EFFECTS OF ROOT AIR–PRUNING ON FRAMWORK TREE SPECIES SEEDLINGS PRODUCTION FOR FOREST RESTORATION IN NORTHERN AND SOUTHERN THAILAND

PREEYAPHAT CHAIKLANG

MASTER OF SCIENCE
IN ENVIRONMENTAL SCIENCE

GRADUATE SCHOOL
CHIANG MAI UNIVERSITY
MAY 2020

EFFECTS OF ROOT AIR–PRUNING ON FRAMWORK TREE SPECIES SEEDLINGS PRODUCTION FOR FOREST RESTORATION IN NORTHERN AND SOUTHERN THAILAND

PREEYAPHAT CHAIKLANG

MASTER OF SCIENCE
IN ENVIRONMENTAL SCIENCE

GRADUATE SCHOOL
CHIANG MAI UNIVERSITY
MAY 2020

EFFECTS OF ROOT AIR–PRUNING ON FRAMWORK TREE SPECIES SEEDLINGS PRODUCTION FOR FOREST RESTORATION IN NORTHERN AND SOUTHERN THAILAND

PREEYAPHAT CHAIKLANG

A THESIS SUBMITTED TO CHIANG MAI UNIVERSITY IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE DEGREE OF MASTER OF SCIENCE
IN ENVIRONMENTAL SCIENCE

GRADUATE SCHOOL, CHIANG MAI UNIVERSITY
MAY 2020

EFFECTS OF ROOT AIR–PRUNING ON FRAMWORK TREE SPECIES SEEDLINGS PRODUCTION FOR FOREST RESTORATION IN NORTHERN AND SOUTHERN THAILAND

PREEYAPHAT CHAIKLANG

THIS THESIS HAS BEEN APPROVED TO BE A PARTIAL FULFILLMENT
OF THE REQUIREMENTS FOR THE DEGREE OF
MASTER OF SCIENCE
IN ENVIRONMENTAL SCIENCE

Examination Committee:

…….....Chairman
(Dr. Cherdsak Kuaraksa)

…….....Member
(Asst. Prof. Dr. Sutthathorn Chairuangsri)

…….....Member
(Asst. Prof. Dr. Pimonrat Tiansawat)

…….....Member
(Dr. Stephen Elliott)

Advisory Committee:

……Advisor
(Asst. Prof. Dr. Sutthathorn Chairuangsri)

……Co-advisor
(Asst. Prof. Dr. Pimonrat Tiansawat)

28 May 2020

ACKNOWLEDGMENTS

First of all, I would like to express sincere to my advisor, Asst. Prof. Dr. Sutthathorn Chairuangsri of Biology Department, Faculty of Science, Chiang Mai University for the continuous support of my master's study and related to this research, for her motivation, and immense knowledge as well as giving me extraordinary experience throughout my work. Dr. Stephen Elliott, of Biology Department, Chiang Mai University that my thesis supervisor is thanked for his good advice, recommendations, and corrections of my thesis, since the start until completion. I also thank Asst. Prof. Dr. Pimonrat Tiansawat of Biology Department, Chiang Mai University that my data science co-advisor, for suggesting this project, help in seedling production descriptions.

I thank the forest in Doi Suthep-Pui National Park, which provided many trees to produce a new generation of researchers and The Forest Restoration Research Unit (FORRU) for providing assistance to carry out field works and also laboratory works successfully including the environmental science program of Chiang Mai University, for all kinds of support and equipment. And also thank Khao Pra Bang Khram Wildlife Sanctuary for supporting the research of the nursery and forest.

My sincere thanks are members of the Forest Restoration Research Unit (FORRU) for their countless assistance during fieldwork. Especially, Miss Kwanpirom Naruangsri for her kindness to help me during my experiments. Thank extended to FORRU staff: Thongyoy, Thonglao at Chiang Mai nursery for much to help for seed collecting and help my experiments. Also thanks to Krabi's FORRU staff: Apisit, Aood, and Taweesak for much help in the forest area and the nursery. I thank all my colleagues from the Environmental Science Program for experiences shared and a great bond of love and understanding.

I am grateful to the Center of Excellence on Biodiversity (BDC) for providing scholarships and finances to achieve my master's degree comfortably. Finally, I am really grateful to my family for their love and good wished to me all the time.

