซ็นต์การงอกและกระตุ้นให้เมล็ดงอกเร็วขึ้น พยายามลดโอกาสที่เมล็ดจะถูกกินเป็นอาหารรวมทั้งกำจัดวัชพืชทุก 2 เดือนสำหรับแปลงทดลองในสภาพธรรมชาติ

การเตรียมเมล็ดก่อนปลูกรวมถึงการใส่ดินจากต้นแม่มีผลเพียงเล็กน้อยต่อพืชบางชนิด พบว่าไม่สามารถเพิ่มเปอร์เซ็นต์การงอกของพืชทุกชนิดและลดเปอร์เซ็นต์การงอกของสลีนกอย่างมีนัยสำคัญในสภาพธรรมชาติ ($p<0.05$) สาเหตุอาจเป็นเพราะต้นกล้าสูญเสียน้ำและถูกทำลายโดยสัตว์

การควบคุมวัชพืชมีผลต่อเปอร์เซ็นต์การรอดชีวิตของพรรณพืชแต่ละชนิดแตกต่างกันอย่างมีนัยสำคัญ ($p<0.05$) คือ เปอร์เซ็นต์การรอดชีวิตของเฉียงพร้านางแอเพิ่มขึ้นแต่เปอร์เซ็นต์การรอดชีวิตของกฤษณา สลีนกและมะกักลดลงอย่างมีนัยสำคัญ ($p<0.05$) การควบคุมวัชพืชมีผลเพียงเล็กน้อยต่อมะค่าโมงและตะคร้อ สาเหตุอาจเป็นเพราะโครงสร้างของต้นกล้าแต่ละชนิดมีผลต่อการสูญเสียน้ำแตกต่างกัน

พรรณพืชที่ศึกษาเปรียบเทียบการเจริญเติบโตระหว่างต้นกล้าจากการปลูกด้วยเมล็ดโดยตรงและต้นกล้าจากเรือนเพาะชำหลังจากปลูกในพื้นที่ธรรมชาติเป็นเวลา 1 ปี คือ *Gmelina arborea* Roxb. (Verbenaceae)(ซ้อ) *Melia toosendan* Sieb. & Zucc. (Meliaceae)(เลี่ยน) *Oroxylum indicum* (L.) Kurz (Bignoniaceae)(เพกา) *Prunus cerasoides* D. Don (Rosaceae)(นางพญาเสือโคร่ง) *Sarcosperma arboreum* Bth. (Sapotaceae)(มะยาง) และ *Spondias axillaris* Roxb (Anacardiaceae)(มะกัก) พบว่าค่าเฉลี่ยของเส้นรอบวงโคนต้น ความสูง ความกว้างทรงพุ่มและเปอร์เซ็นต์การรอดชีวิตของซ้อ เลี่ยน นางพญาเสือโคร่งและมะกักที่ปลูกด้วยเมล็ดโดยตรงมีค่ามากกว่าต้นกล้าจากเรือนเพาะชำอย่างมีนัยสำคัญ ($p<0.05$)

จากการศึกษานี้พบว่าภาวะการแข่งขันระหว่างต้นกล้าและวัชพืชไม่ใช่ปัญหารุนแรงในปีแรกหลังจากปลูกด้วยเมล็ดโดยตรง วัชพืชไม่มีผลต่อเปอร์เซ็นต์การงอก การพักตัวของเมล็ดและการเจริญเติบโตของพรรณพืชหลายชนิดที่ทำการศึกษา ในทางตรงกันข้ามพบว่าพืชบางชนิดได้ผลดีจากร่มเงาของวัชพืชสำหรับป้องกันต้นกล้าจากอุณหภูมิสูงและแสงแดดที่รุนแรง

เทคนิคการเตรียมเมล็ดก่อนปลูกในการศึกษานี้มีผลต่อเปอร์เซ็นต์การงอกและช่วงเวลาพักตัวของเมล็ดที่ไม่แน่นอน จำเป็นต้องมีการศึกษาเพื่อพัฒนาเทคนิคที่มีประสิทธิภาพและให้ผลที่แน่นอนต่อไป

การปลูกด้วยเมล็ดโดยตรงสามารถลดงบประมาณได้ประมาณ 50 เปอร์เซ็นต์เปรียบเทียบกับการใช้ต้นกล้าจากเรือนเพาะชำ ซึ่งคำนวณจากการใช้ต้นกล้าจำนวน 500 ต้นสำหรับพื้นที่ 1 ไร่

การปลูกด้วยเมล็ดโดยตรงอาจเหมาะสมสำหรับโครงการฟื้นฟูป่าที่มีงบประมาณจำกัดแต่จำเป็นต้องมีการวางแผนอย่างเป็นระบบ

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CHAPTER 1

Introduction

Tropical forest loss and degradation are proceeding at unprecedented rates, eroding biological diversity and prospects for sustainable economic development of agricultural and forest resources (Parrotta, 2000). Tropical forests contain a substantial portion of the world's biological resources, richness and diversity. Hence, they are often called a treasury of biological resources. Although tropical forest contains many important natural resources, they have been widely degraded throughout the world. Deforestation means the clearing of forest from large tracts of land, which consequently remain unforested, either as barren land or as agricultural cropland (Bruenig, 1996). Deforestation in the tropics is widely accepted as one of the greatest threats to wildlife on Earth. The last decade of the 20th century saw rapid changes in attitudes towards this problem and some innovative attempts to devise solutions (Elliott, 2000).

Thailand has only about 18% forest cover, compared with 53% in 1961 (Elliott *et al.*, 1996; Kamyorng, 2000). Most remaining forest is located in the northern region of Thailand. It is also the region where the rate of reforestation is highest and the forest area has been reduced from 68.5% or 116,275 km² of the region in 1961 to 43.6% or 73, 886 km² in 1995 (FORRU, 2000). Over-logging; both legal and illegal has caused immense forest destruction. The history of legal logging in this region began in 1864, when the Monarchy allowed teak logging concessions to be controlled by the central government. Conflicts between local regimes in the north and the central government increased. For political as well as economic reasons, the central government decided to invest in infrastructure, such as roads, in this region during 1863 to 1957 (TDRI, 2000). The development of roads led to over-exploitation of forest resources. Illegal logging has also caused forest destruction. Loggers cut down timber and transported it out of the deep forest by elephant or ox-drawn carts.

Illegal logging has been a problem for decades and the government could not solve this problem, because the real problem is not the equipment and the loggers, but the system and the corrupt local authorities (Tuntiwittayapitunk, 1992).

Shifting cultivation or swidden agriculture of tribal people is another main cause of deforestation. Hill-tribe communities have established large-scale monocultures of cash crops, such as cabbage and fruit tree orchards. These are the main causes of continuing forest loss.

Moreover, during 1987-1995, the bubble economy period led to land speculation in the hills. This caused degradation and encroachment of forest areas. In addition, promotion of tourism in the northern region led to construction of a lot of the tourist facilities such as roads, resorts and hotels (Elliott, 1994). Aside from these reasons, an increasing demand for housing land for the rapidly growing human population and other development projects are also the causes of forest destruction (Bhumibhamon, 1986; Svasti, 2000; Elliott, 2000).

Forest provides fundamental ecological resources for life, such as water resources, clean air and soil. Moreover, forest provides products which are important for human beings, such as fuel wood, medicinal plants, food, chemical substances, fiber, recreation, educational values, genetic resources, etc. Indirect benefits of forest include watershed protection and prevention of soil erosion and flood damage (Singpetch, 2001). Deforestation, therefore, reduces the quality of life, since forest destruction causes depletion of top soil, especially on steep slopes without vegetation cover. Consequently, carbon, nitrogen and phosphorus cycles are changed (Vitousek, 1983).

In order to mitigate the loss of forest area, Thailand has initiated reforestation to increase the forest area. In 1985, the national forest policy of Thailand stated that 40% of the total area of the country should be under forest (Klankamsorn, 1990). The Policy and Prospective Plan for Enhancement and Conservation of National Environmental Quality for the 20-year period from 1997-2016 proposed that 50% of the country should be forested. At least 30% is to be designated as conservation forest and 20% as economic forest. However, most forest restoration projects in Thailand were undertaken by establishing plantations of single species such as pine and eucalyptus. So, reforestation does not compensate for deforestation, because plantations are low of value for wildlife conservation and watershed protection (OEPP, 1997).

Forest restoration is one particular form of reforestation. Whereas the term reforestation covers the re-establishment of any kind of tree cover, including plantations and agro-forestry, the term forest restoration is confined to the re-establishment of entire forest ecosystems, as similar as possible to the original forest ecosystem that were present before deforestation occurred (Elliott, 2000).

Sometimes, it is not necessary to plant trees to restore forests. Assisted or accelerated natural regeneration (ANR) is a technologically simple and cost-effective approach to forest restoration, which first emerged in the Philippines in the 1970s (Jensen and Pfeifer, 1989). ANR is a flexible reforestation approach, which depends on identifying factors that limit regeneration of woody plants, then implementing management techniques to overcome those factors (Dalmacio, 1987). This method usually involves no or minimal tree-planting, but instead encourages the natural processes of forest succession (Hardwick *et al*., 2000). However, ANR can only work with the trees that are already established in deforested areas. Most tree species capable of colonizing such areas tend to be fast-growing pioneer trees with small easily dispersed seeds: a small subset of the tree species that comprised the original forest ecosystem. To restore the full tree community, some tree planting is inevitable, since the complete forest tree community includes climax trees with large-seeded tree species too (Elliott, 2000).

This has led to the development of more intensive (and more expensive) systems of forest restoration, involving tree planting, such as the Miyawaki method (Miyawaki, 1993; Alias *et al*., 2000). In Queensland, Australia, the framework species method (Tucker, 2000) uses a mixture of 20-30 pioneer and climax species planted in a single step. In Vietnam, forest succession is mimicked by the accelerated pioneer-climax species or APCS method (Sôû, 2000). In addition, an alternative technique is to make plantations of commercial tree species more attractive to wildlife. This is the so-called plantations-as-catalysts approach (Parrotta, 2000).

Forest restoration is mostly aimed at rehabilitating degraded areas for the conservation of biodiversity (Elliott *et al*., 2000). These natural assets are permanently renewable if wisely conserved. Improvements in economic status and human welfare cannot be sustained unless the conservation of these living resources is drawn into the process of development. Forest restoration and wildlife conservation can contribute to sustainable rural and national development (Bruenig, 1996). One way to achieve this might be to complement natural regeneration by planting native tree species that grow rapidly and attract seed-dispersing animals into planted areas (FORRU, 2000; Svasti, 2000).

In many cases, the rate of natural succession is limited by slow or impeded dispersal of seeds across degraded landscapes. An obvious way to accelerate such succession is to deliberately reintroduce seeds. Various form of direct sowing have been used: in some cases the seed has been broadcast or sown by hand; in others it has been sown from aircraft. Usually the seed must be sown on bare soil so that it can establish quickly in weed-free conditions. Seed reintroduction has been highly developed for use in commercial forestry following post-logging burns; it has also been widely used in mine-site rehabilitation projects, immediately after mining has ceased and before weeds have become established. It can be carried out after sites have been burned or following a herbicide treatment program to eradicate existing ground cover and shrub (Lamb and Gilmour, 2003).

Most forest restoration projects involve planting nursery-raised tree seedlings, but this is the most labour-and capital intensive method of forest restoration. Seed collection, raising seedlings in a nursery, planting and maintaining planted saplings until they can establish and become independent all require substantial labour inputs. So, direct seeding is an alternative method to reduce the cost of forest restoration (Hardwick *et al*., 2000). There is no need to raise seedlings in nurseries and seeds can be spread across the landscape easily, including sites that might be difficult to reach when carrying boxes of seedlings. There are several disadvantages, however. There must be no weed competition at the time the seeds are sown, meaning it may only be possible to use the technique in certain specialized situations. In addition, only certain species can be introduced to a site in this way, since large amounts of seed are often needed. In many cases, only a few of the seeds broadcast germinate. Some seeds are lost to seed predators and some seedlings will die because of dry weather soon after germination (Mergen *et al*., 1981; Allen, 1997).

Result from studies of direct seeding for revegetating degraded land suggest that, the technique may be useful where costs need to be minimised. In comparison to the establishment of nursery-grown seedlings, direct seeding may reduce tree establishment cost by as much as 90% (Thompson, 1992). What is required is a more systematic screening of potential species and their response to direct seeding under field conditions, and evaluations of costs associated with plantation establishment and aftercare, relative to those of more commonly used planting stock such as nursery-grown seedlings (Engel and Parrotta, 2001).

In addition, Steven (1991) stated that the outcome of direct seeding is affected by soil condition, site preparation and techniques for seed germination. Thomson (1992) and Applegate et al. (1993) pointed out that the potential cost-savings associated with direct seeding, particularly for species whose seeds are readily available and amenable to this method of establishment, could outweigh its disadvantages and offer a more economical means for re-establishing forest cover over large areas of degraded lands

Hypothesis

This research was designed to test the hypothesis that appropriate species and techniques of direct seeding can give more efficient results and cost less than planting nursery-raised seedlings for forest restoration.

Objectives

The objectives of the present study were:

1) To identify suitable tree species for direct seeding for forest restoration in northern Thailand.
2) To develop and test appropriate techniques of direct seeding for forest restoration in northern Thailand.

CHAPTER 2

Literature Review

Introduction – the need for forest restoration

Within the last ten years, tropical rainforests have been destroyed at an annual rate of 0.8% of area (Whitmore, 1997). Like many rapidly developing tropical countries, Thailand has experienced extensive deforestation, despite a ban on commercial logging since 1989. Illegal logging has been a problem for decades and still continues. However, the ban on commercial logging has helped to slow the rate of destruction (FORRU, 2000). The main causes of deforestation in Thailand, include; illegal logging, agricultural expansion and various development projects (Bhumibhamon, 1986), such as construction of infrastructure (roads, dams, resorts, etc.) (Elliott, 2001). The productive forest area in Thailand was 58% of the total land area in 1959 (Bhumibhamon, 1986). Between 1976 and 1980, Thailand had the second highest rate of forest depletion in Asia, next to Nepal (Dankelman and Davidson, 1988). By 1992, NGO's considered the area of natural forest to have been reduced to about 18% of Thailand's area (Leungaramsri and Rajesh, 1992), whereas estimates by the FAO put forest cover at around 19.3 % in 2000 AD, down from 53% in 1961 (Elliott *et al*., 1996; Kamyorng, 2000, FAO 2001).

The forests in northern Thailand are one of the most important natural resources of the country. They are the habitats for many wild animal and plant species including 150 species of mammal (Lekagul and McNeely, 1980), 383 species of bird (Round, 1988), and at least 3,450 species of vascular plant (CMU, Herbarium Database, 1999). Although most remaining forest is located in the northern region of Thailand, it is also the region where the rate of reforestation is highest and the forest area has been reduced from 68.5% or 116,275 km² of the region in 1961 to 43.6% or 73, 886 km² in 1995 (FORRU, 2000). In particular, destruction of upper watershed forests is caused by unsuitable land practices (Svasti, 2000). The regional rate of deforestation is approximately 0.9% per year (FORRU, 2000). The consequences of deforestation are particularly serious in the north (Svasti, 2000), as streams dry up in the dry season and rivers become choked with silt, especially in March and April.

In Chiang Mai Province, the forest area was reduced from 93.3% or 16,750 km² of the total land area in 1961 to 70.8% or 14,233 km² in 1995 (Kamyorng, 2000). Satellite images revealed that the area deforested more than doubled in only ten years from 3,235 km² in 1975 to 6,513 km² in 1985 (GRID, 1988). Forest covered about 14,060 km² or 69.96% in 1998 and the rate of forest loss averaged of 0.28% per year (RFD, 1998). The main causes of deforestation are shifting cultivation or swidden agriculture of tribal people, home land for the accelerated growth of human population rates, and development projects (Bhumibhamon, 1986; Elliott *et al*., 2000).

Focusing on Doi Suthep-Pui National Park, upland deforestation is mostly due to land encroachment both by hill-tribe folk, who have destroyed large areas of forest cover and newly arrived hill-tribe families (Elliott *et al*., 1993). In ten years, between 1975 and 1985, forest cover in the park fell from 225.4 km² or 86% to 148.98 km² or 56.7% (Elliott, 2001). Moreover, government agencies and agricultural research stations have occupied large areas of former forest. The remaining forest in the park has become fragmented into tiny patches, which cannot support populations of large animals. The forest needs to be rapidly restored to connect these patches. Forest regeneration can be done by allowing natural succession to occur or accelerated by planting tree seedlings or seeds (Elliott *et al*., 1993).

Current progress with forest restoration

In 1906, the first plantations in Thailand were established by government organizations. At first only teak was planted in association with upland rice or so-called agro-forestry (Bhumibhamon, 1986). Since then, the Royal Forest Department has successfully established plantations with a total area in 1984 of 4,918,332 rais. The RFD also promotes tree planting campaigns for specific occasions such as the King's birthday, Queen's birthday, etc. In 1961, the Army Mapping Department made the first forest map, used for planning the establishment of conserved forests and for logging operations and reforestation programs (Bhumibhamon, 1986). For instance, since 1968 up to 1982, the Forest Industry Organization has been actively engaged in tree planting programs covering totally 50,176.60 ha (Bhumibhamon, 1986) and the Thai Plywood Company has planted about 2,700 ha. However, most reforestation projects used single tree species for instance teak, pine and eucalyptus for the production of timber. They are not so useful for the conservation of biodiversity

(Karimuna, 1995; Elliott *et al*., 1997). Karimuna (1995) suggested that a pine plantation can be used to stimulate the early stages of regeneration, but after that, the pines should be selectively thinned to allow other tree seedlings and saplings to grow naturally.

In 1994, for the first time, a wide range of native forest tree species began to be planted for forest restoration for conservation by both the government and private organizations, to celebrate the Golden Jubilee of His Majesty King Bhumibol Adulyadej (Hardwick, 1999). His Majesty recommended that these projects should plant native tree species (Green World Foundation, 1995). This encouraged a change of the reforestation policy. Native forest trees were recommended in the belief that they can promote biodiversity (Wightman, 1997). Unfortunately, the policy could not be implemented effectively, since there was lack of knowledge about how to grow and plant the seedlings of native tree species (Elliott *et al*., 1996).

Various forest restoration methods have been developed, for instance, the accelerated natural regeneration (ANR) (Jansen and Pfeifer, 1989), the framework species method (Goosem and Tucker, 1995), and the accelerated pioneer-climax series method (APCS) (Sôû, 2000).

Goosem and Tucker (1995) proposed that two major types of tropical rainforest restoration could be adopted in Australian systems: the framework species method (FSM), and the maximum species diversity method (MSDM). They reported that forest restoration using framework species was first developed in Queensland, Australia in the end of 1980. Twenty to thirty selected species were planted in degraded areas, which resulted in 80 woody species colonizing planted sites. The major advantages of this technique are 1) it needs only a single planting and 2) it is self-sustaining. However, the framework species method is suitable only for areas where native vegetation is located close by. In the maximum species diversity method, a larger percentage of species are from the mature phase and primary promoters are generally avoided. The major disadvantage is the slower growth rate of many mature phase forest species, which requires longer and more intensive post planting management.

Keenan *et al*. (1997) tested the hypothesis that tree plantations may catalyze regeneration of natural forest diversity. Their studies focused on *Pinus caribaea*, *Araucaria cunninghamaii, Flindersia brayleana* and *Toona ciliate* plantations ranging from 5 to 63 years plantations is Northern Australia. A total of 350 species, including 176 tree species, were found beneath the plantation. The distance from the rainforest to the plantation edge generally had little effect on the number of tree species. Between 80 and 90% of the tree species found in the plantations were primarily bird-dispersed.

In another study, conducted by Tucker and Murphy (1997) in seven-year-old restoration sites from the Wet Tropics North Queensland, 72 plant species were recruited. Most early successional species recruited in the study sites were zoochorous taxa. They also found that a variety of seedlings recruited in the restored sites were bird dispersed. The study also confirmed that restoration on abandoned lands attracts fauna species and providing suitable condition for native species to germinate.

The idea of accelerated natural regeneration or ANR was discussed firstly in the Philippines and has developed continually for the past 20 years but there have not been so many results from there. This idea is flexible, depending on limiting factors of succession in each area and overcoming these factors is the goal to restore biodiversity, and limiting factors in Philippines are forest fire and weed competition which interfere seedling and coppicing dispersion (Dalmacio, 1987). ANR methods include cutting or pressing the weeds around existing naturally established seedlings, protecting the area from fire and planting with desired species if necessary (Hardwick *et al*., 1997).

Hardwick *et al.* (1997) describes part of a 2-year project in northern Thailand about assisting natural regeneration processes in degraded seasonal evergreen forests and reported that seed germination of *Beilschmiedia* sp. was sharply reduced by lack of rainfall and the seedlings were highly susceptible to scorching by direct sunlight. Raising seedlings in nurseries and planting them out in degraded areas under the shade of existing herbaceous vegetation may be a suitable method to accelerate the regeneration. Seedling recruitment of *Prunus cerasoides* in the clearing was limited mainly by insufficient dispersal of its seeds into the cleared area. Under experimental conditions seeds germinated and seedlings established readily, so direct seed sowing in degraded areas may be appropriate. *Engelhardia spicata* seeds were widely dispersed by wind and weeds appeared to be a limiting factor. This barrier could be overcome by cutting back weeds (particularly grasses and ferns) or by shading them out with nursery trees.

Framework species should have these qualifications 1) fast growing and shade out weeds rapidly 2) edible and attractive fruits especially for birds and bats to increase seed dispersal to the planted area. Moreover, framework tree species must be easily propagated in the nursery. The height of healthy seedlings planted is usually about 50-60 cm (fast growing species may be 30 cm tall). They are be planted spaced about 1.6-1.8 m apart at the beginning of rainy season. Usually, the planted trees are weeded and given fertilizer in the first two rainy seasons after planting and the trees usually grow and shade out weeds efficiently. Framework tree species can re-establish basic ecosystem structure and function, whilst other aspects of ecosystem integrity return naturally. Biodiversity is restored by seed-dispersing wildlife attracted to the planted trees.

The major groups of framework species for northern Thailand are recommended by the Forest Restoration Research Unit (FORRU, 2000) were tree species in the families Moraceae (fig trees), Leguminosae and Fagaceae (oaks and chestnuts). Fig trees usually fruit readily and their figs are eaten by many species of birds. Legume trees can fix nitrogen in the soil, so these trees are particularly suitable for planting where soil degradation has occurred. Although the members of Fagaceae grow slowly, they develop dense crowns, shading out the weed efficiently and providing food sources for wildlife, as well as humans.

Nowadays, there is some evidence that that reforestation plays a key role in the long term of restoration of landscape functioning, as well as economic and social development. Reforestation can catalyse and induce succession of forest ecosystems using native species (Parrotta, 2000). In addition, target areas that are either close to intact forest or which retain an abundance of animals have a high chance for successful restoration, by accelerated biodiversity recovery in the first stages of succession (Parrotta, 2000).

Aide (2000), examining barriers to forest regeneration in an abandoned pasture in Puerto Rico, showed that the major factors were lack of soil seed bank, and seed rain input. Similarly, Richards (1996), Cubina and Aide (2001) and Florentine *et al*. (2003) pointed out that factors, which could delay or slow forest recovery were shortage of tree seeds, seed and seedling predation, drought, competition with established grasses/ weeds, exhaustion of soil nutrients, changes in soil physical properties and absence of soil mycorrhizae.

Direct seeding as an alternative method to tree planting

Most forest restoration projects involve planting nursery-raised tree seedlings, but this is the most labour-and capital intensive method of forest restoration. Seed collection, raising seedlings in a nursery, planting and maintaining planted saplings until they can establish and become independent all require substantial labour inputs (Hardwick *et al*., 2000). Furthermore, root deformities caused by seedlings outgrowing their containers and those caused by careless transplanting techniques can reduce sapling survival in the field (Zangkum, 1998).

The potential advantages of direct seeding over other plantation establishment techniques (i.e. planting of nursery-grown seedlings, wilding or rooted cuttings) include cost savings associated with nursery care and planting, as well as the possibility that trees established by this means may develop more naturally, and quickly, than would transplanted seedlings or cuttings (Engel and Parrotta, 2001). The significant disadvantages of direct seeding that can outweigh these advantages include low germination survival percentages, resulting in either inadequate plantation stocking and increased seed costs to compensate for poor germination and survival; poor early seedling growth relative to nursery-grown seedlings that receive daily care, and increased seedling mortality, associated with weed competition (or increased weeding costs to overcome this) in addition to increased susceptibility to poor weather condition (Evans, 1982). In addition, the major problem is that failure is more common than with tree planting, because of the vulnerability of very young seedlings to climatic extremes, diseases, grazing animals and insect attack (www.netc.net.au, 2004).

The Eden Project in Niger is recommending direct seeding as an appropriate method of establishing trees where water is scarce (Eden Foundation, 2000). It is claimed that nursery plants use precious irrigation water, whereas direct seeding, carried out prior to or during the rainy season does not need irrigation. They further maintain that plants established by direct seeding tend to produce an extensive root system, whereas the above ground shoots grow more slowly. In contrast seedlings raised in nurseries tend to produce large shoots and have to be irrigated or they will suffer high mortality, whereas plants established through direct seeding are more likely to be able to reach moisture remaining in the soil after rainy season (Ochsner, 2001). This was quantified in Senegal by Samba (1992) who sowed the seeds of *Faidherbia albida* at the same time as planting nursery-raised plants. Four months after sowing direct seeded plants were about twice as tall and had a mean dry root mass 25 times higher than that of the nursery-raised plants.

Steven (1991) stated that the results of direct seeding are affected by a number of factors including species, soil conditions, site preparation and techniques for seed germination. In addition, Garwood (1989) pointed out that seed destruction by animals also plays a vital role in reducing seed germination.

Thomson (1992) and Applegate *et al*. (1993) stated that the potential cost savings associated with direct seeding, particularly for species whose seeds are readily available and amenable to this method of establishment, could outweigh its disadvantages and offer a more economical means for re-establishing forest cover over large areas of degraded lands.

Direct seeding in different purposes

Direct seeding has often been reported in agro-forestry literature. For example, in Indonesia, maize was intercropped with the nitrogen-fixing *Leucaena leucocephala*. Maize yield was 14% higher (although not significant) when intercropped with *Leucaena* at a spacing of 1 m. *Leucaena* was smaller when intercropped with maize compared to monoculture, but the idea is that *Leucaena* is protected from livestock during the early phase and, when the maize is harvested, the *Leucaena* is ready to take over. Until the next planting season, *Leucaena* will increase soil nutrients and produce fodder and shade out weeds (Field, 1991). It also appears that direct seeding is particularly effective for agro-forestry in semi-arid environments like the Sahel (Ochsner, 2001).