Preeyaphat Chaiklang

หัวข้อวิทยานิพนธ์	ผลของการใช้อากาศกำจัดรากต่อการผลิตกล้าพรรณไม้โครงสร้างสำหรับฟื้นฟูป่าในภาคเหนือและภาคใต้ของประเทศไทย	
ผู้เขียน	นางสาวปรียาภัทร์ ใจกลาง	
ปริญญา	วิทยาศาสตรมหาบัณฑิต (วิทยาศาสตร์สิ่งแวดล้อม)	
คณะกรรมการที่ปรึกษา	ผศ.ดร. สุทธาธร ไชยเรืองศรี	อาจารย์ที่ปรึกษาหลัก
	ผศ.ดร. พิมลรัตน์ เทียนสวัสดิ์	อาจารย์ที่ปรึกษาร่วม

บทคัดย่อ

การฟื้นฟูป่าด้วยพันธุ์ไม้โครงสร้างถือเครื่องมือสำคัญในการช่วยฟื้นฟูระบบนิเวศ วิธีการนี้ต้องอาศัยกล้าไม้ที่มีคุณภาพหลากหลายชนิด ซึ่งถือเป็นหนึ่งในค่าใช้จ่ายหลักในการการฟื้นฟูป่า งานวิจัยนี้มีวัตถุประสงค์เพื่อเปรียบเทียบกระบวนการผลิตกล้าไม้ 3 แบบ ได้แก่ การเพาะกล้าในภาชนะพร้อมขนย้าย, การกำจัดรากโดยใช้อากาศในภาชนะพร้อมขนย้าย และการผลิตกล้าแบบปกติกับกล้าไม้พรรณไม้โครงสร้างจำนวน 10 ชนิด ในพื้นที่ภาคเหนือ (จังหวัดเชียงใหม่) และภาคใต้ (จังหวัดกระบี่) ของประเทศไทย การทดลองได้ทำการบันทึกข้อมูลการเจริญเติบโตของต้นกล้าทุกเดือน และหลังจาก 6 เดือนเก็บตัวอย่างเพื่อหาน้ำหนักแห้ง ลักษณะและข้อมูลของราก รวมถึงค่าใช้จ่ายทั้งหมดของแต่ละวิธี จากผลการศึกษาพบว่ากล้าไม้ทั้ง 10 ชนิดมีอัตราการเจริญเติบโตในส่วนของความสูง, เส้นรอบวงคอราก ของพืชแต่ละชุดการทดลองและแต่ละสายพันธุ์มีความแตกต่างกันอย่าง มีนัยสำคัญ ($P<.05$) นอกจากนี้ยังพบว่าสุขภาพและลักษณะของรากมีความแตกต่างกันอย่างมีนัยสำคัญ ($P<.05$) ในบางสายพันธุ์พืช อีกทั้งการผลิตกล้าไม้ในภาชนะพร้อมขนย้าย และการกำจัดรากโดยใช้อากาศในภาชนะพร้อมขนย้าย ให้ผลการศึกษาของระบบรากที่มีการพัฒนาดี โดยการกำจัดรากโดยใช้อากาศสามารถเพิ่มการแตกแขนงของระบบราก และลดปริมาณการขดงอของราก ลดอัตราการตายของต้นกล้า และปริมาณของรากที่งอกทะลุถุงปลูก ซึ่งเป็นสาเหตุที่อันตรายต่อต้นกล้าที่จะขนย้ายไปยังแปลงฟื้นฟู รวมถึงมีชีวมวลที่มากกว่าเมื่อเทียบกับการผลิตกล้าไม้แบบปกติ อีกทั้งยังพบว่าการผลิตกล้าไม้ด้วยกำจัดรากโดยใช้อากาศ สามารถช่วยลดต้นทุนโดยเฉพาะในส่วนของแรงงานในการผลิตกล้าไม้ได้ ดังนั้นวิธีการผลิตต้นกล้าแบบการใช้อากาศกำจัดรากสามารถนำไปประยุกต์ใช้เพื่อการพัฒนาคุณภาพของการผลิตต้นกล้าในจำนวนมากต่อไป

Thesis Title	Effects of Root Air-Pruning on Framework Tree Species Seedlings Production for Forest Restoration in Northern and Southern Thailand	
Author	Ms. Preeyaphat Chaiklang	
Degree	Master of Science (Environmental Science)	
Advisory Committee	Asst. Prof. Dr. Sutthathorn Chairuangsri	Advisor
	Asst. Prof. Dr. Pimonrat Tiansawat	Co-advisor