In developed countries, direct seeding is often used when mine-spoils are being re-vegetated to control erosion in the short term and provide forest products in the long term. In the tropics, direct seeding on mine-spoils has only been reported from India and Australia, but the practice may be used in other places without having been reported in available literature (Ochsner, 2001). Mine spoils are a poor medium for establishing plant growth of any kind. As a growing medium, mine-spoils are characterized by being completely without organic material and hence also lacking a natural seed bank. In northern Australia, direct seeding of mine-spoils was applied using aerial seeding of a mixture of 30 native tree species and fertilizer (Foster and Dahl, 1990). In addition, herb seeds were added to the mixture on certain types of mine-spoils in order to provide ground cover.

In India, a field trial on coalmine-spoils investigating several species of trees, grasses and herbs found seedling emergence between 20 and 85% (Jha and Singh, 1993). In some situations, the concentration of plant-available heavy metals may be low enough to allow the direct establishment of commercially available plants onto tailings without resultant phytotoxicity. This is an attractive option, as direct seeding with agricultural seed mixtures is a very economical re-vegetation technique. Organic matter (such sewage sludge) would normally be applied as a thin surface covering to improve the physical structure of the substrate and to provide nutrients in a slow-release form to encourage sward establishment. Once established, legumes such as bird’s foot trefoil (*Lotus corniculatus*) and white clover (*Trifolium repens*) supply the sward with N by atmospheric fixation. A self-perpetuating system can therefore develop, although the application of P-rich fertilizer may be needed. This technique was also used to establish vegetation on abandoned metalliferous fluorspar dams in Derbyshire, UK (Jonhson *et al*., 1976).

Factors affecting seed germination

Seed germination is the activation of the metabolic machinery of the embryo, leading to the emergence of a new seedling (Poulsen and Stubsgaard, 1995). Generally, orthodox seeds are those that can be dried to a moisture level of 1-8% (Roberts, 1973) or 2-5% without losing viability over time and sometimes even down to 0.5% moisture content without a loss of viability and easily stored dried (Baskin and Baskin, 1998). They have a long period of dormancy until the rainy season begins when many species may germinate (Stubsgaard and Poulsen, 1995). In contrast, recalcitrant seeds are intolerant of dehydration and need to be sown immediately after collection or they may die (Roberts, 1973). The moisture content of seeds at the time of maturation is 30-70%, but it varies among species and even within the same species

(Baskin and Baskin, 1998). They lose viability if the moisture content drops below a certain critical level before germination occurs. In addition, they are also vulnerable to chilling injuries at low temperatures.

Seeds of some species do not germinate due to hard seed coats hindering intake of water (dormancy) (Baskin and Baskin, 1998). However, seed treatments can be applied to break dormancy and improve the seed coat permeability. The most convenient measure of dormancy is the median length of dormancy (MLD). This is defined as the number of days between seed sowing and germination of the median seed (Blakesley *et al*., 2002). For germination to be initiated, three conditions must be fulfilled: first, the seed must be viable; that is the embryo must be alive and capable of germination. Second, the seed must be subjected to appropriate environmental conditions, available water, proper temperature regimes, a supply of oxygen, and sometimes light and third, dormancy must be overcome (Stubsgaard and Poulsen, 1995). Internal processes, leading to removal of primary dormancy are collectively known as after-ripening and result from interactions of the environment with the specific primary dormancy condition. After-ripening requires a period of time and sometimes specific methods often seed handling. Even in the absence of primary dormancy and if the seeds are subjected to adverse environmental conditions, a secondary dormancy can develop and further delay germination (Hartmann *et al*., 1990; FORRU, 1998).

There are three stages of germination, 1) imbibition of water, synthesis of enzymes, cell elongation and emergence of the radicle; 2) digestion and translocation; fat, proteins, and carbohydrates, stored in the endosperm, cotyledons, perisperm, or female gametophyte, are digested to simpler chemical substances, which are translocated to the growing points of the embryo axis and 3) seedling growth; the growing point of the root (the radicle) emerges from the base of the embryo axis (Bradbeer, 1988). The growing point of the shoot (the plumule), is at the upper end of the embryo axis, above the cotyledons.

Many tropical tree species are difficult to germinate successfully under normal conditions. Seed dormancy results from interactions between several environmental factors and the hereditary properties of the plants. It may last for only a few days under proper seed handling and storage, or may continue indefinitely until some special requirements are fulfilled. Seed dormancy can be broken if the causes are known and all the necessary conditions for germination and plant growth are fully satisfied (Vongkamjan, 2002). Seed must be exposed to favorable environmental conditions before germinating, such as and adequate supply of water, adequate gas exchange and suitable temperatures and light. Temperature is one of the most important environmental factors affecting germination. It affects germination percentage, as well as rate of germination and its effects vary with different species (Piewluang and Liengsiri, 1989).

Several projects have tested various simple treatments to break dormancy and germinate the seeds of trees from Doi Suthep-Pui National Park (Hardwick and Elliott, 1992; Singpetch, 2001). In native forest tree species, seed dormancy is mostly caused by impermeability of the seed coat. Seeds of such species were classified into two groups: hard and soft seeds. Hard seeds refer to those seeds, which reduce moisture content to levels at maturation. Soft seeds are those which maintain a high level of moisture content, even after maturation. Hard seed coats caused dormancy in 3 different ways: 1) impermeability to water, 2) impermeability to oxygen or gases or 3) mechanical resistance to embryo growth. However, seed treatments can be applied to break dormancy and improve seed coat permeability , such as scarification, soaking in water, boiling or hot water and hot sand (Hardwick and Elliott, 1992; Sighpetch, 2001).

Problems with weeds

Studies conducted by Sun, Dickinson , and Bragg (1995) in the Atherton Tablelands, Australia, found that the survival and early growth of *Alphitonia petriei* through direct seeding are affected largely by weed competition and site conditions. The death of the germinated seedlings, a few weeks after germination in the plots where weeds remained undisturbed throughout the experiment, was most likely due to the effects of competition for light from the existing weeds. Results from both the glasshouse and field experiments also indicated that weed competition severely limited the early growth of *Alphitonia*. The height of *A. petriei* seedlings differed significantly ($P<0.01$) among treatments. Trees grown from both pelleted and non pelleted seeds in weed-free treatments showed a faster growth in height than other treatments. The results from glasshouse showed that *A. petriei* seedlings has the lowest biomass when grown with weeds in the soil medium. The relative biomass of *A. petriei* was largely suppressed by weeds.

Engel and Parrotta (2001) commented that competition with grasses affected mortality in *Chorisia speciosa*, one species established by direct seeding in degraded area in central São Paulo state, Brazil. While early seedling growth was usually rapid, it was highly sensitive to competition. Frequent weeding is therefore needed during the early growth phase.

Problems with predation

Reforestation by direct seeding and natural regeneration sometimes fails to produce well stocked stands. The reasons for this are diverse and can depend on the consumption of seeds and seedlings by other organisms. Seed predation can be severe and losses up to 100% have been reported (Crawley, 1992). Seed predation has identified as one of the biotic barriers to natural forest regeneration in abandoned Amazon pasture derived from rainforest (Nepstad *et al.*, 1991).

Hau (1997) studied about whether seed predation was a barrier to natural forest regeneration on degraded hillsides in Hong Kong. Removal of seeds of eight tree species in the winter of 1995 and 12 in 1996 at four Hong Kong hillside sites was monitored. Most seeds placed in the shrubland sites in 1996 were removed; 11 of 12 species were totally removed from one shrubland site within 60 days, while only one of 12 species was totally removed in one glassland site. Rats were found to be the major seed predator. They included *Niviventer fulvescens* and *Rattus rattus flavipectus*. The tough/thick coated seeds of *Choerospondias axillaris* and *Elaeocarpus sylvestris* had the lowest mean percentage removal. The vulnerability of a seed species to seed predators was not related to its size. Seeds with tough seed coats were less attractive to seed predators. The results of this study suggest that direct seeding may be possible if species with tough/thick coated seeds are used.

Various measures have been tried to reduce seed-predation, for example treating the seeds with repellants (Nolte and Barnett, 2000) and supplying alternative foods (Sullivan, 1979). These methods all rely on making the seeds less attractive, either in themselves by making them distasteful, or in relation to other, perhaps more abundant, food items or, finally, by an increase in predation risk while foraging. One might in addition make the seeds more difficult to detect, for example by covering them with a thin soil cover after seeding. This has been shown to be effective for oaks (Fuchs *et al*., 2000).

Garwood (1989) pointed out that seed destruction by animals also play vital roles in reducing seed germination. She stressed that further research is needed to develop techniques to reduce damage caused by seed predators. However, except for some studies conducted by Crouch and Radwan (1975) recommending seed coating and pelleting as a protector against seed predators, little is known about this technique in tropical situation.

In a study in northern Sweden, Nilson and Hjältén (2003) studied the effect of covering seeds with a thin layer of the substrate on which the seeds were sown immediately after seeding. This technique could decrease seed predation from 9.1 to 2.9% and total seed losses from 64-45%. More seeds, 40% compared to 27%, failed to germinate when covered. At the end of the first growing season, 15.4% of the initially covered seeds were presented as live seedlings compared to 9.2% of the seeds in the uncovered control treatment. The seedlings from the covered seeds were significantly larger than the uncovered treatment (22.97+-1.22 and 18.56+-1.97 respectively, $P < 0.05$), even after the second growing season. They concluded that covering seeds immediately after sowing is a cost-effective way to reduce seed-predation and increase seedling emergence.

The study of Woods and Elliott (2004) was designed based on the premise that scarifying seeds before sowing them in fields cleared of weeds would shorten seed dormancy to decrease the time available for seed predation to occur and that burial conceals seeds from potential predator. They found that ants were the only predators observed. Ants attacked the scarified, unburied seeds, although some of the control seeds (non-scarified) were also attacked. Manson and Stiles (1998) pointed out that the abundance of ants might be due to the absence of weeds, since ants are more prevalent in open habitats, whereas rodents generally forage in vegetation that provides protective cover.

Problem with microorganisms -symbiosis

Plant roots provide an ecological niche for many soil microorganisms. Frank coined the term "mycorrhiza" to describe the symbiotic association of plant roots and fungi in 1885. Mycorrhiza literally means "fungus root". It is very well documented now that mycorrhizal fungi improve growth of plants that are important in agriculture, horticulture and forestry. Mycorrhizal fungi provide a greater absorptive surface than root hairs and thus help in the absorption of relatively immobile ions in soil such as phosphate, copper and zinc. In addition, mycorrhizal plants were shown to have greater tolerance to toxic metals, to root pathogens, to drought, to high soil temperature, to saline soils, to adverse soil pH and to transplant shock than non-mycorrhizal plants (Mosse et al., 1981; Bagyaraj, 1990; Bagyaraj and Varma, 1995). In most tropical soils, available phosphorus is very low. Mycorrhizae constitute efficient root extension organs, involved in uptake and translocation of phosphate and other diffusion-limited nutrients. Thus, mycorrhizae play an important role in plant growth in the tropics (Munyanziza *et al*., 1997).

There are two main types of mycorrhiza in tropical ecosystem: arbuscular mycorrhiza fungi (AMF) and ectomycorrhiza. Surveys conducted in Africa, Asia and South and Central America have shown that the majority of plants of savanna woodlands and rainforests form AMF. Ectomycorrhizae occur mainly in tropical pines, Caesalpiniaceae are reported from both African rainforests and savanna woodlands (Härkönen et al., 1993). High ectomycorrhizal species diversity has been observed in Dipterocarpaceae in Southeast Asia (Smits, 1992).

The conversion of natural forests into industrial forest plantations, subsistence or cash crops brings about changes in which plant species, soil organic matter, soil nutrients, soil structure and soil fungi may be effected (Adejuwon and Ekanade, 1987). There is often a time gap between land clearing and subsequent cropping. This period is usually dry. The removal of host plants, the heat associated with slash burning, the subsequent increase in soil temperature, the soil disturbance and compaction associated with land clearing are detrimental to AMF propagules (Jasper *et al*., 1989). Miller and McGonigle (1992) noted that soil disturbance resulted in a reduction in mycorrhizal colonization and phosphorus absorption in maize plants.

Erosion is the primary force causing soil degradation in the tropics. Most plants in the humid tropics require AMF to gather nutrients, especially phosphorus (P), from land that is often already nutrient poor (O'Neil *et al*., 1991). AMF also improve soil aggregation, thereby allowing water and nutrients to move through (Burns and Davies, 1986). Thus, loss of AMF or changes in their communities can further decrease the fertility of these soils. Finally, evidence is growing that density and species composition and diversity of AMF may determine the productivity and diversity of plant communities (Bever, 1999).

Carpenter *et al*. (2001) assessed spore density and diversity of AMF along an *a priori* spatial gradient of soil degradation on an overgrazed Costa Rican farm and they found that the diversity and composition of AMF changed across the gradient although not in the same pattern as the chemical factors. Their results support previous studies showing that disturbance decreases sporotype diversity. The usual explanation is that at greater levels of disturbance or earlier stages of succession, few species can tolerate the difficult conditions or yet have dispersed into the area opened by the disturbance. After a period of time or at intermediate disturbance levels, many species can tolerate the conditions and have colonized the area, and resources are not yet limited. Over more time, resource limitation dominates and only the best competitors remain, reducing diversity again. Also, their result suggests that severe erosion may simply wash away AMF-spores were more abundant on the tops of the hummocks in the pasture than in the bottoms of the same trails that slope downhill. Therefore, erosion reduces the soil's potential to harbor mycorrhizal inoculum. This slows re-vegetation and continues the exposure of soil to erosion, a vicious cycle. Also, erosion removes or reduces the diversity of AMF, which reduces their soil stabilization effects and leads to increased erosion.

There is evidence that mycorrhizae help plants to thrive in arid condition by increasing the supply of nutrients to the plant, improving soil aggregation in eroded soils, and reducing hydric stress. In degraded zones the mycorrhizal component may disappear or, at least, be severely depleted and so it may be necessary to reinforce or replace it by appropriate inoculation (Boyle and Hellenbrand, 1991).

Caravaca *et al*. (2002) assessed the effectiveness of mycorrhizal inoculation and soil compost addition for enhancing reafforestation with *Olea europaea* subsp. *sylvestris* through changes in soil biological and physical parameters and they found that mycorrhizal inoculation increased soil aggregate stability (AS), indicating that soil biological agents play an important role in improving soil structure. The mycorrhizal fungus, used in the experiment, was *Glomus intraradices*. At the time of planting, the *G. intraradices*-inocutated seedlings had significantly higher percentages of root colonization (on average 62%) than the uninoculated plants (on average 0.4%). One year after planting, mycorrhizal inoculation improved *O. europaea* basal diameter growth with respect to the growth measured in the control soil by at least 38%. Finally, they concluded that both mycorrhizal inoculation and the addition of composted residue were very effective in improving soil quality and the performance of *O. europaea* seedlings under their experimental conditions.

As suggested by several authors, mycorrhizal fungi may improve the performance of seedlings either by stimulating water uptake (Roldán *et al*., 1996), by producing growth promoting substances or by increasing nutrients uptake (Roldán and Albaladejo, 1994).

Ochsner (2001) suggested that if the species used in direct seeding have not grown on the site previously, it is recommended to supply a small amount of soil with each seed. The soil can be collected from the place where the seed was harvested, or from a nearby site where the species grow. The application of soil is to ensure that symbiotic micro-organism like mycorrhiza or in the case of N-fixing trees rhizobium or frankia are applied to the sowing site and can provide better growth and survival of the future trees.

Other problems

The results from Sun *et al*. (1995) showed that compacted and eroded soils are inhospitable to the establishment of *A. petriei* seedlings. The soil restricted root penetration and lack of nutrients appeared to be the direct cause. Similar results have also been found with other tree species in temperate areas (Kerr and Evans, 1993) and on some shrub species in subtropical areas (Sun and Liddle, 1993). It is well documented that root growth in plants is restricted by increasing soil compaction (Materechera *et al*., 1991). Nadian *et al*. (1996) found that the total root length colonized was lower in highly compacted soil than in slightly compacted soil.

Other points to achieve succession of using direct seeding

Sun *et al*. (1995) concluded that, coupled with a suitable technique to break seed dormancy, *A. petriei* seed germination can be achieved with minimal effort, however, weed control and maintenance of nutrient levels are essential for success.

Engel and Parrotta (2001) suggested that what is required is a more systematic screening of potential species and their response to direct seeding under field conditions, and evaluations of costs associated with plantation establishment and aftercare relative to those of more commonly used planting stock such as nursery-grown seedlings. It is strongly recommended that future plantation establishment efforts by direct seeding should pay close attention to seed quality, using fresh seeds collected from several parent trees growing on sites where soils and climatic conditions are broadly similar to those being reforested, and that planting be carried out during periods of expected high rainfall.

Woods and Elliott (2004) suggested that seeds should be sown in the field immediately after fruit collection if possible, especially for recalcitrant seeds, so that seed storage is not needed or its duration is minimized. Further research is needed on proper seed storage and desiccation of orthodox seeds to ensure high seed viability for direct seeding projects. In order to minimize seed storage, species selected for direct seeding should fruit at the beginning of the rainy season when direct seeding is most likely to be successful.

Successes with direct seeding – literature case studies

Success of direct seeding of two species out of five species, *Enterolobium contorstisiliquum* and *Schizolobium parahyba*, in a study in São Paulo, Brazil depended on a suitable screening of direct seeded species. Percent seed germination of *E. contorstisiliquum* and *S. parahyba* were 19.2 and 23.7 respectively. Their height and stem basal diameters were 1.5 m and 4.1 cm for *E. contorstisiliquum* and 1.7 m and 4.6 cm for *S. parahyba*. They showed good seed germinations, seedling survival, and early growth rate, averaging 4.1-4.6 cm stem diameter and 1.5-1.7 m height growth during the first 2 years. These two species constituted 88-100% of the total stand density, which ranged from 1,050 to 1,790 stems ha^{-1} at 2 years. Both of them are members of Leguminosae. This family provides nitrogen to the soil by the bacteria strain in their root knots using nitrogen fixing cycle, so the seedlings could grow although in the degraded area that lack of nutrients. Furthermore, good site preparation; prior to planting, a post-emergence herbicide (glyphosate) was applied to all treatment and control plots to suppress grasses, is necessary for successful direct seeding application. The good maintenances can provide the seedlings more chance to survive, grow and outcome the weeds finally; during the first 2 years, additional spot applications of this herbicide were used, in addition to manual weeding as required around seedlings to ensure seedling survival and good early growth. In addition, ant traps containing a formicide (Myrex™, active ingredient sulfluoramide) were set up at selected spots within the plantations to reduce herbivory damage to seedlings were applied in this study, experimental plots at each site were fenced to provide protection against grazing, and fire lines established around the periphery of the fences enclosing each experiment area. They observed that the natural regeneration of native forest species originating from remnant forest in the general vicinity of their study sites was significantly greater within direct-seeded plots than in unplanted control plots that were protected from fire and other disturbances (Engel and Parrotta, 2001).

Failures with direct seeding – why did the studies fail?

Direct seeding with five early-successional Atlantic forest species was tested at three degraded sites in São Paulo, Brazil. Three of the five species, *Chorisia speciosa*, *Croton floribundus* and *Mimosa scabrella* had low initial survival and subsequent mortality rates. Their percent seed germination were 7.6, 0 and 1.3 respectively. There are several factors causing failure, firstly, sub-optimal seed quality may have been a problem, the seeds having been collected from parent trees in a variety of locations within the region that may or may not have been similar to study site conditions. Furthermore, in the case of *M. scabrella* seeds, despite fairly high germination percentages (70%) obtained in nursery tests, early seedling mortality in the nursery was very high, indicating that these seeds were of poor quality and probably more than 1 year old. A second factor was insufficient rainfall during the days immediately sowing: having broken seed dormancy by pre-treatment immediately prior to planting, this resulted in desiccation and mortality of germinating seeds. This effect was particularly marked in *M. scabrella*. A third factor that contributed to seedling mortality in *Chorisia*, but probably not the other species, was competition with grasses; while the early growth of this species is usually rapid, it is highly sensitive to competition at the seedling stage, and requires frequent weeding in its immediate vicinity during the early growth phase (Angel and Parrotta, 2001).

Seed predation is a major problem for direct seeding application in the tropics because there are plenty of predators. Various measures have been tried to reduce seed predation, for example treating the seeds with repellants, but sometimes treatments appeared to cause a reduction in the germination capacity. For example for the study on direct seeding of *Alphitonia petriei* in the wet tropical region of north-eastern Australia, seeds were coated with fertilizer, fungicide and insecticide before sowing. The unpelleted seeds had higher germination (50-60%) while the pelleted seeds had lower germination (10-20%). Theoretically, seeds have evolved mechanisms to recognize environmental cues, which enable them to confine their germination in particular periods and locations to give them a greater probability of seedling establishment and survival. Therefore, small changes in their environments can reduce germination (Sun *et al*., 1995).

Erythrina subumbrans was one of candidate in a study of direct seeding for forest restoration on abandoned agricultural land in northern Thailand. Seeds were attacked by ants and fungi both in the field and in the nursery. This species had lowest percent seed germination (<10%) comparing with *Lithocarpus elegans*, *Sapindus rarak* and *Spondias axillaris*. It was observed that seeds buried or covered by mulch were better able to escape seed predation by ants than those sown on exposed soil. Stored seeds failed to germinate in the nursery, although fresh seeds before storage achieved good germination results. In the field, however, a few seeds germinated in both burial and mulch treatments, with the burial treatment achieving significantly highest germination per cent (Woods and Elliott, 2004).

Summing up the reasons why direct seeding works or does not work.

Therefore, the main reason why direct seeding can be successful for implementing forest restoration projects is suitable screening of direct seeded species. These species should be suited to the site elevation. For example, *E. contorstisiliquum* and *S. parahyba* are two species which are direct seeded in São Paulo, Brazil. They are members of the Leguminosae, this family can provide nitrogen to the soil by the bacteria strain in their root knots using nitrogen fixing cycle, so the seedlings can grow although in the degraded area that lack of nutrients. In addition, good site preparation is necessary for successful direct seeding. Good maintenance can provide the seedlings higher chances of survival, grow and over-top the weeds. Furthermore, a good plan to take care of the plot is also necessary for direct seeding projects, such as in São Paulo, where experimental plots at each site were fenced to provide protection against grazing animals, and fire breaks established around the periphery of the fences enclosing each experiment area.

Many factors can affect direct seeding results; sub-optimal seed quality is the major reason why projects fail. Failure to germinate is probably because of differences in micro-climate between the natural tree habitat and the study site. In addition, poor quality seed might also give the low percent germination or result in weak seedlings. Aside from the seeds, the environment of the study site is very important, such as rainfall and the dominant weed species. Insufficient rainfall during the early stages of germination could lead to failure of direct seeding, with weeds over-topping the seedling at the beginning of their life span. Furthermore, seed predation is the other main problem for direct seeding projects. Several methods have been created to protect the seeds from predators, such as; coating seeds with fertilizer, fungicide and insecticide before sowing. However, pelleted seeds can have a lower germination percentage than unpelleted seeds in some cases. Some species are sensitive to slight changes in their environments; changes in moisture and temperature can result in unsuccessful germination (Engel and Parrotta, 2001).

Seed dispersal times vary greatly among species. For species that do not produce seed during or just before the optimal direct seeding month, seed storage becomes an important issue. Unsuitable storage conditions can greatly reduce subsequent germination.

Costs and benefits

Angel and Parrotta (2001) reported that the establishment and maintenance costs of direct seeding of five species in central São Paulo state, Brazil during the 2-year study period averaged $747-912 per hectare. Establishment costs constituted 63-68% of the total costs: seeds (\$182 ha^{-1}) and sowing activities (\$117-164 ha^{-1}) were the most costly operations. Maintenance costs (for manual weeding, herbicide and formicide applications) were \$137-155 ha^{-1} during the first year and \$137 ha^{-1} during the second year. These costs compare favorably with those for plantation establishment and maintenance at this site using nursery-grown seedlings of native tree species in other plantation treatments included in same project, which averaged

$1200-2500 ha^{-1} (unpublished data). Therefore, direct seeding in this project can reduce about 63% compared with the plantation using nursery-grown seedlings.

The studies from Sun and Dickinson (1996) indicated that, in comparison to the establishment of nursery grown seedlings (where labour inputs are high), direct seeding may reduce tree establishment cost by as much as 90%.

Identifying gaps in knowledge

Seed traits vary strongly across the tropical forest biome to cope with the variations in the distribution and amount of rainfall, light, temperature and soil nutrient regimes, and the intensity of predation and disturbance (Khurana and Singh, 2001). Seed dormancy can be broken if the causes are known and all the necessary conditions for germination and plant growth are fully satisfied (Vongkamjan, 2003). Direct seeding has often used because of low cost. Formerly, no one has developed a suitable systematic screening method for species selection for forest restoration projects. Therefore, it is very difficult to apply direct seeding in the field because, firstly different fruiting time (include the time for ripening), secondly different time of dormancy, and thirdly different ability for germination. In addition, an application direct seeding in the field is very difficult task. However, nobody has compared the result of direct seeding in the field with planting of raised-nursery seedling before. Nobody has adequately tested direct seeding as a viable method of forest restoration in northern Thailand, especially with the native forest tree species. Nobody has compared directly the performance of nursery-grown trees with direct seeded trees. In addition, no one has applied direct seeding to natural forest restoration with many species, rather than economic forestry with few species. Therefore, this study about appropriate tree species and techniques to apply in forest restoration is necessary to fill the gaps in knowledge that have been identified above.

CHAPTER 3

Methodology

3.1 Study sites description

This study was carried out in two locations with contrasting conditions; one nursery and field site were situated in the uplands and another nursery and field site were situated in the lowlands. In the highland area field plots were established near the village of Mae Sa Mai in Doi Suthep-Pui National Park , with nursery work being carried out a the park Headquarters. The lowland nursery was located just outside Chiang Mai City and with a field site at Ban Mae Ow (Lamphun).

3.1.1 Highland area

- **Field Plots**

Experimental plots were established near Ban Mae Sa Mai (an Hmong hill tribe community) in the north of Doi Suthep-Pui National Park. Trial plots were positioned along or immediately below the ridges of a degraded watershed area, 2-3 km from the village (18° 52'N, 98° 51'E), at 1,207-1,310 m above sea level. Originally, the study site had been covered with evergreen forest, cleared approximately 20 years previously, to provide land for cultivation of cabbages, corn, potatoes and other cash crops. The abandoned fields were dominated by herbaceous weeds such as *Pteridium aquilinum* (L.) Kuhn (Dennstaedtiaceae), *Bidens pilosa* L. var. *minor* (Bl.) Sherf, *Ageratum conyzoid*es L., *Eupatorium odoratum* L. and *E. adenophorum* Spreng. (all Compositae), *Commelina diffusa* Burm. F. (Commelinaceae) and grasses e.g. *Phragmites vallatoria* (Pluk. ex L.) Veldk., *Imperata cylindrica* (L.) P. Beauv. var. *major* (Nees) C.E. Hubb. ex Hubb. & Vaugh. and *Thysanolaena latifolia* (Roxb. ex Horn.) Honda (both Gramineae). The area has two main seasons: the wet season (May - October) and the dry season (mean monthly rainfall below 100 mm, November - April). The dry season is subdivided into the cool-dry season (November to January) and the hot- dry season (February to April) (Figure 1).