ABSTRACT

Tree planting is a simple tool to bring back the forest area. Therefore, seedling production is one of the important steps in forest restoration. Root pruning can promote the root system development of a nursery tree. However, there are consumed a lot of time and labor. Consequently, Air pruning is another efficient method of propagating seedlings for reforestation projects. The study was aimed to determine the effects of air-pruning technique on the growth rate of framework species seedlings and determined about the production cost. The filed study in Forest restoration research unit (FORRU) tree nursery conditions in Northern and Southern of Thailand. Ten framework tree species studies used to comparing 3 different seedling production processes; 1) using crate - steam lining (COG), 2) air-pruning + crate (CAP) and 3) control (CON). Recorded growth rate of ten tree species every month for 6 month and sixth month collect root dry weight and root architecture included comparison a total cost. The results showed that there was a significant difference ($P<.05$) of three treatments in their seedling growth rate. In addition, the COG and CAP improved the root system that was effective fibrous root development, reduced mortality rate. Moreover, the economic viability of root air-pruning can be reduced total cost and labor. The COG technique was more cost-effective than the other two techniques-producing seedling sat below 20 THB each while CAP may reduce the cost of seedling production in long term time period. Therefore, root air-pruning will also help in preparation processes efficiently and management of seedlings production.

CONTENTS

LIST OF TABLES

Page

LIST OF FIGURES

Page

LIST OF ABBREVIATION

°C	Celsius
cm^3	Cubic centimeter
cm	Centimeter
CAP	Crate with air-pruning treatment
CON	Control treatment
COG	Crate on ground treatment
FORRU	Forest restoration research unit
g	Gram
GFW	Global Forest Watch
ha	Hectare
IUCN	International Union for Conservation of Nature
km^2	Square kilometer
m	Meter
mm	Millimeter
T1	Treatment 1
T2	Treatment 2
T3	Treatment 3
R1	Replicate 1
R2	Replicate 2
R3	Replicate 3
RCBD	Randomized complete block design
RPM	Root production method
UN	United Nations
WWF	World-Wide Fund for Nature

CHAPTER 1

Introduction

Tropical forests have the highest biodiversity and primary productivity of any of the terrestrial biomes (Forseth, 2010). In particular, tropical rainforests support higher biodiversity than any other ecosystem. They are home to 50 percent of the Earth's described plant and animal species (Forseth, 2010), and they play a huge role in reducing atmospheric carbon dioxide levels (FAO, 2013). In 2017, around 29.4 million hectares (72.6 million acres) of tree cover disappeared. That's an area equivalent to 41 million soccer pitches and just slightly below the record set in 2016, according to the latest figures from Global Forest Watch (GFW, 2018). Moreover, the area of primary forest decreased in the tropical climatic domain. Particularly in the developing tropical countries, the forest is rapidly being depleted, including Southeast Asia-in Laos, Cambodia, Thailand, Myanmar, and Malaysia. Deforestation is a primary concern in Thailand. From 1973 to 2014 (FAO, 2015) the estimated annual deforestation rate was 0.6% or 140,000 hectares. Forest loss is linked to biodiversity loss and global climate change, due to increases in atmospheric carbon dioxide levels; the latter particularly due to forest fires. Consequently, tree planting could be a useful tool to restore forest ecosystems that play a key role in protecting and enhancing biodiversity and mitigating climate change.

The Royal Forestry Department of Thailand recently announced Volume 12 of the National Economic and Social Development Plan, under which the target was set to increase forest cover to 40 percent or 205,456 km^2 of the kingdom's land surface within 20 years from 2017 to 2036 (25 percent for conservation forest and 15 percent for economics forest). The goal is to reduce biodiversity losses. In 2016, the World-Wide Fund for Nature (WWF) reported that forest cover in Thailand was approximately 30% (95 million Rai or 15.2 million hectare). Therefore, to reach the 40% target, approximately 33 million Rai or 5.28 million

ha must be restored to forest by assisted natural regeneration and/or tree planting to bring initial tree density up to 500/rai calculated according to the protocol of FORRU, 2009).

Where natural regeneration is slow or sparse, tree planting is simple tool that can rapidly restore forest ecosystem and increase forest cover. The most common method is to plant nursery-raised saplings. Therefore, planting stock production is an important step. Planting stock quality strongly influences Seedlings quality is one of the factors that determine survival and growth of saplings post-planting (Duryea, 1984). Forest restoration requires high quality saplings. Their health, growth rate, crown development, flowering and fruiting, are all components of planting stock "quality" (Davis and Jacobs, 2005). Thus, for successful out-planting, high quality seedlings should be secured at an affordable cost. Nonetheless, standard nursery practices-particularly standing down of containerized planting stock on the ground-often allow roots to grow out of containers into the underlying substrate. This causes transplantation shock as roots break when the trees are lifted for transportation to the planting sites. Root-pruning overcomes this problem (Andersen et al., 2000). It also induces root branching and the development of a compact root ball. However, manual root-pruning is laborious. Air pruning requires less effort (Figure 1.3). It happens naturally when roots are exposed to air of low humidity (Walker, 2005). The root apex dehydrates and stops growing, followed by development of more secondary roots within containers. Air pruning may also reduce the total cost of nursery production of saplings. Despite the existence of a substantial amount of information on how to produce high-quality seedlings, there is still a need to develop practices that can be used in nurseries and at planting sites to be able to produce well-growing forest stands in ever-changing environments (Riikonen and Luoranen, 2018). Many root-pruning and air pruning research studies have focused on commercial species, such as hazelnut production in the Hazelnut industry (Wu, 2013). Little information is available about the effects of root-pruning on forest tree production, particularly framework species and impact on the economics of sapling production.

Consequently, this study tested 3 seedling production processes in a small-scale native tree nursery, to reduce sapling production costs and increase sapling quality.

1.1 Literature review

Forests support rural livelihoods by providing watershed services, food, fuel, and medicines, included contributes to economic development (UN, 2013). They also provide habitat to millions of million species which about 80% of the world's documented species can be found in tropical rainforests (WWF, 2011). Approximately 2.6 billion tons of carbon dioxide, one-third of the CO_2 released from burning fossil fuels, is absorbed by forests every year (IUCN 2016). Tropical forest sequester carbon in both above-and below-ground biomass. Karsenty et al, 2003 reported that the amount of carbon in the biomass varies from between 35 to 65 percent of the dry weight (50 percent is often taken as a default value). However, between 1990 and 2015, the world lost some 129 million ha of forest, an area the size of South Africa (WWF, 2019). Forest degradation occurs when forest ecosystems lose their capacity to provide important goods and services to people and nature (IUCN, 2017). In 2017, the world's tropical forests lost roughly 39 million acres of trees, according to a report by Global Forest Watch that used new satellite data from the University of Maryland. The main indirect driving forces of forest change are all expected to increase in the coming years. These include population and economic growth based on the export of primary commodities, national and international demand for agricultural products (food and biofuels), wood products and minerals are all expected to increase in the coming years. Such forests mostly grow in developing countries, where humans clear land for agriculture and urban development due to economic pressures such as Amazon fires, land clearing for soy production to feed livestock around the world (Meek, 2019). Forest restoration is an essential tool to increase forest cover. The success of forest restoration projects depends largely on the availability of the high-quality planting stock and post-planting care.

One successful method of forest restoration combines tree planting with accelerated natural regeneration-the framework species method with modified to restore seasonally dry tropical forests to deforested sites in northern Thailand's conservation areas (Elliott et al., 2006). In this system, tree planting restores basic ecosystem structure and functioning, whilst seed-dispersing mammals and birds, attracted by the planted trees, help to restore species diversity of the vegetation, thus improving wildlife habitats. The framework species method

is the least intensive of the tree planting options since it exploits natural seed dispersal mechanisms to promote biodiversity recovery (Elliott et al., 2006).