- **Nursery**

Germination experiements were conducted at FORRU’s research nursery in the vicinity of Doi Suthep-Pui National Park Headquarters (18˚ 51´ N, latitude and 98˚ 54´ E, longitude) at about 1000 m elevation in a transitional zone between mixed evergreen-deciduous forest and evergreen forest.

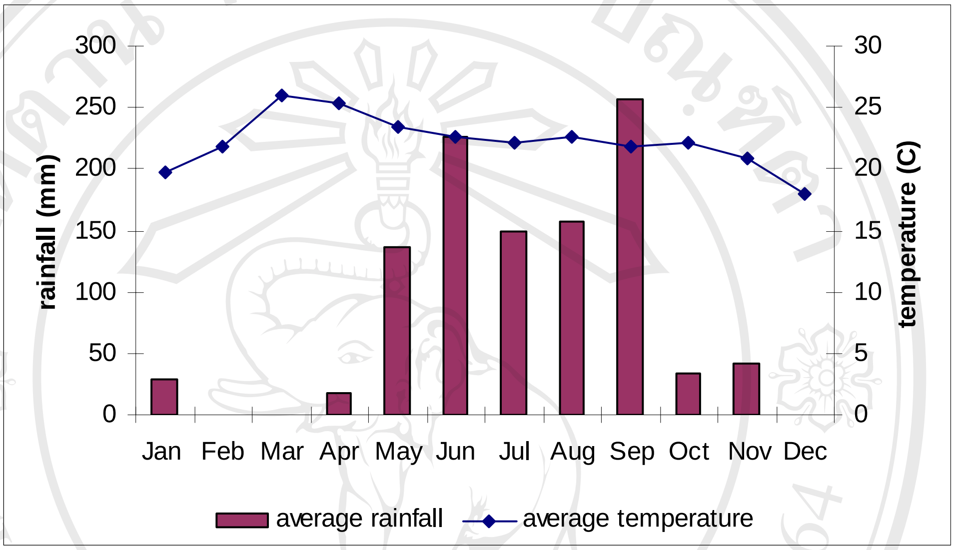


Figure 1. Average temperature and rainfall at Royal Project Centre of Ban Mae Sa Mai (2004) (880 m elevation, about 4 km distance from the study plots)

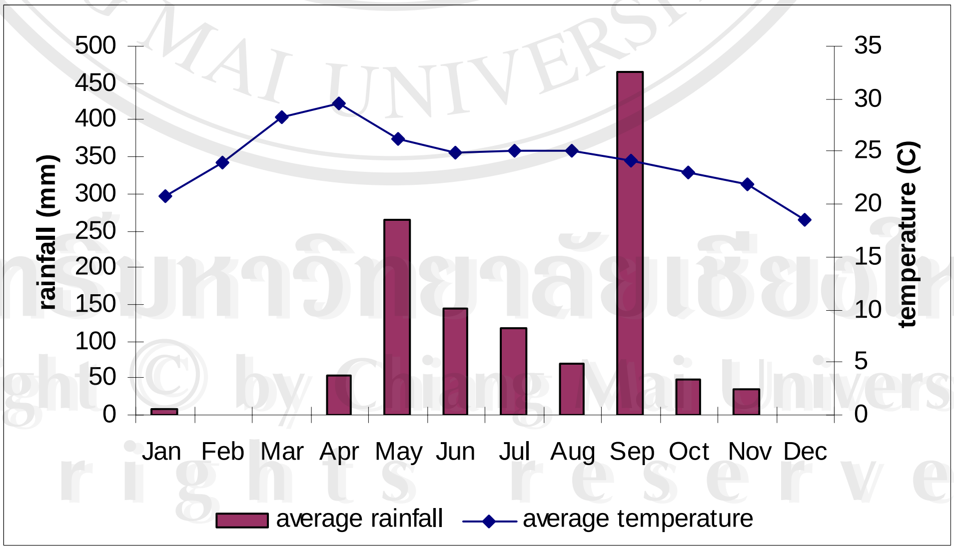


Figure 2. Average temperature and rainfall at Pa Dang plantation of Mae Ow Watershed Development Project center, under Royal Initiatives in Lamphun (2004) (about 20 km from the study plot)

3.1.2 Lowland area

- **Fied Plots**

Field trials were established near Ban Mae Ow, which is located in Mae Ow Watershed Development Project, under the Royal Initiatives in Lamphun. The soil is very poor, containing scattered rocks and sparse leaf litters covers the ground. Originally, the area had been logged for at least 20 years previously and the area had experienced annual frequent burning in the dry season. The trials were positioned between secondary forest and longan orchards (18˚ 22´ N, latitude and 98˚ 50´ E, longitude), at 340 elevation, in a flat area. Grasses dominate the ground flora at this site including *Arundinella setosa* Trin. var. *setosa*, *Heteropogon contortus* (L.) P. Beauv. ex Roem. & Schult. and *Apluda mutica* L. (all in Gramineae). Other species prominent in the ground include *Sericocalyx glaucescens* (Nees) Brem (Acanthaceae). The area was dominated by stunted trees such as *Shorea obtusa* Wall. ex Bl. (Dipterocarpaceae), *Xylia xylocarpa* (Roxb.) Taub. var. *kerrii* (Craib & Hutch.) Niels. (Leguminosae, Mimosoideae), *Terminalia alata* Hey. ex Roth (Combretaceae), *Xantolis cambodiana* (Pierre ex Dub.) Roy. (Sapataceae), *Buchanania lanzan* Spreng. (Anacardiaceae). The site supported approximately 250 stunted trees or live coppicing tree stumps per rai.

- **Nursery**

Nursery germination trial were carried out at FORRU’s lowland research nursery located in U-mong sub-district of Chiang Mai (18˚ 46´ N, latitude and 98˚ 56´ E, longitude) at about 380 m elevation.

3.2 Species selection

The tree species selected for this study flowered from the beginning of May until late of June (unpublished data from FORRU). Tree species selected for study in the highlands were *Aquilaria crassna* Pierre ex Lec. (Thymelaceae), *Balakata baccata* (Roxb.) Esser. (Euphorbiaceae), *Carallia brachiata* (Lour.) Merr. (Rhizophoraceae), *Eugenia fruticosa* DC. (Myrtaceae), *Sarcosperma arboreum* Bth. (Sapotaceae) and *Spondias axillaris* Roxb (Anacardiaceae). Those selected for testing at the lowland site included *Afzelia xylocarpa* (Kurz) Craib (Leguminosae, Caesalpinioideae), *Artocarpus* *lakoocha* Roxb. (Moraceae), *Casearia grewiifolia* Vent. var. *grewiifolia* (Flacourtiaceae), *Eugenia cumini* (L.) Druce (Myrtaceae), *Schleichera oleosa* (Lour.) Oken (Sapindaceae) and *Trewia nudiflora* L. (Euphorbiaceae).

Table 1. Flowering and fruiting months of the species studied (modified from Vegetation and vascular flora of Doi Suthep-Pui National Park, northern Thailand, Maxwell and Elliott, 2001)

Species	Habitat	Elevation	Flower month	Fruit month
Aquilaria crassna	egf	1000-1100	mr-ap	jn-jl
Balakata baccata	streams in	400-1350	fb-ag	ap-sp(dc)
Carallia brachiata	mxf egf	425-1685	dc-fb	(mr-ap) my-jn
Eugenia fruticosa	eg/pine dof bb/df	350-1525	mr-ap	my-jl
Sarcosperma arboreum	mxf egf	650-1400	dc-fb	ap-jn
Spondias axillaris	egf mxf eg/pine	700-1600	ja-mr	mr-ag
Afzelia xylocarpa	bb/df	350-500	mr-ap	jn-fb
Artocarpus lakoocha	dof bb/df	550-1500	fb-ap	mr-my
Casearia grewiifolia	sg	350-500	ap	jn-jl
Eugenia cumini	dof bb/df	375-650	mr-ap	jn-jl
Schleichera oleosa	bb/df	350-600	mr-my	my-jl
Trewia nudiflora	bb/df streams	550-1050	(nv) fb-ap	jl-nv

Note:	**Habitat**	bb/df	degraded teak & bamboo +deciduous forest
		egf	primary evergreen forest
		eg/bb	evergreen forest with bamboo
		eg/pine	evergreen forest with pine
		dof	deciduous dipterocarp-oak seasonal forest
		mxf	mixed evergreen + deciduous, seasonal forest
		sg	secondary forest
	Month	ja	January
		fb	February
		mr	March
		ap	April
		my	May
		jn	June
		jl	July
		ag	August
		sp	September
		oc	October
		nv	November
		dc	December

3.3 Seed collection

Seeds of each species were collected from Doi Suthep-Pui National Park, Chiang Mai University, Mae Hia sub-district and Sa Moeng district in Chiang Mai and Mae Ow sub-district in Lamphun at elevations ranging from 300 to 1,600 m. *A. crassna*, *C. grewiaefolia* and *S. oleosa* were collected by cutting down small branches with a tree pruning pole, whist those of nine species were collected from the ground. Fruits were collected only when the seeds within were properly developed and mature. Good seed tree were selected, avoiding those that appeared diseased or generally unhealthy. The species selected for this study are expected to be fruiting from May till June because this time is the beginning of the rainy season, which is the optimum time for direct seeding. No seed storage was necessary. Species fruiting at that time should have an ability to germinate quickly after sowing in order to take advantage of rainy season. The collection and sowing date in the nursery and field are presented in the table 2.

Table 2. Collection and sowing date in nursery and field

Species	Collection month	Collection date	Sowing date (nursery)	Sowing date (field)
Aquilaria crassna	June	29 June 2004	14 July 2004	2 July 2004
Balakata baccata	June	24 June 2004	14 July 2004	2 July 2004
Carallia brachiata	June	3 June 2004	14 July 2004	2 July 2004
Eugenia fruticosa	June	28 June 2004	14 July 2004	2 July 2004
Sarcosperma arboreum	June	3 June 2004	14 July 2004	2 July 2004
Spondias axillaris	June	28 June 2004	14 June 2004	2 July 2004
Afzelia xylocarpa	June	25 June 2004	14 July 2004	11 July 2004
Artocarpus lakoocha	June	7 June 2004	14 July 2004	11 July 2004
Casearia grewiifolia	June	27 June 2004	14 July 2004	11 July 2004
Eugenia cumini	June	24 June 2004	14 July 2004	11 July 2004
Schleichera oleosa	June	24 June 2004	14 July 2004	11 July 2004
Trewia nudiflora	June	25 June 2004	14 July 2004	11 July 2004

3.4 Seed treatments

This study used two methods to break seed dormancy accelerate seed germination and thus reduce the amount of time available for seed predation: i) soaking in water (48 hrs) and ii) scarification. These techniques were selected because they shown to be popular methods to break seed dormancy that had been suggested from FORRUs' nursery staffs. For the soaking treatment, seeds were soaked in the water for 48 hrs and sown immediately into the plastic trays. For the scarification treatment the seed coats were cracked or nicked with a sharp knife, a hammer or vice, depending on the structure of the seed. Soaking was used for all of the six species tested in the highland area; including *A. lakoocha*, *C. grewiifolia* and *E. cumini* for lowland area also. Differently, scarification was applied for *A. xylocarpa*, *S. oleosa* and *T. nudiflora*, all of them have more or less hard and thick seed coat similarly.

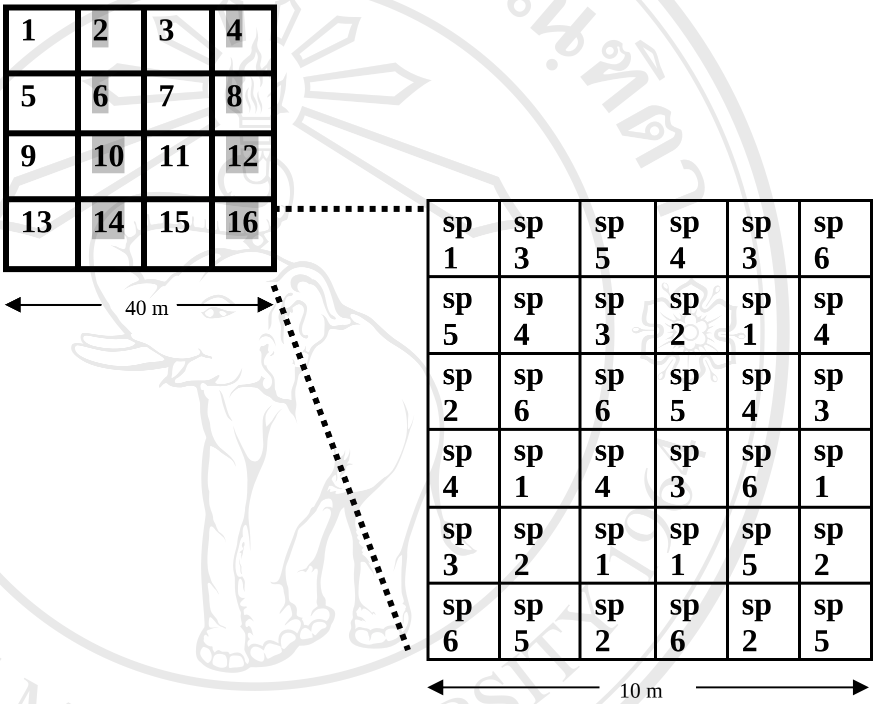
3.5 Study of germination

3.5.1 Germination trials in the nursery

For each species, 3 replicates of 33 seeds were sown in plastic trays, for each experimental treatment (soaking in the water for 48 hours and scarification) and an additional 100 seeds as a control. Seeds in the treatment group received the treatment so far popularly known to test seed germination obtained by the Forest Restoration Research Unit (FORRU). Seed germination was monitored every week for 4 months and seedlings were transferred to plastic bags once they had developed at least one pair of fully expanded true leaves.

3.5.2 Germination trials in the field

A total of 192 seeds were sown into small field plots (10 x 10 m^2) situated on degraded forest land to test their germination (control). Four seeds were sown in each small planting hole, with 6 holes forming one row and six rows in each subplot, replicated 8 times in each forest type and weeding was carried out every 2 months in four subplots. Further samples of 192 seeds of each species were subjected to a management regime to determine the effectiveness of the regime in accelerating or increasing germination. The management regime combined two steps which should improve germination success: i) seed treatment to accelerate germination (the same treatment as applied in the nursery and; ii) application of 500 g of original forest soil collected from near the parent tree (to ensure infection of the seedling with essential beneficial microbial symbionts). In addition for half of the seedlings, weed control was carried out every 2 months in the four subplots marked below by hand. In the other plots, no weeding was done for comparison. Seed germination was checked every week for 4 months.



1	2	3	4
5	6	7	8
9	10	11	12
13	14	15	16

sp 1	sp 3	sp 5	sp 4	sp 3	sp 6
sp 5	sp 4	sp 3	sp 2	sp 1	sp 4
sp 2	sp 6	sp 6	sp 5	sp 4	sp 3
sp 4	sp 1	sp 4	sp 3	sp 6	sp 1
sp 3	sp 2	sp 1	sp 1	sp 5	sp 2
sp 6	sp 5	sp 2	sp 6	sp 2	sp 5

Figure 3. Diagram of experimental plot in highland area (Ban Mae Sa Mai)

Eight blocks (1 to 8) had the management applied (seed treatment and original soil) and eight blocks (marked in grey) had weed control applied every 2 months.

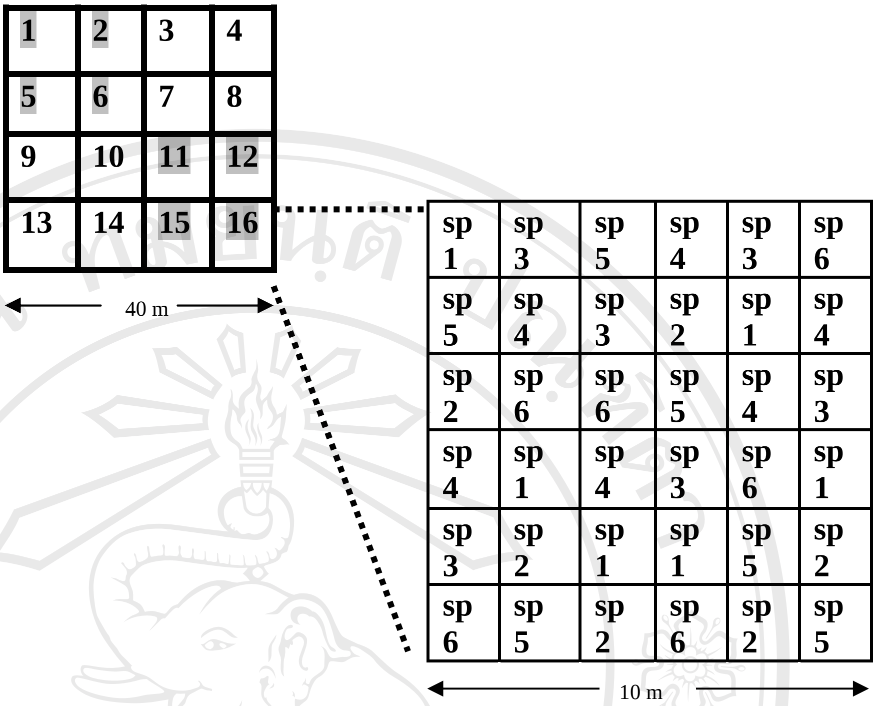


Figure 4. Diagram of experimental plot in lowland area (Ban Mae Ow)

Block 1, 3, 5, 7, 9, 11, 13 and 15 had the management regime applied (seed treatment and original soil), whilst eight blocks (marked in grey) had weed control applied every two months.

3.6 Study of growth

3.6.1 Seedling performance in the first year

For each seedling germinated in both in the nursery and in the field (both highland and lowland species); height, RCD (root collar diameter) and health score (0 = dead to 3 = perfect health) were recorded every month for 8 months. Then seedlings from the nursery were transplanted to nearby the surviving seedlings in the field one year after sowing.

3.6.2 Seedling performance in the second year

Comparison of seedling growth in the second year made use of an experiment already established the previous year. Seedling of six species *Gmelina arborea* Roxb. (Verbenaceae), *Melia toosendan* Sieb. & Zucc. (Meliaceae), *Oroxylum indicum* (L.) Kurz (Bignoniaceae), *Prunus cerasoides* D. Don (Rosaceae), *Sarcosperma arboreum* Bth. (Sapotaceae) and *Spondias axillaris* Roxb (Anacardiaceae), had been grown at the Ban Mae Sa Mai and FORRU nurseries during the rainy season of 2003 and a direct seeding plot already established at Ban Mae Sa Mai. In this study, therefore, seedlings that had already grown in the nursery for 1 year were transplanted next to those that had been germinated in the field plot. In the field height, RCD (root collar diameter) and health score (0-3) were recorded every month from October 2003 till June 2004. Then in July 2004, the seedlings grown in the nursery were transplanted into the field to compare with those germinated in the field, species by species. In addition, the surviving seedlings were monitored (height, RCD, canopy width) 2 weeks after planting (July 2004), the end of the first rainy season (November 2004) and 2 years after planting (July 2005).

3.7 Data analysis

The median length of dormancy (MLD) and per cent germination at the end of the germination trial were calculated. A two-way ANOVA was performed to detect any significant differences in germination percentages and MLDs between nursery and field germinated seeds and to determine the effects of the seed pre-treatments and weed control. A two-way ANOVA was performed to detect significant differences in growth performance of surviving seedlings between nursery and field conditions and comparing the effects of seed pre-treatments (application of original forest soil), and weed control (in the field only). The chi-squared test was used to analyse differences in survival per cent.

Student’s t-test (Paired Two Sample for Means) was performed to compare growth performance (RCD, height and canopy width) between raised-nursery and direct seeded seedlings one year after sowing in the field and to compare relative growth rates of RCD and height two years after sowing for each species. Similarly, survival per cent was tested by using Chi-Squared.

CHAPTER 4

Results

Effects of seed pre-treatments on dormancy and germination

The idea behind pre-treating the seeds was to shorten MLD to reduce the time that seeds are vulnerable to seed predators. In the field, seed pre-treatments failed to reduce MLD of all species tested, whilst in the nursery, seed pre-treatment significantly shortened MLD of only one species, *S. oleosa* ($p<0.05$). A secondary consideration was to use pre-treatments to maximize germination per cent. In the field, pre-treatment significantly increased germination only for one species (*A. xylocarpa*, $p<0.05$) whereas in the nursery it actually reduced per cent germination significantly for 4 species (*A. crassna*, *S. arboreum*, *A. lakoocha* and *C. grewiifolia*, $p<0.05$).A summary of effects of seed pre-treatments on dormancy and germination is presented in Table 3.

Soaking in water significantly reduced the final germination per cent of *A. crassna* ($p<0.05$) in the nursery but had no effect on MLD ($p<0.05$). In the field, germination per cent reached 47% which is considered acceptable for practicable direct seeding (Figure 5).

Soaking had no effect on the final germination per cent of *B. baccata* in the nursery and in the field ($p<0.05$). It also had no effect on MLD, but MLD was significantly shortened in the field and mean MLD of 29 days compared with the nursery (mean of 87 days) ($p<0.05$). Therefore, with 50% germination and MLD <30 days, this species is considered appropriate for direct seeding application (Figure 6).

C. brachiata seeds did not germinate in the nursery at all. In the field only the treated seeds (soaking) germinated, reaching 9% final germination per cent with a mean MLD of 52 days (Figure 7).

Soaking in water had no effect on the final germination per cent or MLD of *E. fruticosa* both in the nursery and in the field ($p<0.05$) (ranging from 70 to 90 per cent). This is considered to be a high percentage for practicable direct seeding. However, field conditions did significantly lengthen MLD (from 10 days in the nursery to 30 in the field) ($p<0.05$), although, at less than 40 days, this is still acceptable (Figure 8).

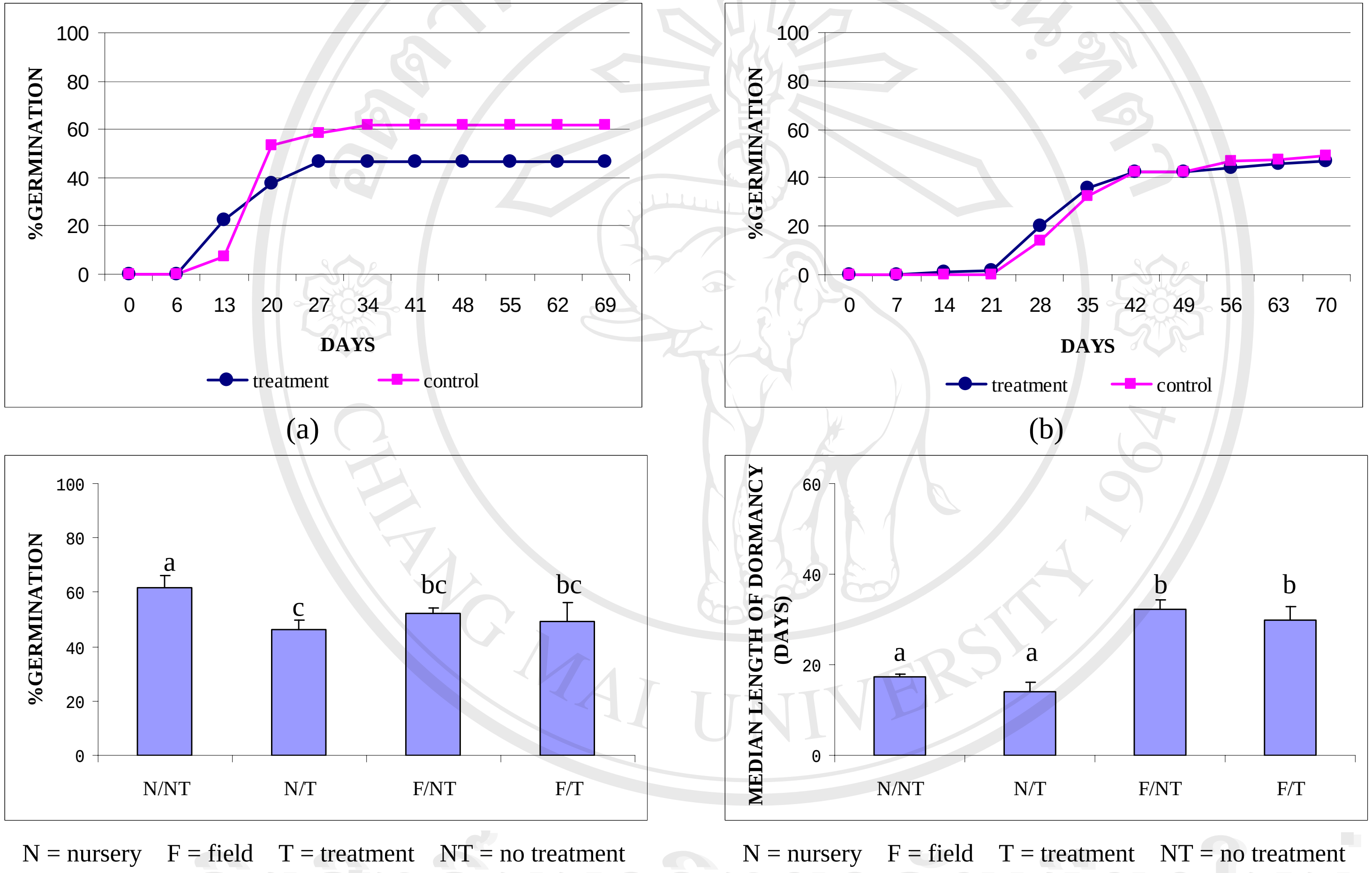
For *S. arboreum*, significantly the highest per cent of germination was obtained in the nursery (67%) with no pre-treatment applied ($p<0.05$). Soaking in water reduced the final germination per cent in the nursery but had no effect in the field ($p<0.05$). However, MLD was significantly lengthened in the field compared with the nursery (56 days compared with 35 days in the nursery) to less than 60 days which is marginally acceptable but soaking in water had no effect ($p<0.05$) (Figure 9).

S. axillaris did not germinate in the nursery and achieved a germination per cent of only 22 in the field. The treatment (soaking) had no effect on both germination per cent and MLD in the field ($p<0.05$) (Figure 10).