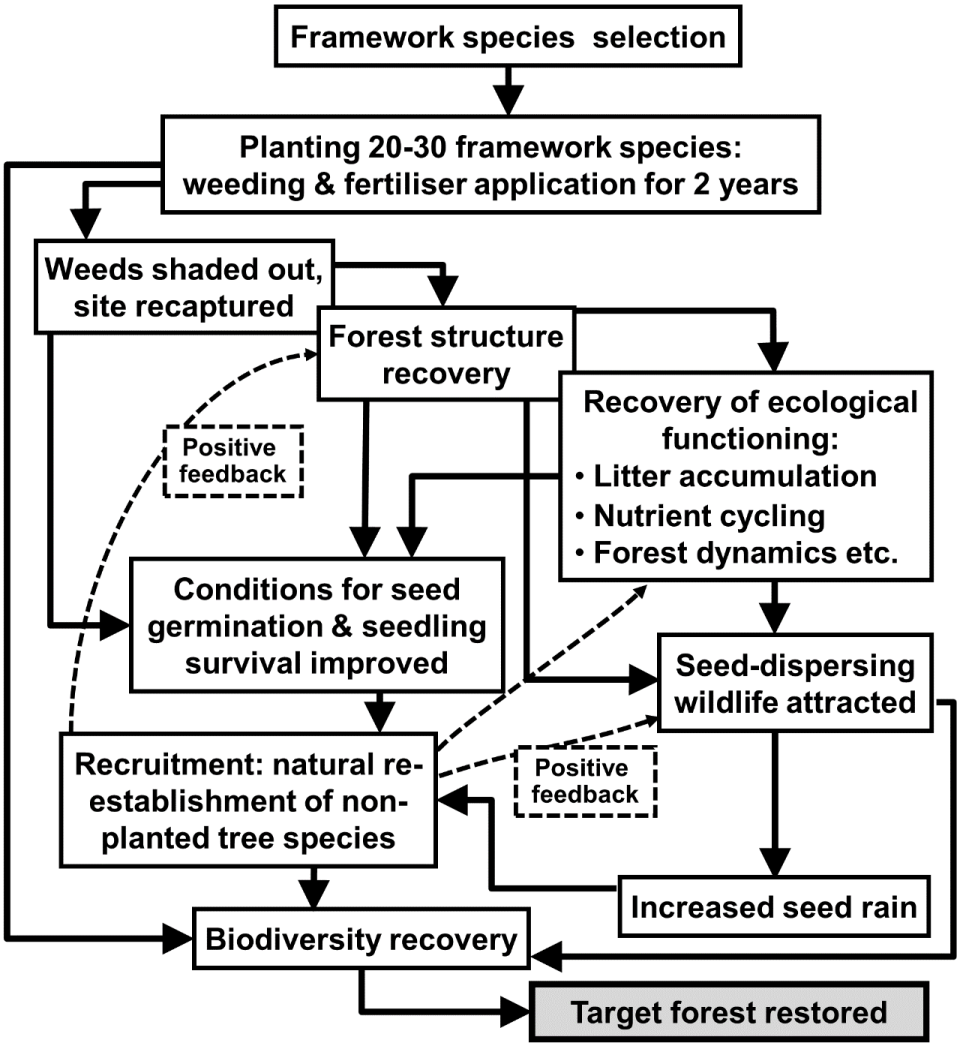


Figure 1.1 shows the framework species method involves planting 20-30 carefully selected tree species. They also re-establish forest structure, by developing a multilayered canopy. Furthermore, they restore ecosystem processes, such as nutrient cycles, and improve conditions for seed germination and seedling establishment of additional (non-planted) tree species, by creating a cooler, more humid microclimate on the forest floor. Moist, nutrient-rich leaf litter, free of weed competition, creates the perfect conditions for germination of incoming tree seeds and survival of tree seedlings. Biodiversity recovery

relies on birds, bats and other small mammals being attracted to the planted trees. The 20-30 tree species planted represent only a fraction of the total number of tree species that grow in tropical forest ecosystems. To restore the forest's original tree species composition, wildlife must be employed as seed-dispersers. Once planted trees have created conditions conducive to tree seedling recruitment, they must produce resources which attract seed-dispersing animals. These animals transport seeds of many additional tree species from nearby surviving forest into the planted sites. It is this next generation of naturally established trees, germinating from the seeds brought in by animals, which ultimately restores the forest to its original condition (Elliott et al., 2006).

Good nursery management can greatly improve sapling growth and survival as high planting stock quality is a basis for tree-planting success. Many studies have shown that field survival and productivity are related to the quality of the seedlings used (Jaenicke, 1999). Seedling quality is a combination of height, diameter, health and root size and shape. These characteristics determine how well the plant establishes in the field, and they affect survival rates. The research showed that seedling quality has two main aspects. The first is the genetic quality or the source of the seed. The second component of seedling quality is physical condition when dispatched to the planting site (Wightman, 1999). Likewise, seedling quality can be determined by environmental factors, such as nursery conditions and practices, a well-developed root system, and a balanced shoot: root ratio. The roots should be healthy, not bent, crossing or injured. Plants that have been left in the nursery too long or pricked out without necessary care, often have bent roots. These seedlings can suffer high post-planting mortality (Jaenicke, 1999). In addition, in the nursery and field, poor quality seedlings consume space and resources. Although most forest restoration projects involve planting nursery-raised tree seedlings, this is the most labor and capital-intensive method of forest restoration (Woods et al., 2004).

Wightman (1999) characterized a “quality” sapling as follows:

- **healthy**, vigorously growing and disease-free; single **stem**, well formed, robust and woody (lignified)
- with large root collar diameter; **crown**, symmetrical and dense; **root** system, well-formed, dense,
- with white root tips and many fine fibrous hairs; well-balanced **shoot: root ratio**.
- **leaves**, healthy, dark green and **acclimated** to short periods without water and full sunlight.

Roots may be distinguished as tap roots and fibrous roots. The former consists of a long thick main root and branch roots therefrom. Fibrous roots branch densely and lack a main root (Harris and Harris, 2006). A dense fibrous root system efficiently absorbs nutrients and water. (Thompson 1985). Root system fibrosity determines the ability of seedlings to establish after out planting and plays a prominent role in root growth potential (the ability to produce new roots) (Kainer and Duryea 1990). Sometimes, smooth plastic bags cause the principal root to coil or spiral along the walls or at the bottom (Figure 1.2), particularly when plants are left in the nursery for too long (Wightman, 1999).