Table 3. Summary of effects of seed pre-treatments on dormancy and germination

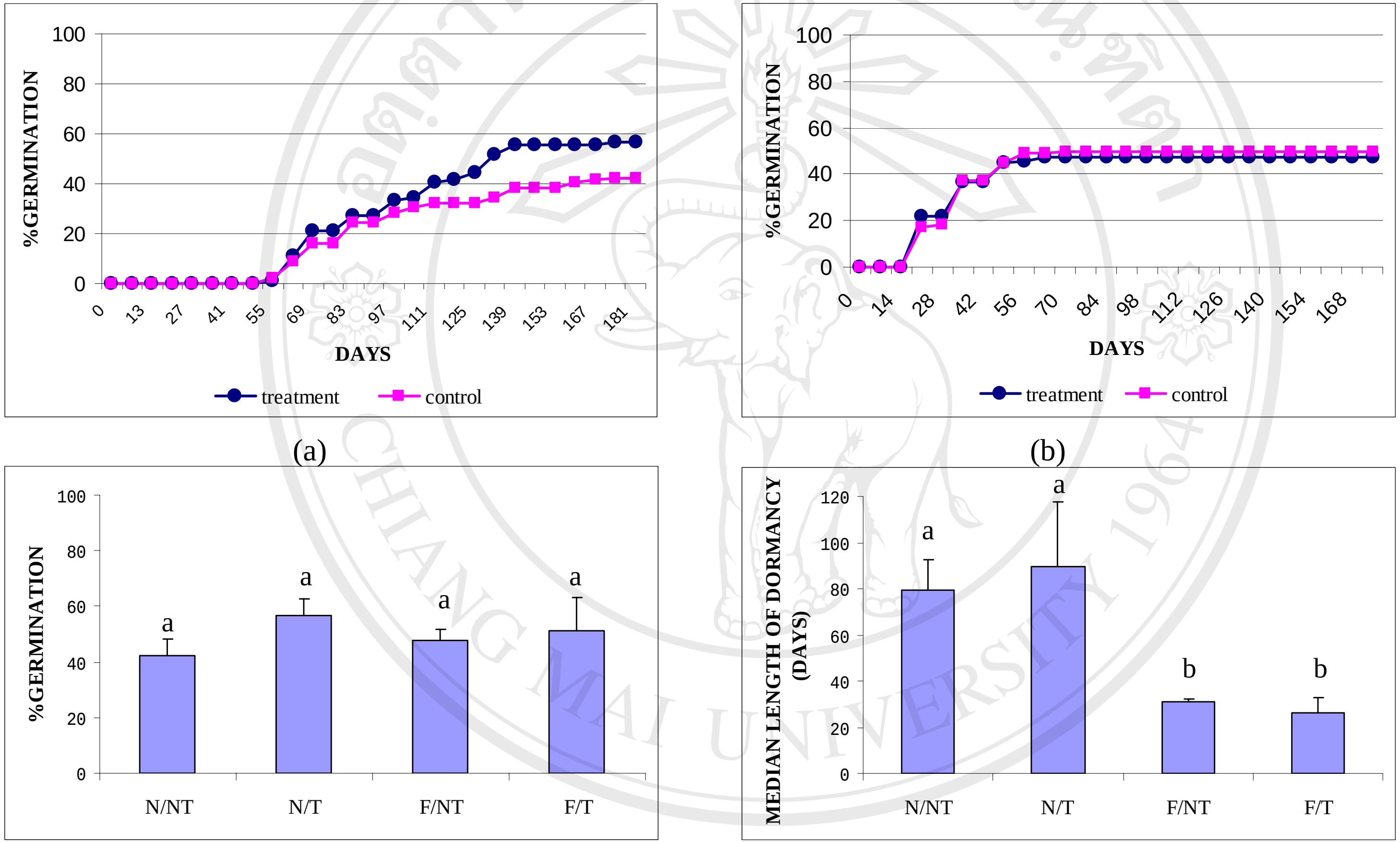
Species	Nursery condition		Field condition		Overall suitable characters for direct seeding	
	% germination	MLD	% germination	MLD	Nursery condition	Field condition
A. crassna	Negative[1]	NE	NE	NE	LM[7]	
B. baccata	NE[5]	NE	NE	NE		LM
C. brachiata	NG[6]	NG	No data to compare	No data to compare		HG[8]
E. fruticosa	NE	NE	NE	NE	LM	
S. arboreum	Negative	NE	NE	NE	LM	
S. axillaris	NG	NG	NE	NE		HG
A. xylocarpa	NE	NE	Positive[2]	NE		HG
A. lakoocha	Negative	Increased[3]	NG	NG	HG	
C. grewiifolia	Negative	NE	NG	NG	HG	
E. cumini	NE	NE	NG	NG	HG	
S. oleosa	NE	Reduced[4]	NE	NE	LM	HG
T. nudiflora	NE	NE	NE	NE		LM

[1] Negative = seed pre-treatment caused lower germination per cent, [2] Positive = seed pre-treatment caused higher germination per cent,
[3] Increased = seed pre-treatment increased MLD, [4] Reduced = seed pre-treatment reduced MLD, [5] NE = no effect from seed pre-treatment,
[6] NG = no germination, [7] LM = lower MLD, [8] HG = higher germination



(a) (b) (c) (d)

Figure 5. Germination per cent and MLD of *A. crassna* (a) germination per cent in the nursery (b) germination per cent in the field (c) final germination per cent and (d) MLD



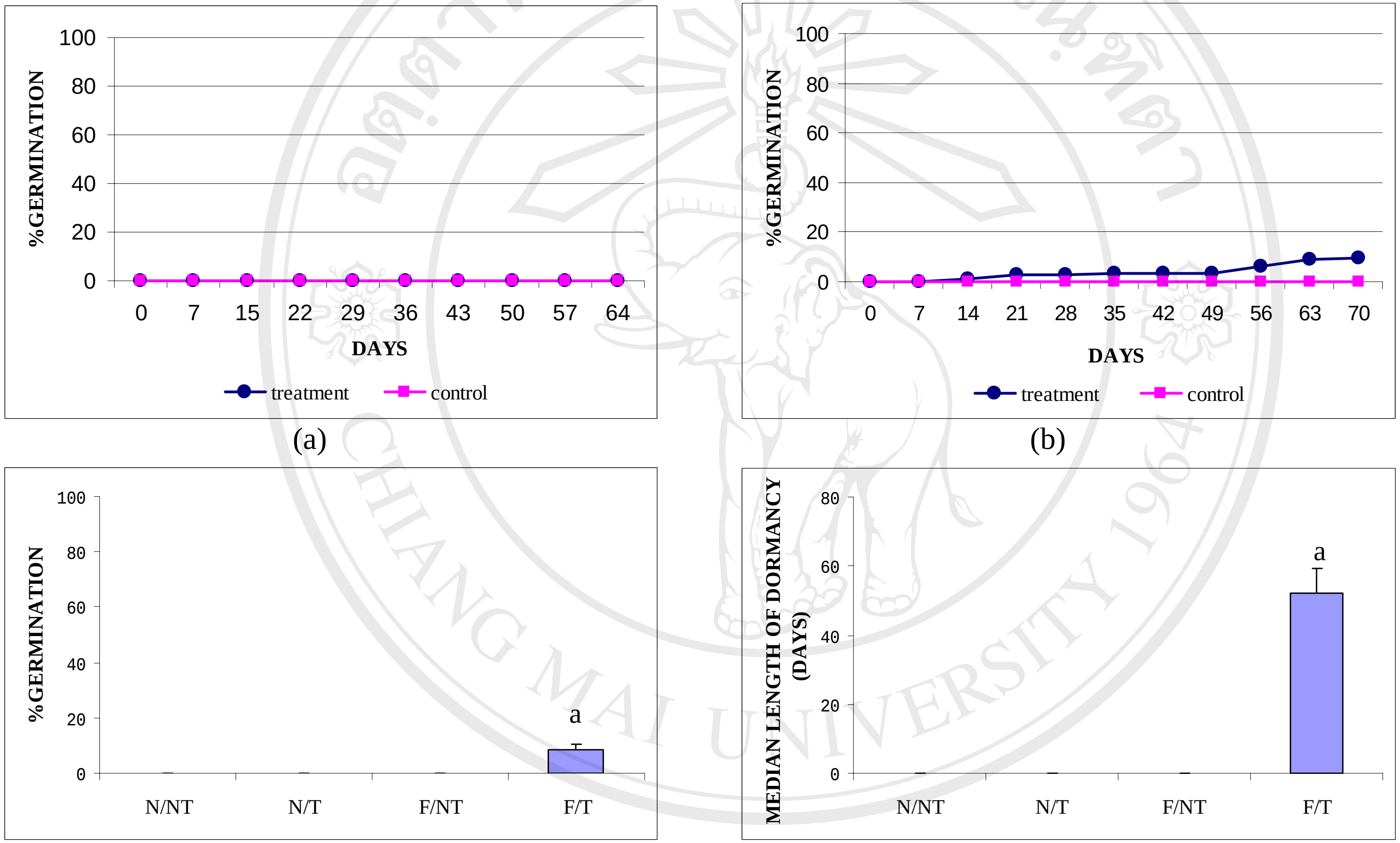
(a) (b)

N = nursery F = field T = treatment NT = no treatment

N = nursery F = field T = treatment NT = no treatment

(c) (d)

Figure 6. Germination per cent and MLD of *B. baccata* (a) germination per cent in the nursery (b) germination per cent in the field (c) final germination per cent and (d) MLD



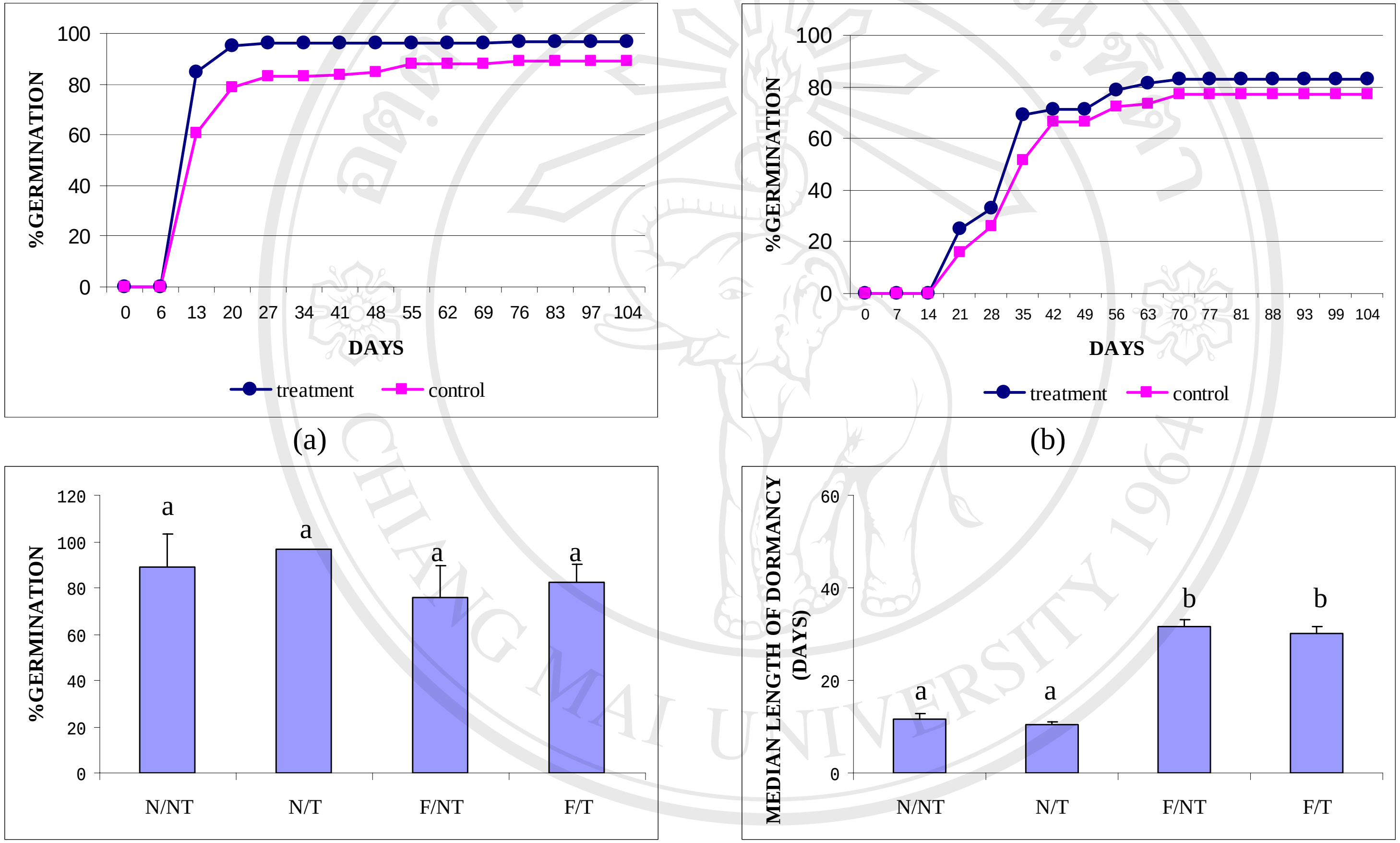
(a) (b)

N = nursery F = field T = treatment NT = no treatment

N = nursery F = field T = treatment NT = no treatment

(c) (d)

Figure 7. Germination per cent and MLD of *C. brachiata* (a) germination per cent in the nursery (b) germination per cent in the field (c) final germination per cent and (d) MLD



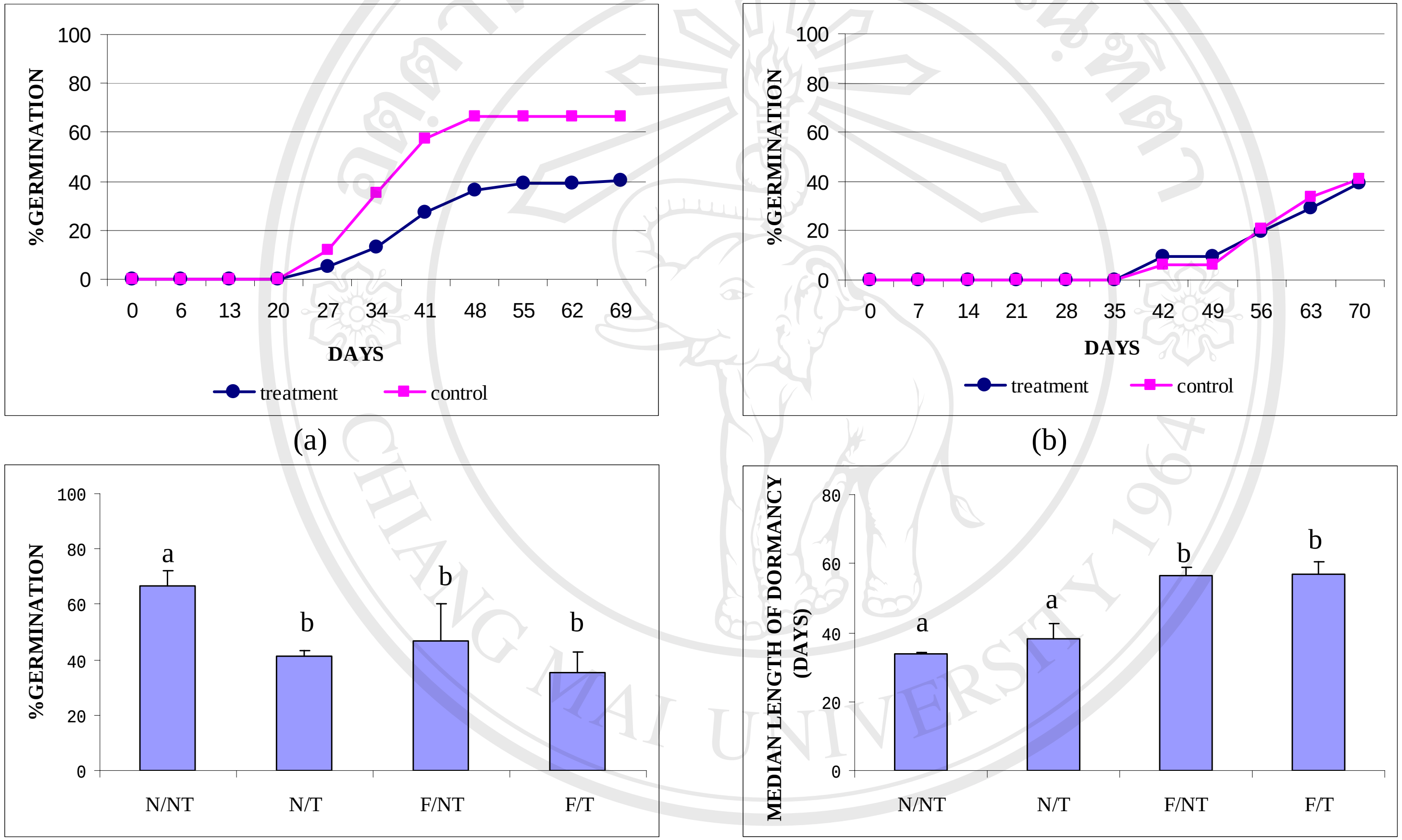
(a) (b)

N = nursery F = field T = treatment NT = no treatment

N = nursery F = field T = treatment NT = no treatment

(c) (d)

Figure 8. Germination per cent and MLD of *E. fruticosa* (a) germination per cent in the nursery (b) germination per cent in the field (c) final germination per cent and (d) MLD

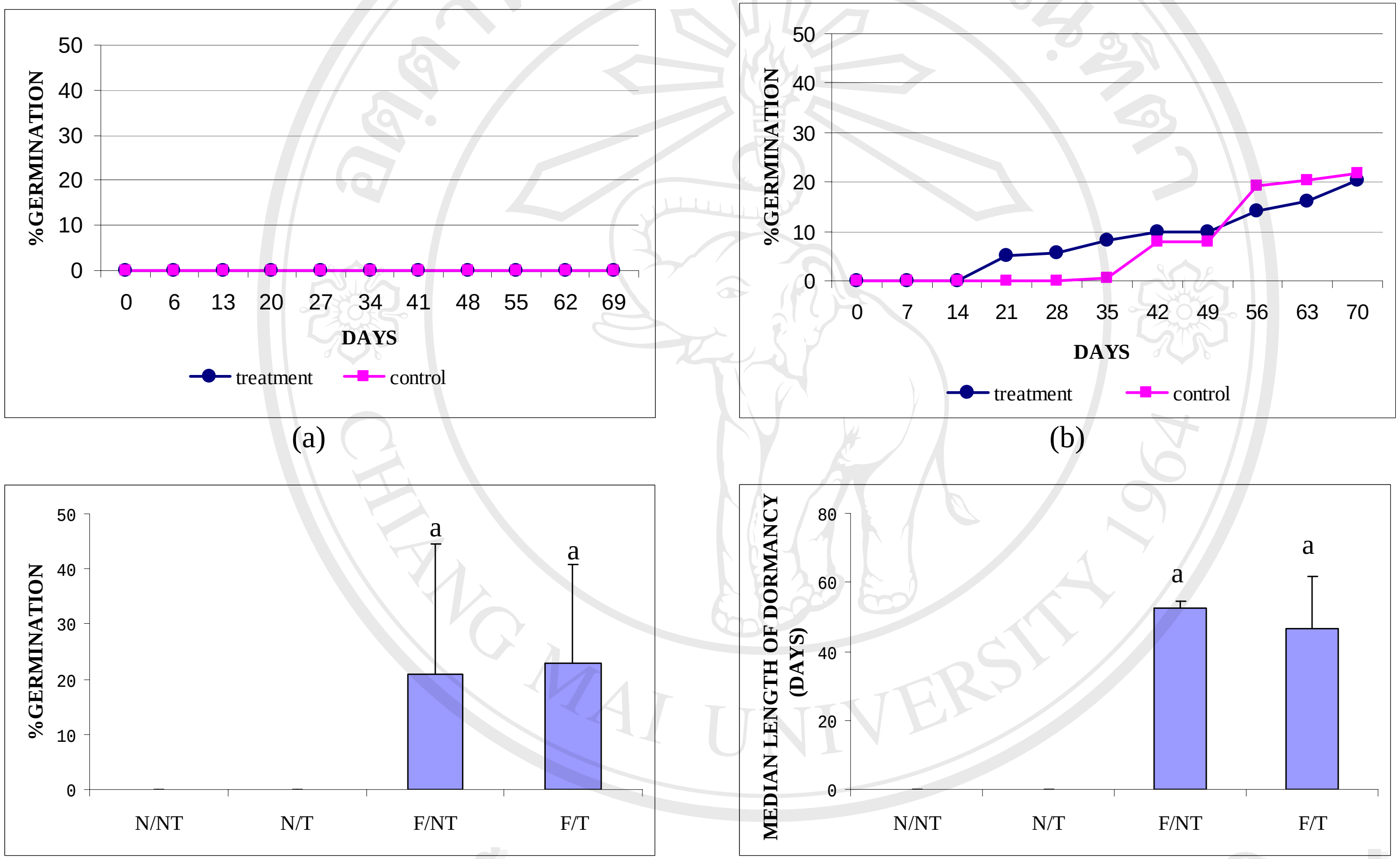


(a) (b)

N = nursery F = field T = treatment NT = no treatment N = nursery F = field T = treatment NT = no treatment

(c) (d)

Figure 9. Germination per cent and MLD of *S. arboreum* (a) germination per cent in the nursery (b) germination per cent in the field (c) final germination per cent and (d) MLD



(a) (b)

N = nursery F = field T = treatment NT = no treatment

N = nursery F = field T = treatment NT = no treatment

(c) (d)

Figure 10. Germination per cent and MLD of *S. axillaris* (a) germination per cent in the nursery (b) germination per cent in the field (c) final germination per cent (d) MLD

The final germination per cent of *A. xylocarpa* in the field was significantly increased by scarification ($p<0.05$) but this treatment had no effect in the nursery. MLD in both the nursery and the field was not affected by pre-treatment application ($p<0.05$). Their lengths were 27 to 32 days (Figure 11).

A. lakoocha did not germinate at all in the field. Soaking in water significantly reduced the final germination per cent and lengthened MLD in the nursery ($p<0.05$) (Figure 12).

Similarly, *C. grewiifolia* did not germinate in the field. Soaking in water significantly reduced the final per cent of germination in the nursery but had no effect on MLD ($p<0.05$) (Figure 13).

The final germination per cent of *E. cumini* was very high (85-95%) for both control and soaked seeds. The treatment had no effect the final germination per cent and MLD ($p<0.05$) (Figure 14). However, this species did not germinate at all in the field.

Field conditions significantly increased final germination per cent and lengthened MLD of *S. oleosa* ($p<0.05$). Scarification had no effect on the final germination per cent in both the nursery and field condition but it significantly reduced the MLD in the nursery ($p<0.05$) (Figure 15).

Scarification had no effect on the final germination per cent and MLD of *T. nudiflora* in both the nursery and field condition ($p<0.05$). However, field conditions significantly reduced the MLD of this species, for treated and non-treated seeds ($p<0.05$) (Figure 16).

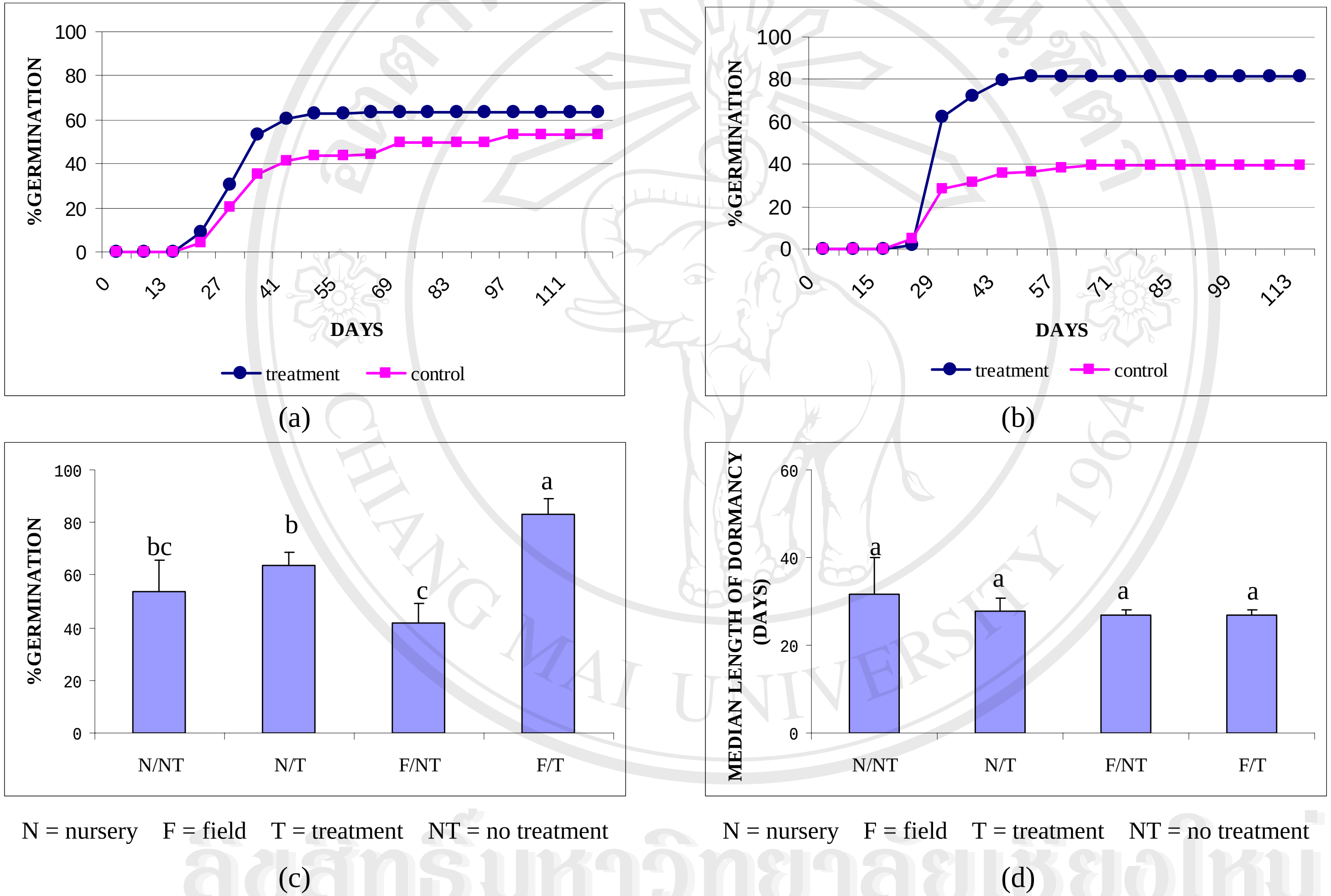
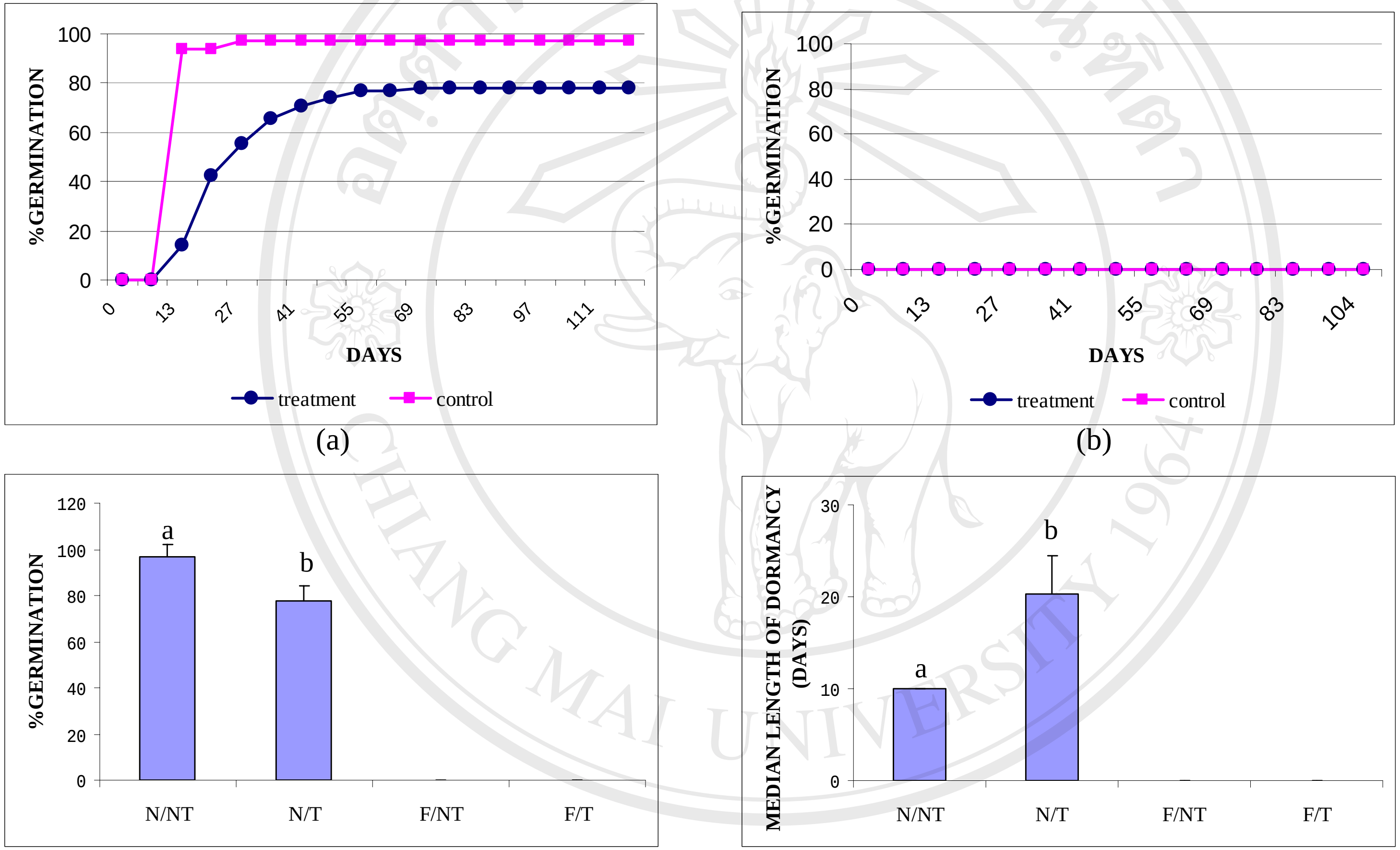


Figure 11. Germination per cent and MLD of *A. xylocarpa* (a) germination per cent in the nursery (b) germination per cent in the field (c) final germination per cent and (d) MLD



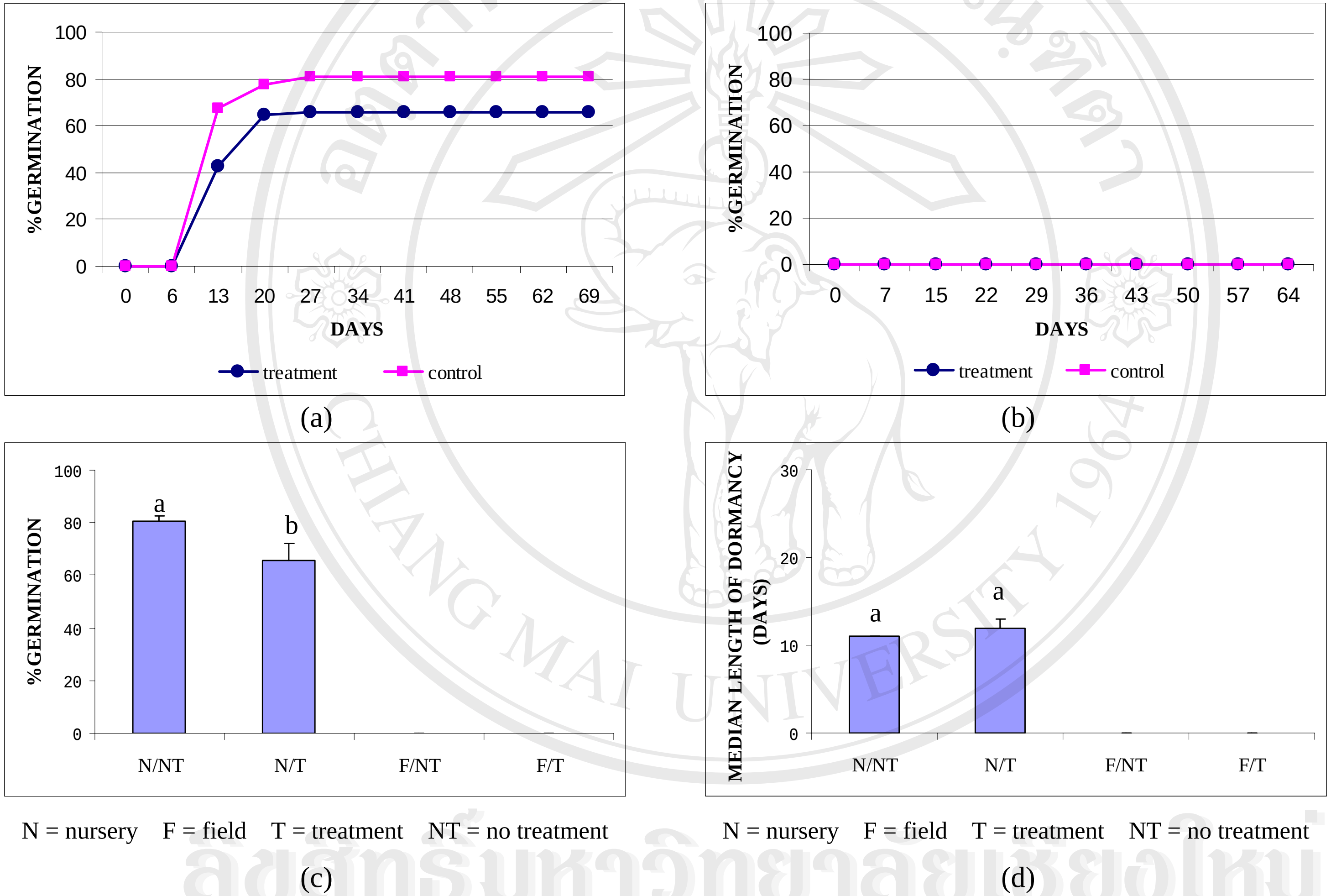
(a) (b)

N = nursery F = field T = treatment NT = no treatment

N = nursery F = field T = treatment NT = no treatment

(c) (d)

Figure 12. Germination per cent and MLD of *A. lakoocha* (a) germination per cent in the nursery (b) germination per cent in the field (c) final germination per cent and (d) MLD



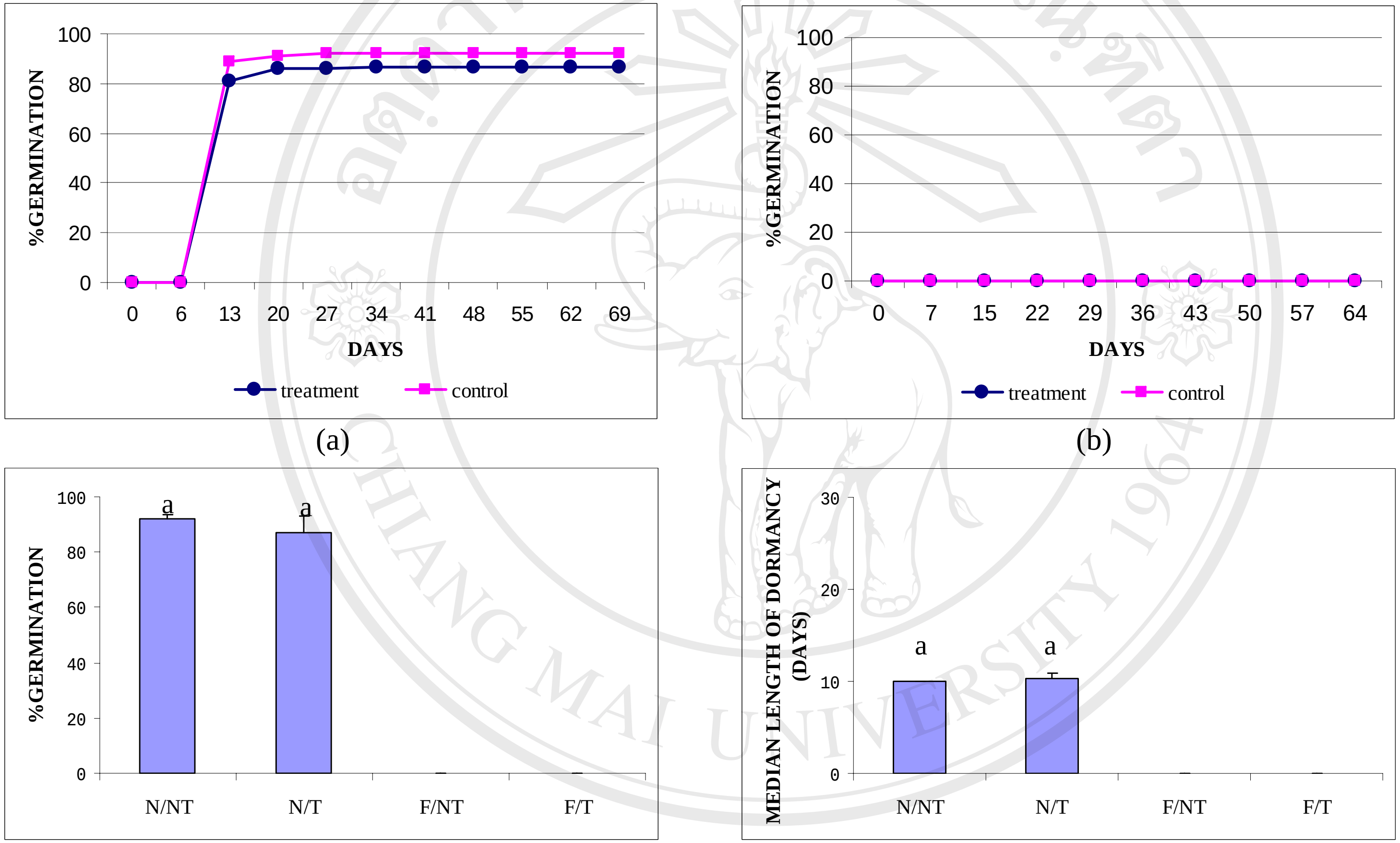
(a) (b)

N = nursery F = field T = treatment NT = no treatment

N = nursery F = field T = treatment NT = no treatment

(c) (d)

Figure 13. Germination per cent and MLD of *C. grewiifolia* (a) germination per cent in the nursery (b) germination per cent in the field (c) final germination per cent and (d) MLD



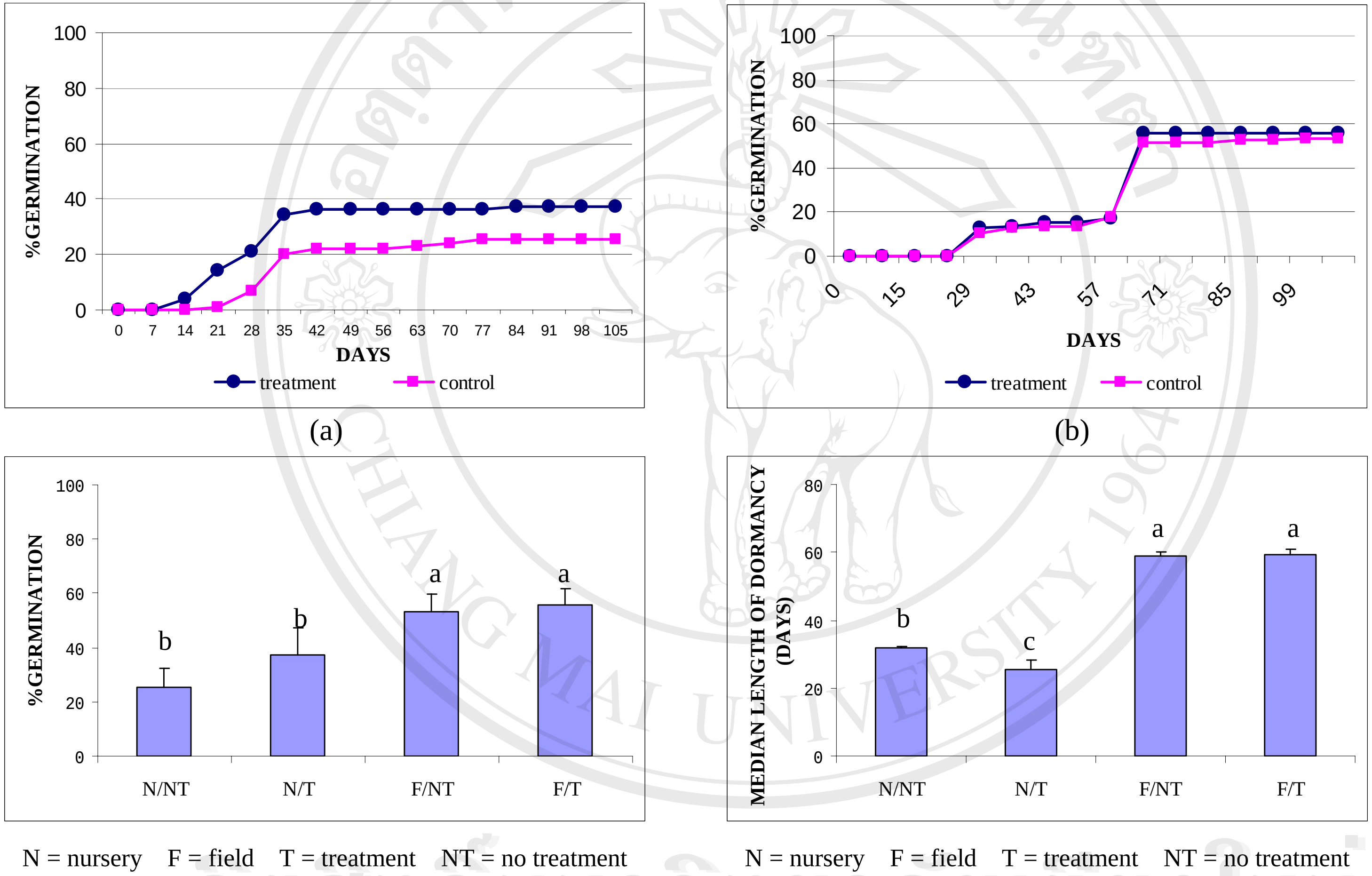
(a) (b)

N = nursery F = field T = treatment NT = no treatment

N = nursery F = field T = treatment NT = no treatment

(c) (d)

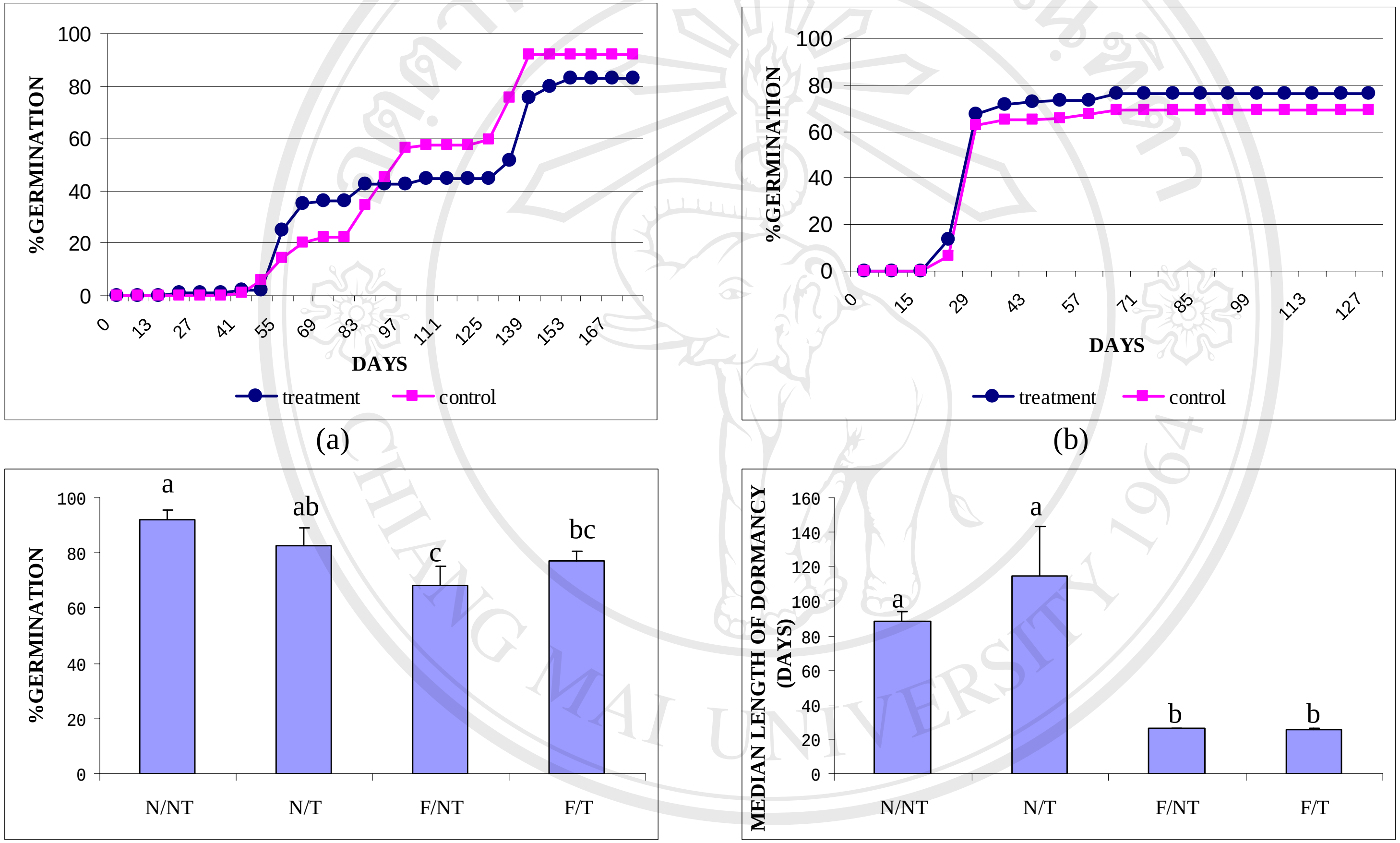
Figure 14. Germination per cent and MLD of *E. cumini* (a) germination per cent in the nursery (b) germination per cent in the field (c) final germination per cent and (d) MLD



(a) (b)

(c) (d)

Figure 15. Germination per cent and MLD of *S. oleosa* (a) germination per cent in the nursery (b) germination per cent in the field (c) final germination per cent and (d) MLD



(a) (b)

N = nursery F = field T = treatment NT = no treatment

N = nursery F = field T = treatment NT = no treatment

(c) (d)

Figure 16. Germination per cent and MLD of *T. nudiflora* (a) germination per cent in the nursery (b) germination per cent in the field (c) final germination per cent and (d) MLD

Effects of weeding on final germination and MLD of seeds sown in the field

In the field, the weeding treatment, had no significant effect ($p<0.05$) on both per cent germination and MLD of all species tested except one. Just for *B. baccata*, it significantly reduced the MLD of pre-treated seeds, but had no effect on non-treated seeds.

Effects of seed pre-treatment on seedling survival

In general, survival of seedlings in the field, during 1 year after sowing, was lower than in the nursery for most species. The species that had significantly lower survival in the field were *A. crassna*, *A. xylocarpa*, *S. oleosa* and *T. nudiflora* ($p<0.05$). The survival of only one species was affected by seed pre-treatment. Soaking in water significantly reduced the survival per cent of *B. baccata* in the field ($p<0.05$). The details for each of the species are as follows:-

Soaking in water and soil (from the mother trees) application had no effect on the survival per cent of *A. crassna* in the nursery and under field conditions ($p<0.05$) in first year after germination. However, the survival per cent of seedlings in the field (40-45%) was significantly lower than in the nursery (85-95%) ($p<0.05$) in the first year after they germinated.

No seedlings of *B. baccata* survived a year in the nursery. In the field, seedlings from pre-treated seeds (soaking in the water and soil from mother trees) had a significantly reduced survival per cent ($p<0.05$).

For *C. brachtiata* only pre-treated seeds (soaking in water and soil from mother trees) germinated in the field.

Soaking in water had no effect on the survival per cent of *E. fruticosa* in the nursery ($p<0.05$) and pre-treatment (soaking in water and soil from the mother trees) application had no effect on the survival per cent in the field ($p<0.05$).

The survival per cent of *S. arboreum* had no effect from pre-treatment and weed control in both nursery and field condition ($p<0.05$).

Pre-treatment (soaking in water and soil from mother trees) application had no effect on the survival per cent of *S. axillaris* in the field ($p<0.05$).

The survival per cent of *A. xylocarpa* in the nursery was significantly higher than in the field ($p<0.05$). Scarification had no effect on the survival per cent in both nursery and field (including soil from the mother trees) ($p<0.05$).

A. lakoocha, *C. grewiifolia* and *E. cumini* produced no seedling in the field. Soaking in water had no effect on the survival per cent of these species in the nursery ($p<0.05$).

In the nursery, scarification (plus soil from the mother trees for the field) had no effect on the survival per cent of *S. oleosa* ($p<0.05$). However, the survival per cent of this species in the nursery was significantly higher than in the field ($p<0.05$).

Scarification had no effect on the survival per cent of *T. nudiflora* in the nursery ($p<0.05$). Only one seedling survived in the field (no pre-treatment with weed control) (Table 4).

Table 4. Effects of seed pre-treatment on seedling survival over one year after sowing

N = nursery F = field T = treatment NT = no treatment NG = no germination
( ) represents standard deviation

Species	Treatment	%survival
A. crassna	NT/N	94^{a} (2.6)
	T/N	89^{a} (7.9)
	NT/F	44^{b} (16.8)
	T/F	40^{b} (0.6)
B. baccata	NT/N	0
	T/N	0
	NT/F	81^{a} (0.5)
	T/F	64^{b} (16.8)
C. brachiata	NT/N	NG
	T/N	NG
	NT/F	NG
	T/F	67 (35.4)
E. fruticosa	NT/N	99^{a} (1.7)
	T/N	94^{ab} (6.4)
	NT/F	96^{ab} (0.0)

Table 4. (Continued)

Species	Treatment	%survival
S. arboreum	T/F	93^{b} (2.7)
	NT/N	90^{a} (8.2)
	T/N	92^{a} (26.1)
	NT/F	93^{a} (4.5)
S. axillaris	T/F	93^{a} (2.9)
	NT/N	NG
	T/N	NG
	NT/F	69^{a} (10.7)
A. xylocarpa	T/F	81^{a} (0.0)
	NT/N	98^{a} (3.2)
	T/N	98^{a} (2.7)
	NT/F	44^{b} (3.2)
A. lakoocha	T/F	52^{b} (10.7)
	NT/N	82^{a} (4.4)
	T/N	87^{a} (0.0)
	NT/F	NG
C. grewiifolia	T/F	NG
	NT/N	94^{a} (7.9)
	T/N	96^{a} (16.3)
	NT/F	NG
E. cumini	T/F	NG
	NT/N	95^{a} (7.3)
	T/N	93^{a} (1.9)
	NT/F	NG
S. oleosa	T/F	NG
	NT/N	100^{a} (0.0)
	T/N	100^{a} (0.0)
	NT/F	71^{b} (11.6)
T. nudiflora	T/F	67^{b} (2.2)
	NT/N	93^{a} (3.4)
	T/N	96^{a} (5.1)

Table 4. (Continued)

Species	Treatment	%survival
	NT/F	6^{b} (7.9)
	T/F	0

Effects of weeding on seedling survival

It was expected that weeding would be essential to increase survival of the young seedlings germinating in the field. This proved not to be the case. Weeding had no effect on most of the species tested and it actually reduced survival of seedlings from non-pre-treated seeds of *S. axillaris* and *B. baccata* ($p<0.05$). Weeding only increased seedling survival of one species, *C. brachiata* grown from pre-treated seeds ($p<0.05$). It also had no effect on growth performance.

Table 5. Effects of weeding on seedling survival over one year after sowing

T = treatment NT = no treatment W = weed NW = no weed NG = no germination
( ) represents standard deviation

Species	Treatment	%survival
A. crassna	NT/NW	57^{a} (0.0)
	T/NW	41^{b} (19.3)
	NT/W	33^{b} (15.7)
	T/W	40^{b} (0.0)
B. baccata	NT/NW	83^{a} (7.9)
	T/NW	76^{a} (7.1)
	NT/W	83^{a} (12.9)
	T/W	52^{b} (21.2)
C. brachiata	NT/NW	NG
	T/NW	50^{b} (14.1)
	NT/W	NG
	T/W	100^{a} (0.0)
E. fruticosa	NT/NW	95^{a} (6.4)
	T/NW	92^{a} (11.8)

Table 5. (Continued)

Species	Treatment	%survival
S. arboreum	NT/W	96^{a} (6.4)
	T/W	95^{a} (6.4)
	NT/NW	95^{a} (7.1)
	T/NW	91^{a} (0.0)
S. axillaris	NT/W	89^{a} (0.0)
	T/W	95^{a} (6.4)
	NT/NW	93^{b} (10.1)
	T/NW	100^{a} (0.0)
A. xylocarpa	NT/W	78^{c} (35.4)
	T/W	100^{a} (0.0)
	NT/NW	42^{b}
	T/NW	46^{ab}
A. lakoocha	NT/W	46^{ab} (11.8)
	T/W	56^{a} (26.5)
	NT/NW	NG
	T/NW	NG
C. grewiifolia	NT/W	NG
	T/W	NG
	NT/NW	NG
	T/NW	NG
E. cumini	NT/W	NG
	T/W	NG
	NT/NW	NG
	T/NW	NG
S. oleosa	NT/W	NG
	T/W	NG
	NT/NW	64^{b} (12.9)
	T/NW	65^{b} (7.1)
	NT/W	80^{a} (0.0)

Table 5. (Continued)

Species	Treatment	%survival
T. nudiflora	T/W	68^{ab} (6.4)
	NT/NW	0
	T/NW	0
	NT/W	11 (17.7)
	T/W	0

The effects of weeding on growth performance

Weed control had no effect on the mean RCD, mean height, relative growth rate of RCD and height of all species tested (Table 6).