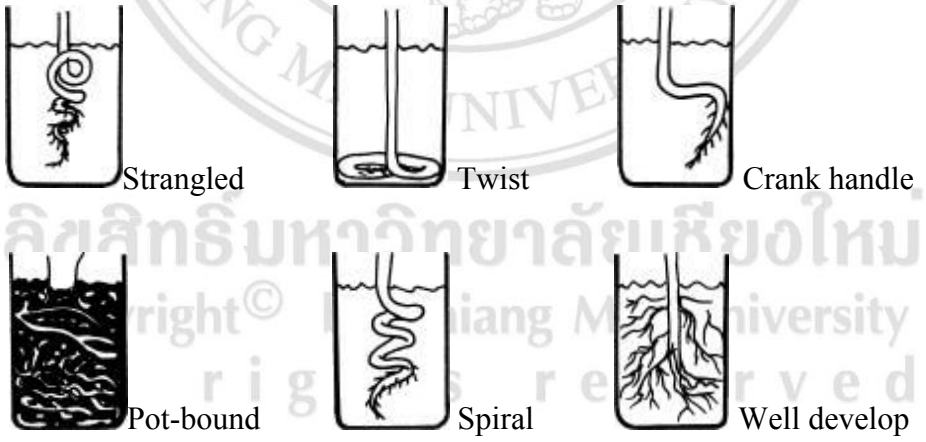


Figure 1.2 Comparison of poor root structures to a well-developed root structure (https://depts.washington.edu/propplnt/Chapters/air-pruning.htm)

Root-pruning is the act of cutting the roots of shrubs or trees to induce growth of a fibrous root system root system and consequently development of a dense root ball (Budiarto 2019). Moreover, Root-pruning techniques vary depending on intensity and plant growth stage. They include air root-pruning (Figure 1.3), knife root-pruning, modern pruning using root pruner machines mounted on a tractor (Budiarto 2019) and chemical pruning (Shevade, 2011). Knife pruning has been used by traditional citrus growers in Garut, West Java, Indonesia to accelerate flowering. Grim (1956) and (Mullin, 1966) reported that root-pruning at the seedling stage, increases transplant survival and post-transplant growth, whilst Watson et al (1987) showed that it also induces fibrous root density in dicots, like Citrus. Moreover, Thaler (1997) reported that taproot-pruning stimulates lateral root growth at the cut end and Watson et al. (1987), growth stimulated following root-pruning can double root surface area. Thus, root-pruned trees should be more resistant to transplantation shock and should have higher survival rates. Root pruning improves the flowering response of mature fruit trees: apple (Khan et al., 1998), mango (Ali et al., 2014) and peach (Tsukahara et al., 2009). In Romania, root-pruning apple trees increased fruit yield (Mitre et al., 2012).

Figure 1.3 photos of seedling production that air root-pruning techniques vary depending on the material from Queensland nursery, Australia.

Air-pruning works by killing root-tips, due to desiccation upon exposure (Walker, 2005). It works in the same way as cutting roots in that secondary roots are stimulated to develop, thus increasing nutrient absorption, which enables plants to grow more rapidly (Shevade, 2011). Kamizore (1998) recommended that plant containers be raised at least 30cm above the ground. Valli (1995) also showed that good aeration is essential for root development. Air pruning reduces root spiraling. Marshall et al. (1998) and O'Conner et al., (2013) reported that Accelerator®-air pruning containers with corrugated sides increase the number of descending roots, compared with smooth-sided containers. Ortega et al. (2006) obtained similar results with specially design containers that promoted air pruning; reduced root spiraling and fewer L-shaped roots.

Whitcomb (1972) showed that growing *Carissa grandifloras* trees in square, bottomless containers on raised wire bench, increased seedling quality, growth rate, establishment and vigor. Both he and Walker (2005) recommended using wire benches 18 (or 16) to 24 inches above the ground to promote air circulation. Olave et al. (2003) also obtained promising results using containerization on raised benches. Louppe et al. (1992) also reported advantages of using air pruning to grow *Faidherbia albida* in nurseries compared with regular polyethylene pots, including more secondary and fine roots. In addition, air pruning requires less labor both in the nursery and during transplantation.