Table 6. Effects of weeding on growth performances (mean of RCD, height, relative growth rate of RCD and relative growth rate of height) over one year after sowing

T = treatment NT = no treatment W = weed NW = no weed NG = no germination
NS = no survival ( ) represents standard deviation

Species	Treatment	N	RCD (mm)	Height (cm)	RGR of RCD	RGR of Height
A. crassna	NT/NW	8	2.5^{a} (0.4)	12.0^{a} (2.0)	73.6^{a} (47.4)	28.7^{a} (23.1)
	T/NW	9	2.1^{ab} (0.5)	11.0^{a} (3.1)	28.8^{a} (35.6)	54.1^{a} (31.7)
	NT/W	6	2.5^{ab} (0.6)	13.2^{a} (2.4)	99.6^{a} (69.0)	57.7^{a} (41.2)
	T/W	8	2.0^{b} (0.3)	9.8^{a} (3.2)	31.7^{a} (70.7)	58.1^{a} (51.1)
B. baccata	NT/NW	15	2.4^{a} (0.7)	18.4^{a} (6.4)	113.1^{a} (57.5)	78.0^{a} (45.4)
	T/NW	15	2.9^{a} (0.7)	22.7^{a} (6.6)	71.7^{a} (42.9)	129.9^{a} (40.3)
	NT/W	18	2.9^{a} (0.8)	23.6^{a} (9.4)	129.4^{a} (58.5)	112.1^{a} (54.9)
	T/W	11	2.6^{a} (0.6)	20.7^{a} (8.0)	70.0^{a} (43.1)	105.7^{a} (39.1)
C. brachiata	NT/NW	0	NG	NG	NG	NG
	T/NW	5	2.0^{a} (0.4)	8.8^{a} (1.1)	34.2^{a} (46.9)	60.2^{a} (34.6)
	NT/W	0	NG	NG	NG	NG
	T/W	5	2.2^{a} (0.4)	9.4^{a} (1.7)	49.0^{a} (38.9)	68.3^{a} (14.9)
E. fruticosa	NT/NW	21	1.8^{a} (0.6)	12.6^{a} (5.6)	82.7^{a} (60.1)	47.4^{a} (53.5)
	T/NW	22	1.8^{a} (0.6)	12.9^{a} (4.0)	77.6^{a} (50.3)	94.7^{a} (30.0)
	NT/W	21	1.8^{a} (0.8)	15.7^{a} (6.6)	86.8^{a} (67.4)	84.3^{a} (54.4)

Table 6. (Continued)

Species	Treatment	N	RCD (mm)	Height (cm)	RGR of RCD	RGR of Height
	T/W	21	1.9^{a} (0.4)	13.1^{a} (4.0)	88.6^{a} (35.2)	90.1^{a} (26.2)
S. arboreum	NT/NW	19	2.8^{a} (0.5)	16.6^{a} (2.8)	86.4^{a} (44.2)	2.0^{a} (30.2)
	T/NW	20	2.9^{a} (0.6)	17.0^{a} (2.5)	24.8^{a} (41.2)	33.4^{a} (37.6)
	NT/W	16	3.0^{a} (0.6)	18.9^{a} (5.4)	80.5^{a} (37.8)	29.8^{a} (48.8)
	T/W	21	2.9^{a} (0.5)	18.1^{a} (3.4)	33.9^{a} (62.9)	43.2^{a} (37.3)
S. axillaris	NT/NW	13	1.9^{a} (0.8)	14.0^{a} (8.1)	70.1^{a} (59.1)	46.5^{a} (39.5)
	T/NW	8	2.4^{a} (0.7)	20.6^{a} (10.0)	47.6^{a} (51.5)	97.4^{a} (24.7)
	NT/W	6	2.9^{a} (1.5)	24.1^{a} (8.2)	70.0^{a} (64.0)	90.9^{a} (47.2)
	T/W	8	2.6^{a} (1.0)	20.5^{a} (9.1)	51.9^{a} (51.8)	94.5^{a} (52.2)
A. xylocarpa	NT/NW	4	7.2^{a} (1.3)	27.0^{a} (10.2)	23.1^{a} (26.0)	-35.3^{a} (71.4)
	T/NW	10	6.4^{a} (1.1)	29.4^{a} (4.8)	12.3^{a} (22.8)	23.1^{a} (36.7)
	NT/W	5	6.3^{a} (1.1)	26.5^{a} (5.1)	33.3^{a} (21.4)	12.5^{a} (21.6)
	T/W	7	6.8^{a} (1.4)	29.1^{a} (5.1)	9.4^{a} (26.2)	29.6^{a} (34.1)
S. oleosa	NT/NW	14	2.7^{a} (0.7)	14.3^{a} (4.1)	28.7^{a} (54.9)	-10.9^{a} (43.4)
	T/NW	13	2.7^{a} (0.4)	13.7^{a} (2.9)	40.2^{a} (47.7)	8.6^{a} (40.6)
	NT/W	16	3.1^{a} (0.9)	14.1^{a} (4.4)	23.9^{a} (48.6)	-1.7^{a} (47.7)
	T/W	15	2.8^{a} (0.6)	14.7^{a} (3.9)	37.3^{a} (42.2)	12.3^{a} (32.6)
T. nudiflora	NT/NW	0	NS	NS	NS	NS
	T/NW	0	NS	NS	NS	NS
	NT/W	1	3.0	4.0	0	0
	T/W	0	NS	NS	NS	NS

Effects of treatments on growth performance

In general seed pre-treatments had little or no effect on subsequent growth of seedlings over the first after germination in the field and in the nursery. The only exception was *A. crassna*. RCD of seedlings germinated from pre-treated seeds was significantly reduced in the field ($p<0.05$). The details for affected species are as follows:-

After germination, seedlings of *B. baccata* did not survive at all in the nursery. Soaking in water and soil (from the parent tree) application had no effect on the mean of height, relative growth rate of RCD and relative growth rate of height under both nursery and field conditions ($p<0.05$).

Pre-treatment application (soaking in water and soil from mother tree) in the field condition was only one factor that could support germinated seedlings of *C. brachiata*.

No seeds of *A. lakoocha*, *C. grewiifolia* and *E. cumini* could germinate in the field condition. Soaking in water and soil (from the parent tree) application had no effect on the mean of RCD, mean of height, relative growth rate (RCD and height) of these species in the nursery ($p<0.05$).

However, relative growth rate of RCD *S. oleosa* significantly reduced in the field condition both control and pre-treatment application ($p<0.05$).

No seedling of *T. nudiflora* could survive after germinated for 8 months in the field. Scarification had no effect on the mean of RCD, mean of height, relative growth rate of RCD and height ($p<0.05$) (Table 7).

Table 7. Effect of treatments on growth performance (mean of RCD, height, relative growth rate of RCD and relative growth rate of height) over one year after sowing

N = nursery F = field T = treatment NT = no treatment NG = no germination
NS = no survival ( ) represents standard deviation

Species	Treatment	N	RCD (mm)	Height (cm)	RGR of RCD	RGR of Height
A. crassna	NT/N	41	3.4^{a} (0.7)	10.4^{a} (2.6)	117.2^{a} (31.1)	99.2^{a} (38.4)
	T/N	22	3.2^{a} (0.7)	9.4^{a} (1.7)	114.8^{a} (49.5)	82.3^{a} (44.1)
	NT/F	14	2.5^{b} (0.5)	12.5^{a} (2.2)	84.7^{a} (56.7)	41.1^{a} (34.1)
	T/F	17	2.1^{c} (0.4)	10.4^{a} (3.1)	30.1^{a} (53.1)	56.0^{a} (40.6)
B. baccata	NT/N	0	NS	NS	NS	NS
	T/N	0	NS	NS	NS	NS
	NT/F	34	2.7^{a} (0.8)	21.3^{a}(8.5)	122.2^{a}(57.8)	97.1^{a} (53.1)
	T/F	27	2.8^{a} (0.7)	21.9^{a}(7.1)	71.0^{a}(42.2)	120.0^{a} (40.9)
C. brachiata	NT/N	0	NG	NG	NG	NG
	T/N	0	NG	NG	NG	NG

Table 7. (Continued)

Species	Treatment	N	RCD (mm)	Height (cm)	RGR of RCD	RGR of Height
	NT/F	0	NG	NG	NG	NG
	T/F	10	2.1 (0.4)	9.1 (1.4)	41.6 (41.4)	64.3 (25.4)
E. fruticasa	NT/N	71	3.2^{a} (0.6)	19.5^{a} (3.7)	153.2^{a} (34.1)	197.8^{a} (54.3)
	T/N	74	2.8^{a} (0.6)	17.5^{a} (4.9)	117.8^{a} (42.1)	139.7^{a} (56.6)
	NT/F	44	2.7^{a} (0.8)	21.3^{a} (8.5)	122.2^{a} (57.8)	97.1^{a} (53.1)
	T/F	43	2.8^{a} (0.7)	21.9^{a} (7.1)	71.0^{a} (42.2)	120.0^{a} (40.9)
S. arboreum	NT/N	37	4.4^{a} (0.7)	20.4^{a} (4.2)	118.7^{a} (28.2)	136.1^{a} (48.8)
	T/N	25	4.2^{a} (0.6)	19.3^{a} (5.0)	105.1^{a} (22.2)	87.3^{a} (35.9)
	NT/F	36	2.9^{a} (0.6)	17.5^{a} (4.2)	84.7^{a} (40.6)	15.2^{a} (41.1)
	T/F	42	2.9^{a} (0.5)	17.5^{a} (3.0)	29.2^{a} (52.4)	38.2^{a} (37.7)
S. axillaris	NT/N	0	NG	NG	NG	NG
	T/N	0	NG	NG	NG	NG
	NT/F	20	2.3^{a} (1.2)	17.6^{a} (9.4)	107.7^{a} (81.4)	62.0^{a} (46.5)
	T/F	17	2.5^{a} (0.8)	20.5^{a} (9.3)	49.6^{a} (50.0)	96.0^{a} (38.7)
A. xylocarpa	NT/N	33	7.7^{a} (1.2)	33.5^{a} (9.0)	50.8^{a} (30.2)	82.0^{a} (39.3)
	T/N	41	7.5^{ab} (1.4)	39.5^{a} (12.4)	46.4^{a} (25.6)	92.8^{a} (51.4)
	NT/F	11	6.7^{bc} (1.3)	26.7^{a} (7.4)	28.7^{a} (23.0)	-9.2^{a} (53.8)
	T/F	17	6.6^{c} (1.2)	29.3^{a} (4.8)	11.1^{a} (23.5)	25.8^{a} (34.7)
A. lakoocha	NT/N	17	3.6^{a} (0.6)	31.6^{a} (10.2)	130.9^{a} (57.7)	261.8^{a} (106.9)
	T/N	44	4.0^{a} (0.8)	34.4^{a} (11.1)	145.5^{a} (55.0)	269.6^{a} (77.9)
	NT/F	0	NG	NG	NG	NG
	T/F	0	NG	NG	NG	NG
C. grewiifolia	NT/N	24	2.4^{a} (0.5)	10.9^{a} (2.9)	135.5^{a} (29.7)	239.8^{a} (54.6)
	T/N	40	1.5^{a} (0.3)	5.4^{a} (1.1)	74.4^{a} (46.3)	134.1^{a} (46.6)
	NT/F	0	NG	NG	NG	NG
	T/F	0	NG	NG	NG	NG
E. cumini	NT/N	64	2.6^{a} (0.6)	22.2^{a} (6.7)	175.3^{a} (53.8)	307.0^{a} (49.5)
	T/N	59	3.6^{a} (5.1)	22.1^{a} (5.8)	202.0^{a} (91.0)	277.5^{a} (62.5)
	NT/F	0	NG	NG	NG	NG
	T/F	0	NG	NG	NG	NG
S. oleosa	NT/N	14	3.4^{a} (0.5)	19.8^{a} (3.4)	138.3^{a} (71.1)	204.7^{a} (91.1)

Table 7. (Continued)

Species	Treatment	N	RCD (mm)	Height (cm)	RGR of RCD	RGR of Height
	T/N	14	3.4^{a} (0.5)	18.9^{a} (3.0)	139.5^{a} (46.2)	205.3^{a} (90.6)
	NT/F	30	2.9^{a} (0.8)	14.2^{a} (4.2)	26.1^{b} (50.8)	-6.0^{a} (45.2)
	T/F	28	2.7^{a} (0.5)	14.2^{a} (3.5)	38.7^{b} (44.0)	10.6^{a} (35.9)
T. nudiflora	NT/N	39	4.7^{a} (1.2)	41.8^{a} (12.8)	177.3^{a} (69.1)	303.9^{a} (89.0)
	T/N	27	5.6^{a} (0.8)	53.7^{a} (8.6)	221.5^{a} (47.2)	394.4^{a} (66.2)
	NT/F	1	3.0	4.0	0	0
	T/F	0	NS	NS	NS	NS

Comparing nursery-raised and direct seeded trees in the field

Nursery-raised plants were transplanted into the field next to direct seeded plants of the same species grown from the same seed batches. In general, direct seeded plants survived and grew much better than the nursery-raised plants in their second year of growth.

- **Survival per cent during 2nd year after sowing**

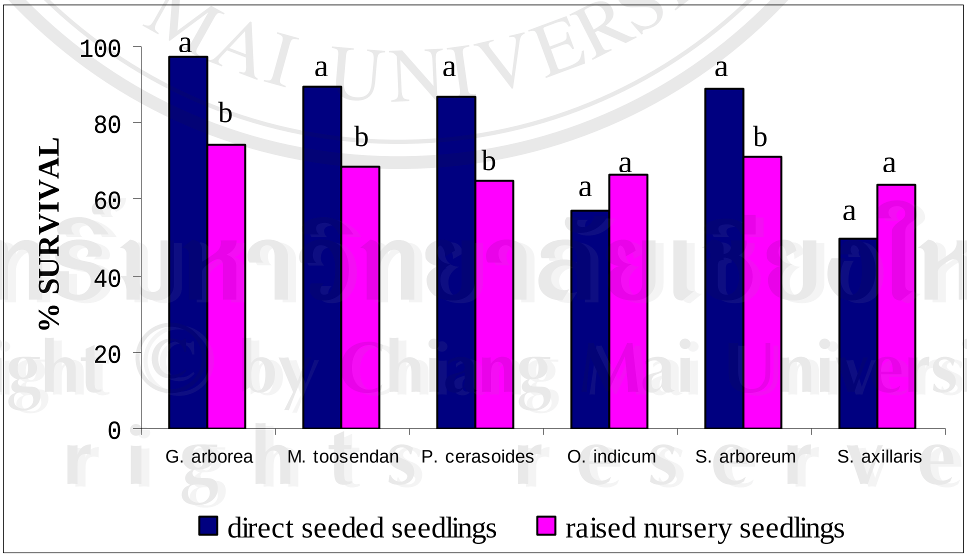


Figure 17. Survival per cent of directed seeded and transplanted nursery-raised seedlings over the second year after sowing (2005)

Direct seeded plants, mostly survived better than transplanted nursery-raised plants over the 2nd year monitoring period. Four out of the 6 species tested had significantly higher survival rates for direct seeded plants than for nursery-raised plants. For the other two species (*O. indicum* and *S. axillaris*) there were no significant differences in mean survival rates between nursery-raised and direct seeded plants. ($p<0.05$) (Figure 17).

Survival rates of all direct seeded plants were above 50% (range 50 – 90 %) over two years, which is considered acceptable for forest restoration purposes.

- **Growth performance**

In general, direct seeded plants of most of the species tested species grew significantly larger in the field plots, even within one year, compared with nursery-raised plants that were subsequently transplanted into the field. The differences which developed during the first year after seed sowing became even more pronounced during the second year of growth, after nursery-raised plants had been transplanted into the field and grew alongside the direct seeded ones.

One year after sowing, the mean RCDs of the direct seeded saplings of all species except one (*S. arboreum*) were significantly greater ($p<0.05$) than those of nursery-raised nursery seedlings ($p<0.05$), just after they were planted out (Figure 18a). Similarly one year after the nursery-raised saplings had been planted out, the RCDs of all species, except *S. arboreum*, were even more significantly larger for direct seeded seedlings than for nursery-raised ones (Figure 18b).

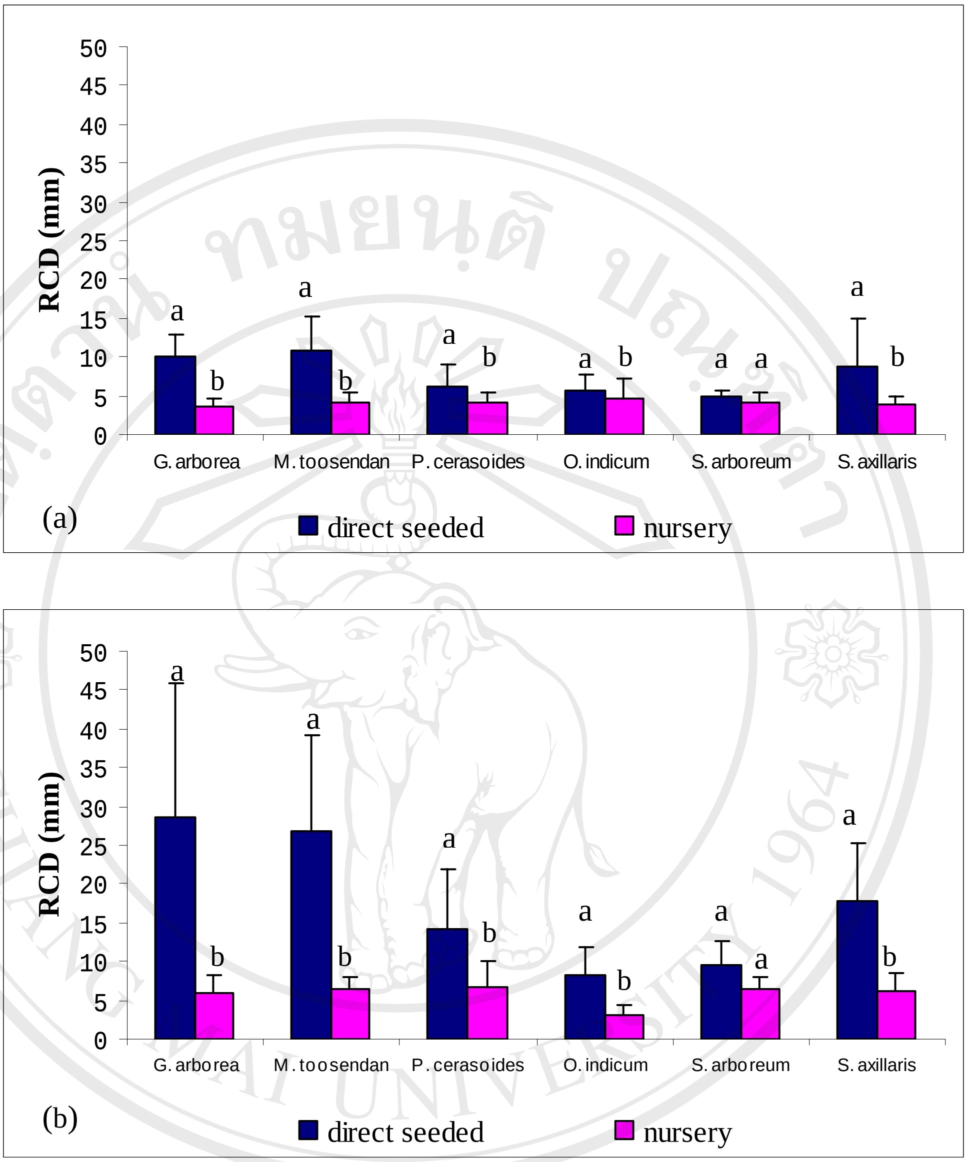


Figure 18. Mean of RCD of six species (a) after one year (by mid-2004) and (b) after two years (mid-2005) after sowing

Similarly relative growth rates of RCD of all species except *O. indicum* and *S. arboreum* were significantly higher for direct seeded plants than for nursery-raised ones (p<0.05) (Figure 19). Values ranged from 30 to 80 which are considered acceptable for forest restoration purposes. In addition, *O. indicum* seedlings were often cut during weeding, probably the seedlings were as tall as weeds. Therefore the data from damaged seedlings were removed before calculation.

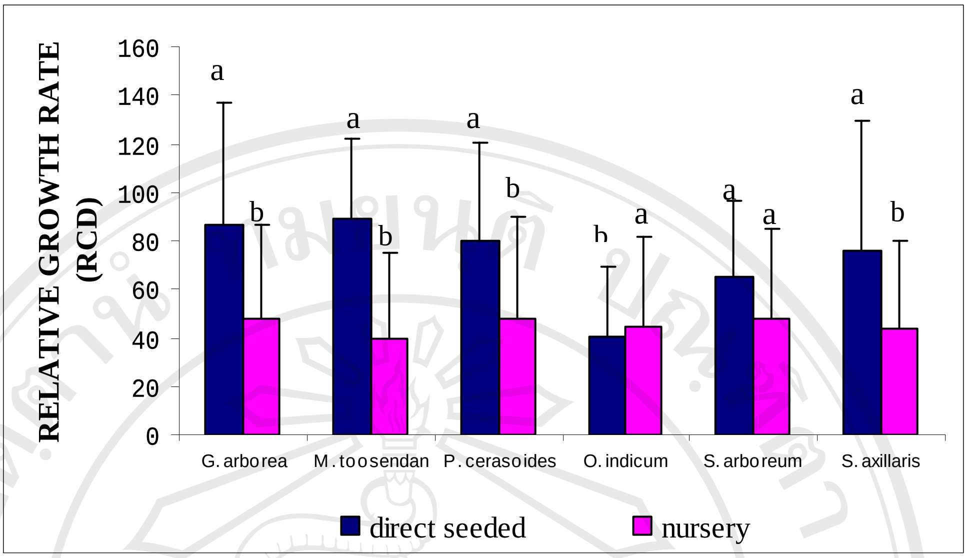


Figure 19. Mean of relative growth rate of RCD of six species in second year after sowing (2005)

Within one year, direct seeded *G. arborea*, *M. toosendan*, *P. cerasoides* and *S. axillaris* trees had all achieved mean heights taller than the usual recommended height of saplings from the nursery selected for planting (ie. 30-50 cm).

Direct seeded *M. toosendan*, *P. cerasoides* and *S. axillaris* seedlings grew significantly taller than nursery-raised seedlings (p<0.05) within a year after sowing and the difference became even greater during the second year of growth, following transplantation of nursery-raised plants into the field.

Direct seeded plants of *G. arborea* and *O. indicum* took two years to grow significantly taller than nursery-raised ones (p<0.05). Only for *S. arboreum* did seedlings raised in the nursery grew significantly taller than direct seeded ones and the difference was quite small (76 cm for nursery-raised and 52 cm for direct seeded plants).

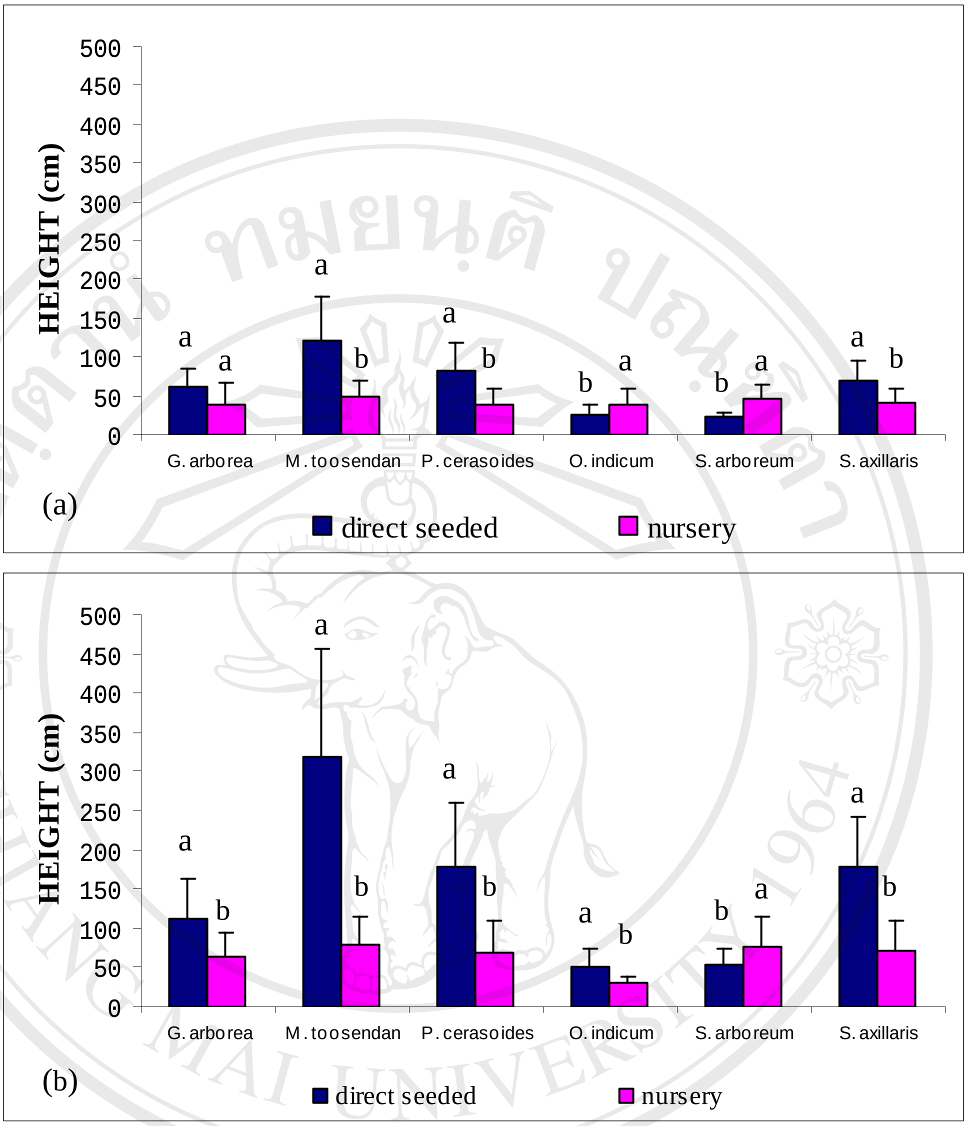


Figure 20. Mean of height of six species in (a) one year, 2004 and (b) two year, 2005 after sowing

Similary for RGR-height over the 2nd year of growth of four species (*M. toosendan*, *P. cerasoides*, *O. indicum* and *S. axillaris*) was significantly higher for direct-seeded plants than for nursery-raised ones.

For *G. arborea* and *S. arboreum* the difference was non-significant (Figure 21).

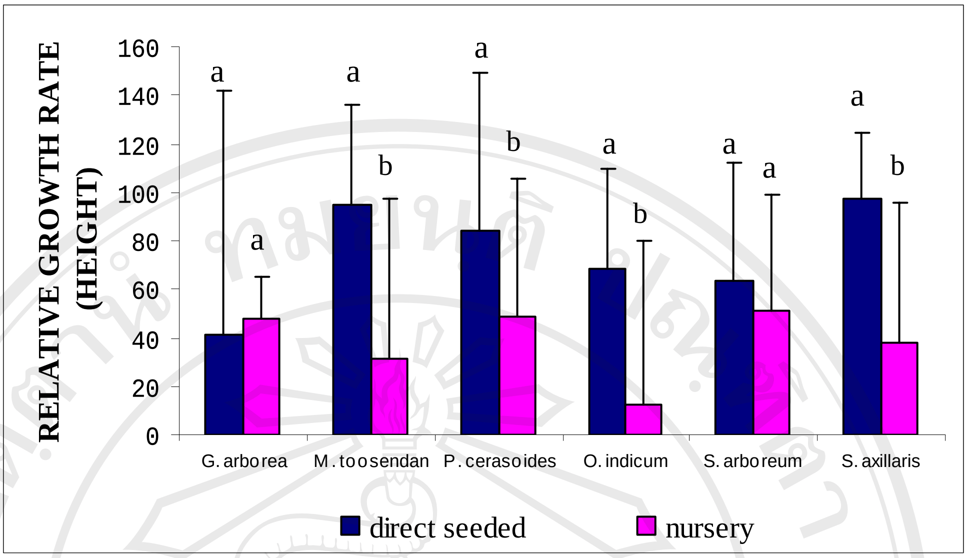


Figure 21. Mean of relative growth rate of height of six species in two years after sowing (2005)

A similar pattern was observed for crown expansion. Direct-seeded plants of all species tested grew wider crowns than nursery raised plants, except for *S. arboreum*. For the latter species, crown width was not significantly different between nursery-raised and direct seeded plants by two years after sowing ($p<0.05$). (Figure 22).

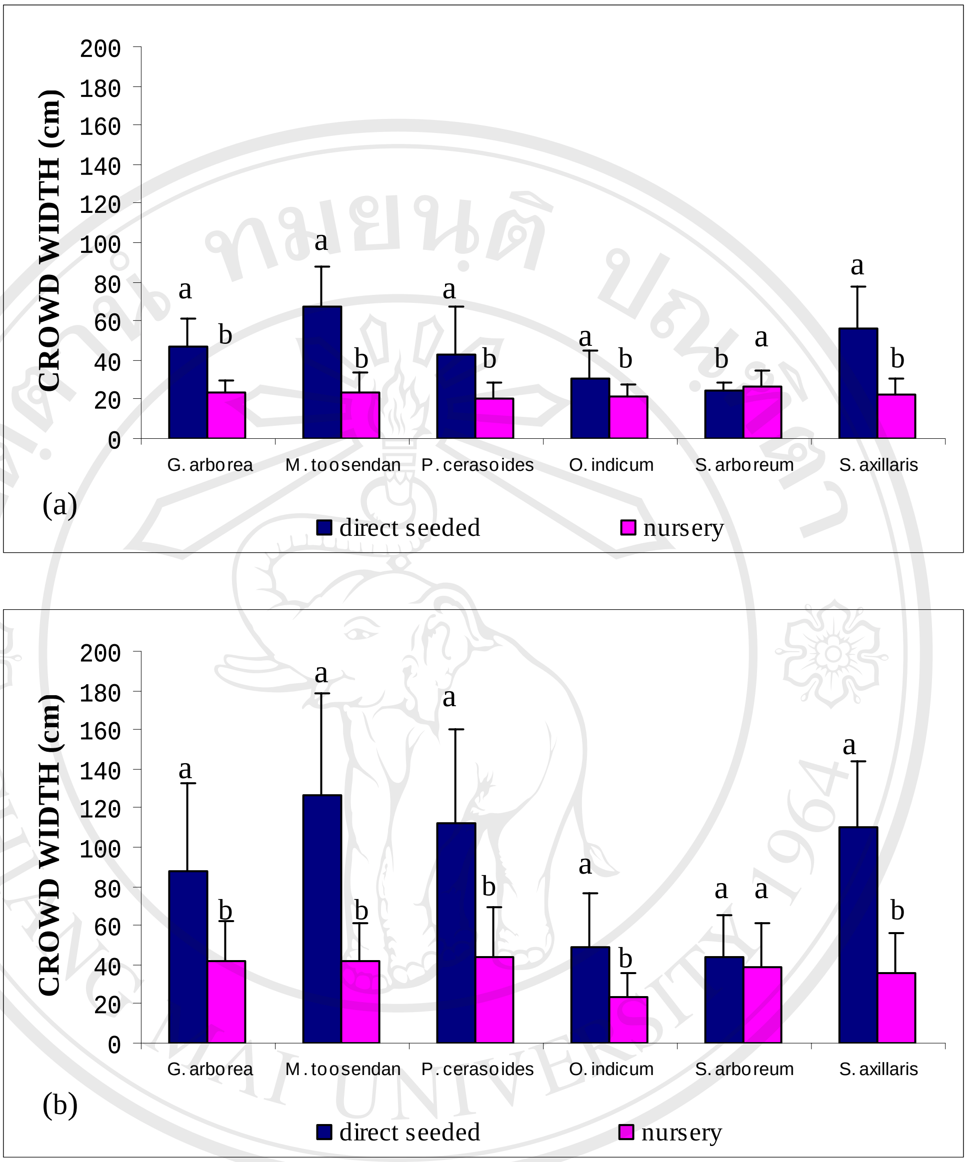


Figure 22. Mean of crown width of six species in (a) one year, 2004 and (b) two year, 2005 after sowing

Comparing costs between direct seeded and nursery-raised plants establishment

Establishment of direct seeded plants could save about 50%, compared with nursery-raised plants in the same scale. Most activities in a nursery; germination, potting and growing will be eliminated and direct seeded method could save about 15% for these activities. In addition, a transferring cost and casual labours could be reduced about 26% during sowing season and also the maintenance cost could be reduced about 9% compared with nursery-raised planting. The details were presented in table 8.

Table 8. Comparing cost between direct seeded and nursery-raised plants establishment (The calculation was based on a stocking density of 500 trees per rai, 18.75 baht/hr for casual labour)

Items	Cost	
	Nursery-raised plants	**Direct seeded plants**
Establishment costs		
• Seed collection (0.038 baht/seed, 4 hrs for 2000 seeds)	76.00	76.00
• Seed preparation (0.072 baht/seed, 7.73 hrs for 2000 seeds)	144.00	144.00
• Germination		
- Plastic baskets (0.10 baht/seed, 100 seeds/basket, 30 baht/basket, 3 planting seasons/basket)	200.00	0
- Media (0.98 baht/basket, 100 seeds/basket)	19.60	0
- Labour (1 hr for 2000 seeds)	18.75	0
• Potting		
- Plastic bags (0.38 baht/bag, 120 bags/kg, 45 baht/kg)	190.00	0
- Media (0.005 baht/bag)	2.50	0
- Labour (0.5 baht/bag)	250.00	0

Table 8. (Continued)

Items	Cost	
	Nursery-raised plants	Direct seeded plants
• Growing		
- Fertilizer (32.50 baht/time, 3 times/planting season)	97.50	0
- Watering (6 hrs/planting season)	112.50	0
- Maintenance (apply fertilizer, weeding, grading) (36 hrs/planting season)	675.00	0
Site preparation		
• Manual weeding (4 persons/rai)	600.00	600.00
• Herbicide (0.40 gallon/rai, 610 baht/gallon)	244.00	244.00
• Labour (apply herbicide) (2 persons/rai, 300 baht/person)	600.00	600.00
Planting/Sowing		
• Seedlings transferring (vehicle and gasoline)	2000.00	0
• Planting/sowing (vehicle and gasoline)	2000.00	2000.00
• Planting/sowing (labour) (5 persons/planting, 2 persons/sowing)	750.00	300.00
• Fertilizer	310.00	0
• Labour (apply fertilizer)	150.00	0

Table 8. (Continued)

Items	**Cost**	
	Direct seeded plants	**Nursery-raised plants**
Maintenance (1st year)		
• Manual weeding (3 persons/rai, 3 times/rainy season/for planting, 2 times/rainy season/for sowing)	1350.00	900.00
• Fertilizer (3 times/rainy season/for planting, 2 times/rainy season/for sowing)	930.00	620.00
• Labour (apply fertilizer)	450.00	300.00
Total	11169.85	5385.85

CHAPTER 5

Discussion

Effects of seed pre-treatment on germination

Candidate species suitable for direct seeding must have an acceptably high germination per cent and rapid germination. The standard "acceptable" levels for this study were set at germination percentage more than 40% and MLD < 30 days.

The species that met those standards were *A. crassna*, *B. baccata*, *E. fruticosa*, *A. xylocarpa* and *T. nudiflora*. MLD of *A. crassna* and *E. fruticosa* in the field was significantly longer than in the nursery ($p<0.05$) for both the control seeds and those soaked in water. The most obvious reason for this is lower soil moisture in the field leading to prolonged enforced dormancy. In the nursery, seeds were watered frequently, whereas in the field, vegetation cover had been cleared before direct seeding, which might have caused the soil to dry out.

Tunjai (2004) studied the influence of soils on seed germination and found that *A. crassna* tended to grow under conditions of high humidity. Relative soil moisture in its natural habitat was about 35%. Another factor that might lengthen the MLD of *A. crassna* in the field was the depth of sowing. In the field, seeds must be sown deeper than in the nursery to prevent predation. Unfortunately, if they are sown too deep this might reduce light levels which can trigger germination in some species.

In contrast, germination of *B. baccata* in the field was significantly accelerated compared with the "ideal" conditions in the nursery ($p<0.05$). Recalcitrant seeds are those intolerant of dehydration and need to be sown immediately after collection or they may die (Roberts, 1973). This species has recalcitrant seeds and it is difficult to produce seedlings in the nursery. Although the seeds were sown two days after collection, only 21 seeds germinated, 9 seedlings could be potted in the containers and 6 healthy seedlings were eventually produced from 100 seeds. Moreover, pests and diseases can considerably reduce seedling survival in the nursery (FORRU, unpublished data). In the field, seeds were sown in 8 days after collection, whereas in the nursery, seeds were kept 20 days before sowing. Therefore, the period of time before sowing, or the storage method might affect seed dormancy of this species. More research is needed to find out weather the range or methods of seed storage affect MLD under both field and nursery conditions. Seeds in the field probably experienced higher temperatures (and temperature fluctuations), higher light intensity and drier conditions than seeds in the nursery. These factors should be tested in the nursery to see if the shorter MLD recorded in the field can be reproduced in the nursery.

The final germination per cent of *A. xylocarpa* in the field was significantly increased by scarification ($p<0.05$) probably because seed coat dormancy had been overcome. Individual seeds may become permeable to water at different times, resulting in staggered seedling recruitment, which provides an insurance against spells of unfavourable conditions (Khurana and Singh, 2001).

In the field, the MLD of *T. nudiflora* both of control seeds and scarified seeds was significantly reduced, compared with MLD of seeds sown in the nursery ($p<0.05$). Temperature might be an important factor for this species to overcome dormancy. Optimal temperature for germination may vary from species to species (Bell *et al*., 1995). For example, a pioneer rain forest species from Mexico, *Heliocarpus donnell-smithii* requires more than 10˚C of daily temperature alternation for full germination. An increase in temperature triggers germination by changing the internal enzymatic kinetics and thus the biochemistry of seed cells or by melting the sub-layer in seed coat sclerenchyma or at micropyle, allowing the seed to take up water (Vazquez-Yanes and Orozco-Segovia, 1982).

Species in this study which did not meet the acceptable standard for direct seeding in this study because of long MLD (>30-60 days) but which might still be useful if methods to break dormancy could break seed dormancy more quickly were *S. arboreum* and *S. oleosa*. In the nursery, soaking in water significantly reduced the final germination per cent of *S. arboreum* ($p<0.05$). This might have been because soaking washed out complex enzymes required for germination along with any germination inhibitors (Bradbeer, 1988). Similary to *A. crassna* and *E. fruticosa*, the MLD of *S. arboreum* in the field was significantly longer than in the nursery ($p<0.05$) probably because the seeds were sown deeper and received lower intensity of light.

Plummer and Bell (1995) suggested that light stimulates germination in several forest tree species. Seeds that require light for germination are called photodormant or positive photoblastic seeds.

Seed dormancy is particularly associated with environments characterized by variable rainfall and with extended dry periods within the annual cycle (Khurana and Singh, 2001). Field conditions significantly increased the final germination per cent and lengthened MLD of *S. oleosa* ($p<0.05$). The MLD of *S. oleosa* in the field was 60 days; the seeds were sown in July and had the highest average rainfall in September which is about 60 days after sowing. Possibly, the moisture content might be the key role for germination of *S. oleosa*.

Unfortunately, those spices following were unacceptable for direct seeding because they experienced low germination per cent and failed to germinate in the field, they were *C. brachiata*, *A. lakoocha*, *C. grewiifolia* and *E. cumini*.

C. brachiata only germinated in the field, achieving a germination per cent of only 9% with soaking and soil from the mother tree. Such poor germination may have been due to storing the seeds too long after collection. The seeds were sown after 41 days in the nursery and after 29 days in the field, whereas the result from FORRU (unpublished data) showed that seeds of *C. brachiata* showed more that 50% germination, where seeds were sown 13 days after collection. According to FORRUs' nursery staff, *C. brachiata* is a very rare species in Doi Suthep-Pui National Park, with few mature trees which fruit every alternate year. This species probably grows in specific environments. Tunjai (2004) studied the physical factors of the soil (relative soil moisture, pH, N, P, K and organic matter) under *C. brachiata* trees and found that it grew in the soil that had nearly 50% of relative moisture, pH 5, N 0.74g/100g, P 2.03 mg/kg, K 107.5 mg/kg and OM 14.0 g/100g which is very different from other species.

Recalcitrant seeds are intolerant of dehydration and must be sown immediately after collection or they may die (Roberts, 1973). Three of species studied, *A. lakoocha*, *C. grewiifolia* and *E. cumini* could not germinate in the field probably due to dessication in the very dry conditions of the lowland site. Although the average rainfall and temperature at Pa Dang plantation of Mae Ow Watershed Development Project center, under Royal Initiatives in Lamphun (about 20 km from the study plot) were 100 mm and 26 ˚ C respectively in July of 2004 (one month after sowing), the moisture holding capacity of the soil was very low because of high level compaction (per.obs.).

In the nursery, soaking in water significantly reduced germination percentage and lengthened MLD of *A. lakoocha* ($p<0.05$) probably due to leaching of enzymes or fungal infection. Therefore, there is no need to apply seed pre-treatment for this species in the nursery next time. Similarly, soaking in water significantly reduced the germination per cent of *C. grewiifolia* but had no effect on MLD ($p<0.05$) In contrast, soaking in water had no effect on the final germination per cent and MLD of *E. cumini* seeds ($p<0.05$) probably because chemical inhibitors are not suspected to be involved in the dormancy mechanisms. Moreover, *E. cumini* has no proper seed coat, so the water can go through the embryo directly. In the nursery, this species showed high germination percentage (80-90%) in both control and pre-treatment application; however it failed to germinate in the field and thus is an unacceptable candidate for direct seeding in dry lowland forest.

Particularly, out of the above species, *S. axillaris* should be considered carefully because it had low germination percentage (<30%) and quite long of MLD (49 days) which made it unacceptable for direct seeding. In contrast, its growth performance was significantly better for direct seeded plants than for raised nursery seedlings planted next to each other (in final part of the results). One way to maximize germination percentage might be to sow smaller pyrenes, since Pakkad (2003) showed that germinated pyrenes had a slight, but significantly lower mass than those which failed to germinate. In addition, *S. axillaris* seeds have been shown to rapidly loose viability during storage (Pakkad, 2003). According to FORRUs' staff, *S. axillaris* retains high viability after storage for 1 year (under room conditions). Therefore, additional experiments to test the germinability of *S. axillaris* pyrenes after various periods of storage are required.

Anyway, seed pre-treatment methods used in this research did not increase germination percentage or reduce MLD for some species which was the main aim of the treatment, therefore additional research to discover more appropriate seed pre-treatments is necessary to make direct seeding a success.

Effects of weed control on germination and dormancy

The presence or absence of weeds had no effect on the final germination per cent and MLD of twelve species in this study. Therefore, weed control is apparently not need in the initial stage of forest restoration by direct seeding. This result agrees with those from another study. In north-eastern Australia, weed competition did not affect germination of *A. petriei* seeds. There were no significant differences ($p>0.25$) in germination between the weed control treatments and the un-weeded treatments (Sun *et al*., 1995).

Effects of seed pre-treatment on survival per cent of seedling over one year after sowing

Seed pre-treatment (plus soil from mother tree) had little significant effect on some species increasing the survival percentage for none and significantly reducing it for *B. baccata* in the field. The reasons for this were probably seedling predation and desiccation.

Seed pre-treatment had no effect on the germination per cent and MLD of *B. baccata* but significantly reduced the survival per cent ($p<0.05$). Due to the soft structure (both leaf and stem) of young seedlings, *B. baccata* seedlings were consumed easily by insects especially ants (per.obs.). Woods and Elliott (2004) found that ants were the only predators observed in the area where this trial was established. Seedling predation might occur at different levels in different microhabitats (e.g. slope, light intensity, distance from the edge of the forest, etc.); the parameters, which were not measured in this study.

Effects of weed control on survival per cent of seedlings over one year after sowing

Weed control had different effects on different species, significantly increasing the survival per cent only for *C. brachiata* and significantly reducing it for *A. crassna*, *B. baccata* and *S. axillaris* and having little effect on *A. xylocarpa* and *S. oleosa*. The reasons for this were probably seed desiccation, which occurred at different levels due to the different characters of each species.

Survival of *B. baccata* seedlings was not affected by weed control in the subplot with non-pre-treated seeds ($p<0.05$). Conversely, weed control significantly reduced the survival per cent of *B. baccata* in the pre-treatment subplots ($p<0.05$), probably because of lack of shelter for young seedlings in the first few weeks after germination.

Weed control significantly reduced the survival per cent of *A. crassna* in the pre-treatment seeds ($p<0.05$), probably because of seedling desiccation after clearing weeds. Since *A. crassna* seedlings are weak, they could not survive after lack of shelter to protect them from strong sunlight and seedling predators.

This lack of major effects of vegetation clearing could be linked to two factors. First, cut vegetation could re-sprout rapidly, so there was little difference between weeded and non-weeded plots for most of the experimental period.

Secondly, it is important to note that in a harsh environment, rather than competing with tree seedlings, surrounding vegetation may act as a shelter for young seedlings, protecting them from excessive solar radiation and water stress (see examples of this nursery effect in Jobidon *et al*. (1998)). Instead of competition, weeds may be the supporter of small seedlings in the field, through screening direct sunlight and protecting the seedlings from desiccation. Similarly to Hardwick's (1999) conclusion, the effect of weeds is season-dependent. In her research, weeds reduced seedling survival and height growth for most species during rainy and cold seasons. During the hot season, weeds generally facilitated seedling survival. The facilitating effect of weeds in the hot season is probably due to the provision of shade. Final data, to analyse the survival per cent, was collected in June, which is at the end of the hot season. Seedlings lose moisture because of light without covering weeds. Scorched leaves were often noted in the records during monitored time.

Survival of seedlings of *E. fruticosa* and *S. arboreum* was not affected by weed control, both in the nursery and in the field ($p<0.05$), probably because they were strong enough to survive in fluctuating environments. *S. arboreum* seedlings have strong stems and large leaves. Therefore they could survive, even in direct sunlight and were not attractive to seedling predators.

Effects of weed control on seedling growth

Surprisingly weed control had no effect on the mean RCD, mean height and relative growth rates (of both RCD and height) of ten species that germinated in the field ($p<0.05$), measured 1year after sowing.

In contrast, studies conducted by Sun *et al*. (1995) in the Atherton Tablelands, Australia, found that early growth of *A. petriei* through direct seeding was affected largely by weed competition and site conditions. Results from both the glasshouse and field experiments indicated that weed competition severely limited the early growth of *A. petriei*. Sun *et al*. measured seedling height and biomass to measure early growth of seedlings, 6, 15, 25, 34, 42 and 52 weeks after seed germination but differently this study used RCD, height and relative growth rate for measurements monthly and finished in 8 months after seed germination.

Hardwick (1999) found that weeds help to protect seedlings during the dry season, from desiccation because in the hot season, the weed canopy had a beneficial effect on survival of seedlings (except some species that need high amount of light). In the cut treatment, seedlings of most species of her studied were observed to be suffering from brown and necrotic patches on the leaves which indicated scorching, implying that high leaf temperatures contributed to seedling death when the seedlings were exposed to direct solar radiation. Longer monitoring of seedlings in the study presented here may have yielded significant differences since in the second rainy season, as the seedlings grow bigger, competition with weeds is likely to become more intense.

Effects of seed pre-treatment on seedling growth

In the field, mean RCD of *A. crassna* seedlings (one year after sowing) was significantly lower than that of seedlings grown in the nursery ($p<0.05$), probably because of the longer MLD. The seeds took longer to germinate in the field, therefore seedlings had less time to grow.

Although, there was no significant difference in MLD of *A. xylocarpa* between seeds sown in the nursery and those sown in the field, RCD of both control and pre-treated seedlings in the field was significantly lower than for seedlings in the nursery (p<0.05) probably because of drought and the poor quality of soil in the study site. Therefore, the seedlings grew slowly.

Field conditions significantly lengthened MLD of *S. oleosa* (p<0.05) and relative growth rate of RCD was significantly reduced for both control and pre-treated seedlings (p<0.05). However, there was no significant reduction in RCD or height. Therefore, the delay in germination and slow growth had no effect.

The seeds used longer time to germinate in the field; therefore the seedlings had less time to synthesis their food and accumulate their tissues. In addition, poor quality of soil (lack of essential nutrients and compaction) might be a major factor that cause dwarf seedling in the field. The results from Sun *et al*. (1995) showed that compacted and eroded soils are inhospitable to the establishment of *A. petriei* seedlings. The soil restricted root penetration and lack of nutrients appeared to be the direct cause.

Comparing survival per cent and growth performance between direct seeded and nursery-raised seedlings in the field

Direct seeded seedlings performed much better in most aspects than seedlings grown in nursery and planted out after sowing for one year. Directed seeded plants of 4 out of the 6 species (*G. arborea*, *M. toosendan*, *P. cerasoides* and *S. arboreum*) tested had significantly higher survival rates than nursery-raised plants. In contrast, Espelta *et al*. (2003) studied an evaluation of reforestation methods to recover burned *Pinus nigra* forest in NE Spain, broadcasting and spot seeding were applied to be one part of the study, seedling establishing after sowing was very poor and they were excluded from data analysis because their almost complete failure.

Tree species of direct seeded (*M. toosendan*, *P. cerasoides* and *S. axillaris*) seedlings grew significantly taller than nursery-raised seedlings (p<0.05) within a year after sowing and the difference became even greater during the second year of growth and included two more direct seeded species (*G. arborea* and *O. indicum*), which grew significantly taller than nursery-raised seedlings in the second year. The roots of direct seeded seedlings could penetrate into the soil directly, whereas the root system from raised-nursery seedlings had been restricted in the containers. Nobody had compared the results of direct seeding in the field with planting nursery-raised seedling before, although same authors have compared planted nursery-raised seedlings with seeds sown at the same time. Löf *et al*. (2004) showed that four years after the start of the experiment, the heights of transplanted seedlings of beech, oak and wild cherry remained greater than seedlings derived from direct sowing ($p<0.01$). However, it was not a fair comparison since for direct seeded seedlings had less time for growing. Therefore, they could not grow taller than transplanted seedlings which had already had 1-2 years of growth in the nursery.

Similarly for RGR-height, four species (*M. toosendan*, *P. cerasoides*, *O. indicum* and *S. axillaris*) grew significantly faster as direct-seeded plants than as nursery-raised ones. Direct seeded plants had significantly higher relative growth rate of height than nursery-raised seedlings two years after sowing ($p<0.05$). In contrast, seeds of *Alphitonia petriei*, *Acacia aulacocarpa* and *Omalanthus populifolius* were sown in northern Queensland and showed similar growth rates between planted and direct seeded trees (Snell and Brooks, 1997).

Five species of seedlings grown from direct seeding (except *S. arboreum*) had significantly higher crown width than nursery-raised seedlings in both one year and two years after sowing ($p<0.05$) probably due to an efficient root system, which was an advantage of direct seeding.

Does direct seeding work- what is its place in forest restoration programs?

The objectives of this study were achieved to discover suitable species for forest restoration in northern Thailand although more species need to be tested systematically.

For certain suitable tree species, direct seeding could offer a cost-efficient alternative to out-planting nursery-raised trees for forest restoration projects, particularly in montane areas (Woods and Elliott, 2004). Direct seeding may give cost less than planting nursery-raised seedlings for forest restoration in northern Thailand. Establishment of direct seeded plants could save about 50%, compared with nursery-raised plants in the same scale. Most activities in a nursery; germination, potting and growing will be eliminated. In addition, a transferring cost and casual labours could be reduced during sowing season. Sun and Dickinson (1996) also indicated that, in comparison to the establishment of nursery grown seedlings (where labour input are high), direct seeding may reduce tree establishment costs by as much as 90% in the previous studies.

However, further study is needed to ensure wider applicability of the technique. Germination is crucial for the success of direct seeding. Candidate species should germinate easily and rapidly under field condition.

Further research on seed storage is particularly important if direct seeding is to be applied to species that fruit and disperse their seeds at times other than at the beginning of the rainy season to ensure that seeds do not lost their ability for germination at the time of sowing.

In this study, several of the seed pre-treatments applied failed to increase germination percent or reduce MLD in both nursery and field conditions, so more research needed to improve the methods that could break seed dormancy and accelerate germination per cent, especially in the field condition.

Conditions were strongly implicated as causing low germination or high mortality of young seedlings in the lowland site; therefore systematic screening is very important at the first stage, further study on establish suitable criteria of tree seed that appropriate for direct seeding in lowland site is needed especially an ability to germinate and survive in the field condition.