Whitcomb, 2003 reported that RootMaket® (Figure 1.4) is one of container that requires a wire bench or other support 18 to 24" above the floor to allow good air circulation and thus efficient air-root-pruning on all sides of the container, not just the bottom. These containers to promote root branching, whereas, in contrast, Shevade (2011) failed to show advantages of using RootMaket®, compared with traditional containers for growing *Catalpa speciosa*, *Quercus coccinea*, *Quercus rubra*, *Quercus alba*, and *Hydrangea macrophylla.* Similarly, the experiment of Marler et al., 1996 they found air pruning technique effectively controlled root; produced a more fibrous root system. Previous studies by Mullan et al., 2002 showed Banksia (Proteaceae family) and Acacia spp. (Mimosaceae family) comparing two methods of air root-pruning and chemical pruning in seedling tray.

Figure 1.4 Air root-pruning RootMaker® propagation containers. (https://rootmaker.com and Nebraska Forest Service)

Sambeek et.al, 2016 evaluated the long-term filed performance of repeated air pruning of seedlings of swamp white oak (*Quercus bicolor* Willd.) that included bare-rooted planting stock. Measured by randomly selected trees: incipient and final stem diameter and height and above-ground green weight and Shaw et.al, 2003 report showed the benefit of air-root-pruning produced lateral roots under the root collar in container stock. The root systems on the air-root-pruning container oak planted weight 64 g with a volume 140 cm^3 compared to the bareroot planting stock about 21 gram and 33 cm^3. In addition, propagation of air root pruned container stock is assembly adaptable internationally to locally available sources of organic matter and open bottom containers.

1.2. Objectives of the study

The objectives of this study were:

1. To determine the effects of root air-pruning on seedling growth rate and root branching of native forest tree species, grown for forest restoration purposes in a small-scale tree nursery.

2. To compare the cost effectiveness of various seedling production methods.

CHAPTER 2

Materials and Methodology

2.1 Study Area

The study was conducted in small scale tree nurseries at 1) Chiang Mai University's Forest Restoration Research Unit (FORRU-CMU) in Doi Suthep-Pui National Park, Chiang Mai Province and 2) FORRU-Krabi, Khlong Thom District, Krabi Province, Thailand (Figure 2.2). The trees in both of these nurseries were being grown for forest restoration projects using the framework species method, in collaboration with the local communities with.

The experiment was located in the accommodation center of Doi Suthep-Pui National Park in Northern Thailand (18°48'24"N 98°54'59"E at 1,050 meters above sea level), about 30 kilometers from Chiang Mai city. Experiments in the forest were located in primary, evergreen, seasonal forest (Maxwell and Elliott, 2001) All work was carried out between elevations of 1,020 m. and 1,450 m. above mean sea level. The nursery experiment was carried out at the Forrest Restoration Research Unit Nursery (FORRU) in primary evergreen, seasonal, hardwood forest, granite bedrock. Chiang Mai has a tropical climate 3 seasons: summer (mid-February to mid-May), rainy (mid-May to mid-October) and winter (mid-October to mid-February). Temperatures of Kog-ma Watershed Research Station. The climate data 1982-2012 is classified as Aw by the Köppen-Geiger system. (Figure2.1 (a.)). The average amount of annual rainfall at the base of Doi Suthep-Pui National Park (c.350m.), is 1067.8 mm, the average amount of rainfall at the national park headquarters (c.1050 m.) is 1067.8 mm per year and 2095 mm at Puping village (c.1375 m.). August and September have the most rain with an average of 235.5 mm per month. The lowest amount of rainfall is from January-February with an average of 7 mm per month. The average annual rainfall is 1,184 mm. The least humid month is March (38.8% relative humidity), and the most humid month

is September (71.7%) (Maxwell and Elliott, 2001). Average lowland temperatures range from a low of 21.9 ºC during December-February and a high of 28.5 ºC during April-May. The average annual temperature is 25.6 °C.