In this study it was impossible to separate the effects of mycorrhizae in soil from the mother tree from the effects of seed pre-treatment in field condition due to unclear plans. Therefore, further research on micro-symbionts in the original is needed to be established clearly because in most tropical soils, available phosphorus is very low and mycorrhizae constitute efficient root extension organs, involved in uptake and translocation of phosphate and other diffusion-limited nutrients. Thus, mycorrhizae play an important role in plant growth in the tropics (Munyanziza *et al*., 1997).

In this study the effects of seed predation were not taken into account when calculating per cent germination which might cause biased results, therefore further research needed are finding the seed predators in the site and their effects on seed germination.

In this study no fertilizer was applied. It is therefore recommended to repeat the work to test if fertilizer application could increase the number of species suitable for direct seeding. Suitable species and appropriate techniques are summarized in Table 9.

Table 9. Summary of several aspects of the candidate species over (A) 1 and (B) 2 years after sowing applied for direct seeding (in the field)

Species	**Per cent germin**[1]	**MLD**[2]	**Seedling survival**[3]	**Seedling growth**[4]	**Overall suitability for direct seeding**	**Notes – particular research questions raised etc.**	**Habitat elevation**
A. crassna[A]	A	A	M	M	Acceptable	e.g. Needs more work to boost field performance	1000-1100
B. baccata[A]	M	A	E	E	Excellent	e.g. Needs new treatments to increase germination	400-1350
C. brachiata[A]	U	A	M	M	Unacceptable	e.g. Could be suitable if a more effective seed pre-treatment could be found	425-1685
E. fruticosa[A]	E	A	E	E	Excellent		350-1525
S. arboreum[AB]	M	M	E	A	Acceptable		650-1400

Table 9. (Continued**)**

Species	**Per cent germin**^{1}	**MLD**^{2}	**Seedling survival**^{3}	**Seedling growth**^{4}	**Overall suitability for direct seeding**	**Notes – particular research questions raised etc.**	**Habitat elevation**
S. axillaris$^{\mathbf{AB}}$	U	M	A	E	A	e.g. Suitable seed storage needed	700-1600
A. xylocarpa$^{\mathbf{A}}$	A	A	M	M	Acceptable	e.g. Needs acceptable seedling height	350-500
A. lakoocha$^{\mathbf{A}}$	U	U	U	U	Unacceptable	e.g. More effective of systematic species screening for lowland site	550-1500
C. grewiifolia$^{\mathbf{A}}$	U	U	U	U	Unacceptable		350-500
E. cumini$^{\mathbf{A}}$	U	U	U	U	Unacceptable		375-650
S. oleosa$^{\mathbf{A}}$	A	M	A	U	Acceptable		350-600

Table 9. (Continued**)**

Species	**Per cent germin**[1]	**MLD**[2]	**Seedling survival**[3]	**Seedling growth**[4]	**Overall suitability for direct seeding**	**Notes – particular research questions raised etc.**	**Habitat elevation**
T. nudiflora[A]	E	A	U	E	Unacceptable	e.g. Needs more work on seedling survival	550-1050
G. arborea[B]	-	-	E	M	Acceptable		350-1475
M. toosendan[B]	-	-	E	E	Excellent		700-1450
P. cerasoides[B]	-	-	E	E	Excellent		1050-1685
O. indicum[B]	-	-	A	A	Acceptable		500-850

[1] Excellent = >70%, Acceptable = 50-70%; Marginal = 40-50%; Unacceptable =<40%

[2] Excellent = <20 days, Acceptable = 20-40 days; Marginal = 40-60 days; Unacceptable =>60 days

[3] Excellent = >70%, Acceptable = 50-70%; Marginal = 30-50%; Unacceptable =<30%

[4] Excellent = >80%, Acceptable = 50-80%; Marginal = 20-50%; Unacceptable =<20%

CHAPTER 6

Conclusions

1. Excellent tree species for direct seeding for forest restoration in highland sites were *B. baccata* and *E. fruticosa* (with seeds treated by soaking in water). They had high germination percentages (>50%), short dormancy (MLD < 30 days) and high survival per cent in the field (>70%). Acceptable species was *A. crassna* (with no seed treatment), it gave high germination percentage (>50%), intermediate dormancy (MLD 31-60 days) and medium survival percentage (>30%). In addition, *S. arboreum* and *S. axillaris* also have been suggested to be suitable species for direct seeding in northern Thailand. Although *S. arboreum* had an intermediate mean germination percentage and MLD, seedlings had very high survival percentage (>90%). For *S. axillaris*, although it had quite low germination percentage (<30%) and intermediate dormancy (MLD 31-60 days), seedlings had quite high relative growth rates for both RCD and height (>50% per year) and it showed significant means of RCD, height and crowd width in second year after sowing compared to raised nursery seedlings.

2. Based on 2nd year growth, *G. arborea M. toosendan* and *P. cerasoides* are also suggested for direct seeding through their significant higher means of RCD, height and crown width and the survival per cent of direct seeded than the raised-nursery seedlings in second year after sowing (p<0.05).

3. The harsh environment of the lowland forest site at Lamphun caused low performance of several species. *A. lakoocha*, *C. grewiifolia* and *E. cumini* failed to germinate in the field, because of seed desiccation. Suitable tree species, recommended for restoration of lowland forest are *A. xylocarpa* and *S. oleosa*. Seeds of *A. xylocarpa* (with scarification) had high germination percentage (>50%), short dormancy (MLD < 30 days) and seedlings had high survival per cent in the field (> 50%). Although, *S. oleosa* had intermediate dormancy (MLD 31-60 days), seedling survival was quite high (<60%).

4. Weed competition was not a serious problem in the first year after sowing. It had no effect on germination per cent, MLD and growth performance of most of the species in this study. Some species appeared to be nurtured and supported by the surrounding vegetation, which might protect them from strong sunlight and high temperatures.
5. Treatments used to increase germination per cent and reduce MLD had variable and inconsistent effects. Therefore more research to develop more reliable treatments to accelerate germination are required.
6. Establishment of direct seeded plants can reduce cost by about 50%, compared with nursery-raised plants. Costs of most activities in the nursery, for transport and for casual labour is reduced. Therefore, a large direct seeding component may suitable for forest restoration projects with low budgets.

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Appendix

Species studied descriptions **(Reference from a Field Guide to Forest Trees of Northern Thailand, Gardner *et al*., 2000)**

Afzelia xylocarpa (Kurz) Craib (Leguminosae, Caesalpinioideae)

(มะค่าโมง, มะค่าหลวง)

Deciduous tree to 30m with broad, rounded crown & stout trunk, up to 100 cm diam. or more, usually dividing near base into large, spreading branches. **BARK** pale grey or yellowish, slightly rough. **LEAF** 18-25 cm, even-pinnate with 3-5 pairs of opposite leaflets, 5-9x4-5 cm, elliptic with blunt or slightly notched tips & rounded base. Young shoots slightly hairy, mature leaves completely smooth, sometimes slightly glaucous below. Leaflet stalks 0.3-0.5 cm, twisted, stipules minute & falling early. **FLOWER** 2.5-3.5 cm, in branches clusters at end of twigs, 5-15 cm, individual stalks 0.7-1 cm, 4 sepals, 1-1.2 cm, bright green, oblong, finely velvety outside. Single green or reddish petal with long thin stalk, much larger than sepals. 7-8 fertile stamens, as long as petal, 3 much shorter infertile onces, single slender style with tiny stigma, ovary hairy with narrow stalk. **FRUIT** 12-20x7-9 cm, thick & woody, dark brown or almost black, splitting into 2 section. 2-4 seeds, 2.5-3 cm, black with fleshy orange coat at one end, arranged across the pods with thin partitions between them.

Aquilaria crassna Pierre ex Lec. (Thymelaceae)

(กฤษณา, ไม้หอม)

Evergreen tree to 30 m with narrow crown and slender, drooping branches. **BARK** brownish-grey, shallowly fissured and flaking in thin strips, inner bark pale yellow with patches of fragrant, dork-colored resin in old trees. **LEAF** 6-11x3-5 cm, simple, alternate, spirally-arranged, lanceolate or narrowly elliptic with tapering tip and blunt or pointed base, untoothed but often wavy. Young shoots densely silvery silky-hairy, mature leaves leathery, dork green above, smooth or with scattered silky hairs on main veins below. 3 main veins from base, 12-19 pairs of faint side veins with many parallel intermediated ones. reaching margin, tertiary veins ladder-like. Stalks

0.2-0.7 cm, no stipules. **FLOWER** 0.6-0.8 cm, white or pale green, regular, bisexual, in simple clusters (fascicles) at or opposite upper leaf axils, Individual stalks 0.6-1 cm, slender, silky-hairy, main stalks 0.3-1 cm. Calyx (perianth) bell-shaped with 5 lopes, 3-4 mm, no corolla but with 10 hairy petal-like scales attached to mouth of calyx tube opposite lobes, ±1 mm 10 stamens in 2 rows, fused to mouth of calyx, ± as long as lobes. Style <1 mm, stigma 2-4 lobes, ovary superior, brown-hairy, no disc. **FRUIT** 2.2-4 cm, bright green, silky-hairy when young, obovoid or oval with a narrow longitudinal ridge and persisstent enlarged calyx at base, thinly leathery, becoming strongly wrinkled and eventually splitting into 2 sections, 1(2) glossy seeds with a long, tail-like appendage.

Artocarpus lakoocha Roxb. (Moraceae)

(หาด, ขนุนป่า)

Deciduous tree to 24 cm. **BARK** red-brown to dark brown, becoming rough and scaly with age. **LEAF** 10-30x5-15 cm, alternate, ±planar, oval to broadly ovate or obovate with blunt or shortly pointed tip and rounded or slightly heart-shaped base, often asymmetric, untoothed or with minute teeth. Young shoots densely red-brown hairy, mature leaves leathery, dark green and slightly rough above, grey-green and finely hairy below. 8-20 pairs of conspicuous side veins, joined at margin, obvious network of smaller vein, joined at margin, obvious network of smaller veins. Stalks 1.4-3.3 cm, finely brown-hairy with small lanceolate stipules with fall early. Twigs rather stout, without ring scars. **FLOWER** heads dirty yellow to pale pink or orange, solitary at leaf axils or just behind leaves. Male heads 0.8-2 cm. Female heads 1.2-2.3 cm, oval or oblong, stalks 2.5-3.5 cm **FRUIT** 2.5-8 cm, stalks 1.2-3.8 cm, pale yellow or orange, irregularly globose or fist-shaped, knobbly and velvety outside, pink inside with many oblong seeds, ±1.2 cm.

Balakata baccata (Roxb.) Esser. (Euphorbiaceae)

(โพบาย, สลีนก)

Large evergreen tree to 35m, with spreading rounded crow & thick steeply ascending branches with drooping tips. Trunk stout, up to 200 cm diameter, slightly buttressed when older. **BARK** pale grey & quite smooth with large lenticels when young, becoming dark grey-brown & deeply fissured with age, inner bark pale yellow, no latex in trunk but often with white latex in twigs. **LEAF** 8-18x3-8 cm, alternate, spiral, elliptic or ovate with pointed or tapering tip & blunt or rounded base, slightly peltate in younger trees, untoothed, completely smooth. Young leaves red-purple, mature leaves dark green above, grey-green (glaucous) below, usaully reddish along margins & on stalks, with 2 dark knop-like glands at base of leaf. 11-13 pairs of ±parallel side veins, tertiary veins ladder-like. Stalks 3-7.5 cm, slender, slightly swoolen at both ends, Stipules small & falling early. Old leaves clear yellow but with red stalks. **FLOWER** minute, in branches spike-like clusters at end of twigs & upper leaf axils, 4-22 cm, all males or with males & females in same cluster. Males in group of 6 in axil of an obovate bract, ±1 mm, flanked by 2 large oblong glands. 2-3 sepals fused into a toothed cup, ±1mm, no petals, 2 stamens, no disc. Females solitary, ±5 mm, calyx as males but larger, 2 styles, slightly fused at base, 1-1.5 mm. **FRUIT** 0.8-1.3 cm, dark green with grayish dusting & whitish sap when young, ripening dark purple-black, pearshaped or subglobose, ± slightly 2-lobed, with 2 small recurved styles at top & persistent calyx at base. Individual stalks slender, 0.6-0.9 cm. Outer layer thin, not splitting, with leathery inner layer & 2 black seeds which remain attached to the central column for along time after fruits disintegrate.

Carallia brachiata (Lour.) Merr. (Rhizophoraceae)

(เฉียงพร้านางแอ, ส้มป้อง)

Evergreen tree to 20 m, usually much smaller. **BARK** pale creamy brown to warm red-brown, quite smooth with many lenticels. **LEAF** 4-17x2.5-8 cm, simple, opposite-planar, oval to broadly obovate with blunt or abrupt tip and slightly pointed base, untooted or with scattered fine teeth. Mature leaves leathery, completely smooth, glossy dark green above, yellow-green with many tiny dark dots below. At least 15 pairs of side veins with many intermediate ones, looped near margin, mid vein sunken above. Stalks 0.4-1 cm, stout. Buds narrowly conical, thinly coated with resin, enclosed by a pair of large (1-2 cm) stipules which fall early, leaving distinct ring scars. Twigs dark brown, slightly swollen at nodes. **FLOWER** ±0.6 cm, white or pale yellow-green, bisexual, in head-like cluster (cymes) at leaf axils. Individual flowers without stalks, main stalks 1-2.5(6) cm. Calyx bell-shaped with 5-8 free petals with short stalks, 10-16 slender stamens, petals and stamens attached to top of calyx tube around a thin disc, 1 slender style with 3-4 lobed stihma, all parts completely smooth.

FRUIT 0.5-1(1.8) cm, pale reddish-orange to dark red-purple, globose with persistent calyx teeth at top, slightly grooved, fleshly with 1(2) large kidney-shaped seeds surrounded by a thin orange coating (aril).

Casearia grewiifolia **Vent. var.** ***grewiifolia*** **(Flacourtiaceae)**

(กรวยป่า, ก้วย)

Deciduous tree to 24 m, slightly buttressed when older. **BARK** pale brown, smooth, without thorns, inner bark pale orange, gritty. **LEAF** 8-18x3.5-6 cm, narrowly oblong with tapering tip, finely toothed, covered with short translucent dashes (only visible when held up to a strong light). 8-12 pairs of side veins with a delicate network of smaller ones. Stalks 0.6-1.0 cm, with small (1.5 mm) triangular stipules which fall early. Twigs smooth, dark brown, zigzagging. **FLOWER** tiny, green, bisexual, clustered in leaf axils or on okd leafless branches. 4-5 sepals, 2-3 mm, no petals, 8-10 fertile stamens, alternating with as many infertile ones, 1 styles. **FRUIT** 3.5-5 cm, 3-angled, splitting into 3 sections, seeds with bright reddish-orange coat (aril).

Eugenia cumini **(L.) Druce (Myrtaceae)**

(หว้าขี้แพะ)

Evergreen tree to 25 m, sometimes partly deciduous in drier sites. **BARK** grey, slightly flaking, inner bark reddish. **LEAF** 6-10(15)x 3-7 cm, rarroly elliptic or oblong with slightly tapering tip and pointed or blunt base. 19-30 pairs of faint side veins, 1 marginal vein, midvein sunken. Stalks 0.6-2.8 cm, quite slender. Twigs pale grey and squarish when young. Old leaves red. **FLOWER** ±1 cm, white or cream, in branched clusters usually behind leaves, 4.5-10 cm, individual flowers without stalks, main stalks rounded or slightly angled. Buds 1-3 mm, calyx cup 2.5-6 mm, funnel shaped with 1-2 mm stalk and 4 obscure teeth. 4 petals, 2 mm, joined into a cap and falling as soon as flower opens, scattered glands. Outer stamens 4-6 mm, style 2-6.5 mm, stout. **FRUIT** 0.8-2 cm ovoid or oblong, pink turning dark red-purple or black, juicy, edible.

Eugenia fruticosa DC. (Myrtaceae)

(หว้าขี้กวาง)

Tree to 12 m, very similar to E. cumini **LEAF** 7-12x3-6 cm, 12-16 pairs of side veins, 2-6 mm apart. Stalks slightly winged, twigs brown, rather squarish. **FLOWER** main stalks short, axes distinctly 4-angled. Calyx cup 2-3 mm, with very short stalk (<0.5 mm) outer stamens and style 2-4.5 mm. **FRUIT** 0.8-1.3 cm, globose or ovoid.

Gmelina arborea Roxb. (Verbenaceae)

(ซ้อ, แต้งขาว)

Deciduous trees to 25 cm with a narrow crown and slender, dropping branches. **BARK** pale creamy-brown or greyish, smooth with pale corky lenticels, becoming cracked and flaking with age, inner bark cream. **LEAF** 10-19x7-15 cm, simple, clustered near end of twigs, oval or broadly ovate to nearly triangular with shortly tapering tip and blunt, flattened or slightly heart-shaped base, untoothed. Young shoots densely covered with yellowish star-shaped hairs, mature leaves smooth or with scatterd hairs especially below, often glaucous. 3(5) basal veins, 4-7 pairs of side veins. Stalks 4-11 cm, slender, with a pair of rounded glands at the top. **FLOWER** 2.5-3.5 cm, yellow-brown, in narrow branched clusters (thyrses) at end of leafless twigs and in axils of fallen leaves, stalks densely hairy with small linear bracts at base. Calyx 0.3-0.4 cm, cup-shaped wit 4-5 short teeth, densely brown-hairy outside. Corolla funnel-shaped with a wide mouth and 5 very unequal lobes, the upper 2 fused together and curved slightly backwards, the lower 3 fused together and curved forward with the middle lobe much larger than the side ones, usually densely hairy outside. 4 stamens, one pair longer than the other, attached to corolla tube and projecting slightly beyond the mouth. Style short with 2 small, unequal stigmas, ovary smooth. **FRUIT** 2-3.2 cm, greenish-yellow, smooth and slightly glossy, globose or obovoid with persistent calyx at base, fleshy with a hard 1-2 seeded stone.

Melia toosendan Sieb. & Zucc. (Meliaceae)

(เกรียน, เลี่ยนดอกม่วง)

Deciduous tree to 25 m with very open crow and widely spreading branches. **BARK** pale grey or brown with narrow fissures, inner bark cream. **LEAF** bipinnate or tripinnate, clustered near end of twigs, 4-5 pairs of side stalks each with 2-5 pairs of opposite leaflets, 3-7 x 1.2-2 cm, ovate with narrow tips, margin usually with scattered irregular teeth. Mature leaflets smooth, sometimes with whitish powder below (glaucous). Leaflet stalks 0.2-0.4 cm. **FLOWER** 2.5-3 cm, white with violet centre, in large open branched clusters grouped near end of twigs. 5-6 small curved backwards. Stamen tube violet, cylindrical, as long as petals, 8-10 anthers attached just below rim between teeth. Single slender style as long as stamen tube with unlobed stigma. **FRUIT** 1.6-2 cm, green, thinly-fleshy, 6-8 lobes each with a single small stone.

Oroxylum indicum (L.) Kurz (Bignoniaceae)

(เพกา, มะลิดไม้)

Evergreen or semi-deciduous tree to 10(20) m. Young trees have a single main stem with the leaves clustered at the top like a palm tree. After flowering the stem splits, developing into an irregular, sparsely branched crown. **BARK** pale creamy brown or pale grey, smooth or finely cracked with large leaf scars on younger trees. **LEAF** up to 150 cm, 3 or 4x pinnate with upper side stalks once divided, middle ones twice divided and lower ones 3x divided, giving the whole leaf a triangular appearance. Leaflets 5-10 cm, oval or broadly ovate, long-tipped, not toothed, smooth or with scattered very short white hairs below. Leaflets stalks 5-8 mm, side stalks and main stalk arched, swollen at base and at nodes. **FLOWER** 8-12 cm, reddish-brown or purple outside, greyish-white or cream inside, clustered near top of an upright, fleshy stem at end of twigs, 60-180 cm, usually with both flowers and fruits together on the same stem. Calyx 2-4 cm, irregularly lobed or unlobed. Corolla trumpet-shaped, thick and wrinkled with scattered glands outside and dense hairs inside. 5 stamens, hairly at base. **FRUIT** 30 to 120 cm, dark brown, flattened, slightly curved at base with a fine ridge on each side, woody, splitting into 2 sections lengthways. Seeds 4-8 cm, flat with a broad, semi-transparent wing.

Prunus cerasoides D. Don (Rosaceae)

(นางพญาเสือโคร่ง)

Deciduous tree to 18 m. BARK red-brown, shiny, peeling in horizontal strips with large tan lenticels. LEAF 5-12 x 3-5 cm, narrowly ovate with tapering tip and blunt or rounded base, sharply toothed, with 2-4 orange glands on margin near base of leaf or at top of stalk. Stalks 0.8-1.5 cm, slender with large, deeply divided stipules, soon falling. FLOWER 1-2.5 cm, bright pink or rarely white, in clusters with or without a common stalk, often 3-flowered, individual stalks slender, 0.7-2 cm, no hairs, behind young leaves. Calyx pink, with triangular lobes, smooth. Ovary without hairs. FRUIT 1-1.5 cm, ellipsoid (ovoid), pink or bright red and shiny, thinly fleshy, with single bony, wrinkled stone (pyrene).

Sarcosperma arboreum Bth. (Sapotaceae)

(มะยาง, เหมือดหอม)

Evergreen tree to 14 m. **BARK** red brown or creamy-brown, smooth or shallowly fissured, corky, inner bark pale cream. **LEAF** 16-26x5-8 cm, rarely to 35x13 cm, opposite, oblong or lanceolate with tapering or abrupt tip and pointed base, untoothed. Mature leaves leathery, dark green above, completely smooth with colorless crater-like glands in vein axils, ± 1 mm, 6-14 pairs of prominent arching side veins, open at margin, tertiary veins ladder-like, ± at right angles to midvein, raised both sides. Stalks 1.2-2.5 cm, flat at both ends, with inconspicuous stipules which soon fall, leaving triangular scars ± 1mm. **FLOWER** pale yellow or greenish, midly fragrant, in slender branched or unbranched clusters at leaf axils, 5-20 cm, stalks finely hairy. Calyx 2.5-3.5 mm with 5 rounded lobes in a single row, subequal, strongly overlapping, densely hairly outside. Corolla tube ±2 mm with 5 rounded lobes, 2-2.5 mm, overlapping in bud. 5 fertiles stamens alternating with tiny sterile ones, attached to corolla tube with short filaments and oblong anthers. Ovary smooth. **FRUIT** ± 2.5 cm, dark purple with pale grey sheen which easily rubs off, ellipsoid with blunt tip and persistent recurved calyx at base, firmly fleshy, 1-2 dark brown seeds.

***Schleichera oleosa* (Lour.) Oken (Sapindaceae)**

(ตะคร้อ, มะโจ้ก)

Deciduous tree to 25 m with irregular crown, short trunk and large, spreading brances. **BARK** creamy-brown, slightly flaking, becoming dark grey and more or less deeply cracked with age, inner bark cream or pink, turning brownish when cut. **LEAF** 25-46 cm, odd- or even-pinnate, 1-4 pairs of opposite leaflets, with or without an end one, upper pairs much larger, 7-30x4-11 cm, oval or broadly obovate with short tip (rarely notched) and blunt or rounded base, usually slightly asymmetric, no teeth. Young leaves silky-hairy, dark red-purple, quickly changing to pale green, mature leaves thin, completely smooth or with hairy glands (domatia) in vein axils below. 10-21 pairs of side veins, not joined or joined near apex only. Leaflet stalks 0.1-0.2 cm, main stalks 5-17 cm. **FLOWER** ±0.5 cm, pale green or yellow-green, slender branched or unbranched clusters in leaf axils, to 19 cm. Individual stalks ±0.3 cm. 4-6 triangular sepals, subequal, white-hairy outside, no petals. 5-9 slender stamens, 2-3x longer than calyx, usually slightly hairy, disc thin and wavy but not broken, stigma 3-4 lobed. Bisexual and male flowers usually on different trees. **FRUIT** 1.5-2.5 cm, bright green, turning brownish, globose with short tip, ont lobed, smooth or with a few soft points, thin-skinned, not splitting. 1-2 brown seeds covered with thing pale yellow or translucent jelly-like coat (sarcotesta).

***Spondias axillaris* Roxb (Anacardiaceae)**

(มะมือ, มะกอกหนัง)

Briefly deciduous tree to 30 m. **BARK** dark grey or red-brown, cracked and peeling in vertical flakes, inner bark red. **LEAF** odd-pinnate, 3(5)-13 pairs of opposite leaflets, 7-13x3-5 cm, upper ones largest , narrowly ovate or lanceolate with tapering tips and oblique base, young leaves with scattered teeth, mature leaves of ten without teeth. 8-16 pairs of side veins, often with tufts of hairs in axils, no marginal vein. Side leaflet stalks 0.7-1.3 cm, end one 1.5-4 cm. **FLOWER** 0.4-0.5 cm, dark red, males in large branched clusters at end of twigs and upper leaf axils, bisexuals in small groups of 2-3 flowers in leaf axils. Calys <2 mm, 5 lobed, dark red-purple, smooth outside, glandular-hairy inside. 5 petals, pointed, smooth, overlapping. 10 stamens alternating with disc lobes, bisexuals with 5 very short styles near top of large, globular ovary.

FRUIT 2-3 cm, green or yellow, ovoid with 5 depressions at top, single large stone with up to 5 holes at top and the same number of seeds.

Trewia nudiflora **L. (Euphorbiaceae)**

(มะฝ่อ, มะปอบ)

Briefly deciduous tree to 25 with irregular crown, large spreading branches and stout trunk. **BARK** grey-brown, often with paler patches, smooth or flaking in thin pieces when older. **LEAF** 8-22x5-16 cm, (sub) opposite in 2 rows, ovate or triangular with tapering or pointed tip and flattened or heart-shaped base, never peltate, not toothed. Young leaves densely coated with star-shaped hairs, mature leaves thin, yellow-green, with star-shaped hairs at least on veins below. 3-5 basal veins, ±½ as long as leaf, 3-6 pairs of side veins with indistinct glands in axils. Stalks 4-7(10) cm, hairy, stipules narrowly triangular, 2-3 mm, fallin early. **FLOWER** greenish, flowering when leafless or with young leaves, males and females on different trees. Males ± 1 cm, in drooping unbranceed clusters with densely hairy axes, 7-20 cm. Individual stalks slender, ± 5 mm. (3)5 sepals, ± 4 mm, hairy especially outside, no petals, 60-90 stamens, no disc. Females in smaller clusters of 1-4 flowers, 3-8 cm. Calyx spathelike, splitting irregularly into 2-4 lobes, ±5 mm, finely hairy. 2-6 styles, ± 20 mm, fused together near base, with recurved feathery stigmas. Ovary 5 mm, hairy, no disc. **FRUIT** 1.6-3.4 cm, pale green ripening brownish-yellow when ripe, globose, not splitting. Outer layer leathery and slightly rough with pale cream "potato-like" flesh surrounding a thin crusty stone, containing 2-5 hard black seeds, ±8 mm.

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