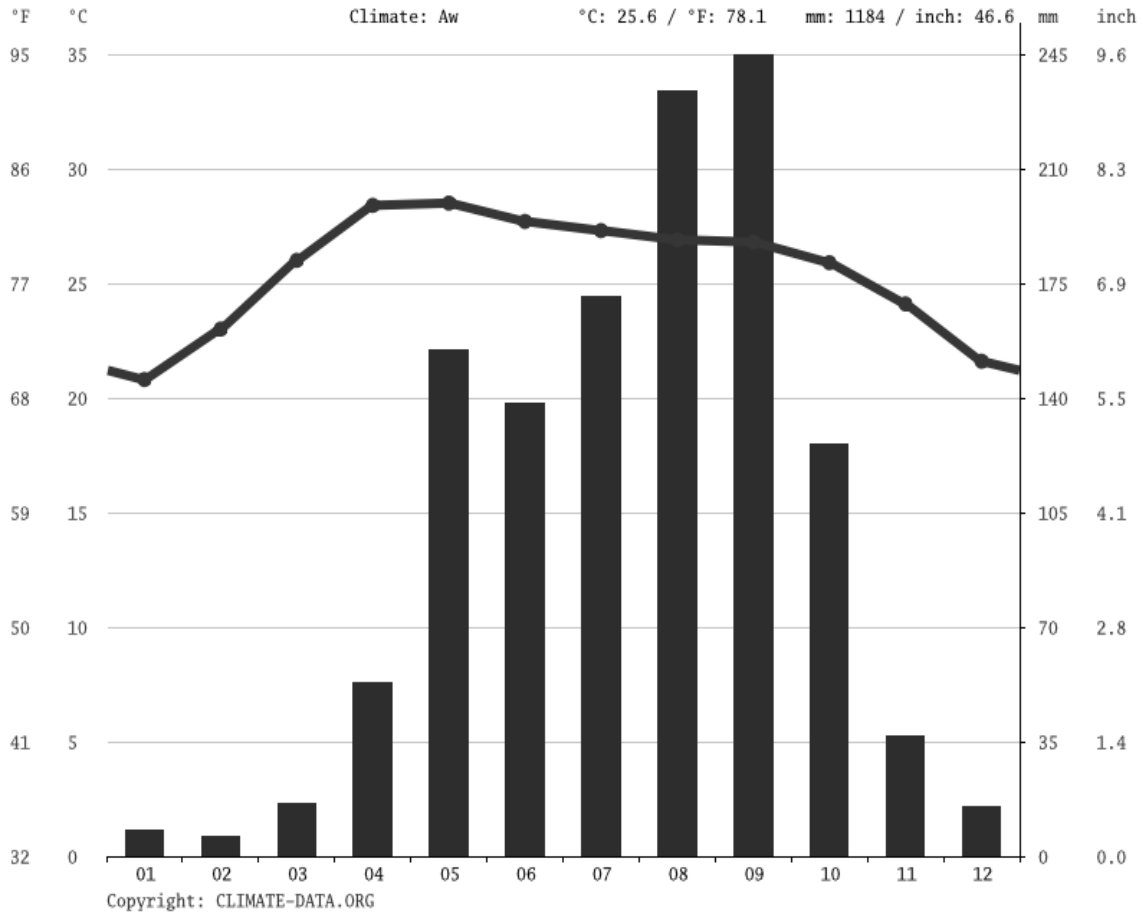


Figure 2.1 (a.) Chiang Mai climate graph-average monthly rainfall (solid bars), mean temperatures (solid lines) in 1982-2012 from CLIMATE-DATA.

The climate of Krabi Province is monsoonal and hot and humid all year round, with two seasons: the rainy season from May to November and the dry season from December to April. Humidity levels are high throughout the year, from 75% to 100%. Temperatures range from a minimum of 21.8°C to a maximum of 33.7°C, but mean monthly temperatures vary little from 26.3°C in December to 28.5°C in April (Figure 2.1 (b.)). Annual rainfall averages 2,040 mm, with monthly peaks in September (327 mm) and October (263 mm.). The seasons are dictated by tropical monsoon winds, which blow from the northeast for half the year, then reverse and blow from the southwest, producing a dry season and a wet season respectively. The dry season begins in December and usually lasts until March. The northeast monsoon draws cool, dry air from the Asian continent, resulting in a slight drop in temperature. The dry season climate is characterized by gentle breezes and clear blue skies, with monthly rainfall falling to about 30-78 mm from December to March. It is also the coolest time of year. The south-west monsoon brings moist air in from the Indian Ocean, causing the rainy season from June until November. However, rainfall is not evenly spread over the months. A started in May (190 mm) is followed by a slight increase in June to August (c. 222-259 mm), followed by a sharper peak in September (c.327 mm). There are two transitional periods, each lasting 4-6 weeks, during which the weather is highly unpredictable. The period before the rainy season, around March-May, is the hottest time of year. There may be prolonged periods of either dry weather with clear skies or overcast skies with rain. The September-October transition is cooler with erratic rainfall events. This has implications for the timing of tree planting. Ideally, trees should be planted at the beginning of the rainy season, to allow maximum time for development of a root system before onset of the dry season. However, even though monthly rainfall in April averages an acceptable 143 mm, the timing of rainfall events is unreliable and there is the possibility of dry periods lasting several days or weeks. Planting earlier than mid-May, therefore, is risky, since even 2-3 days without rain immediately after planting (with temperatures reaching the mid- 33's°C during the daytime) can result in very high mortality of planted trees (FORRU, 2006).

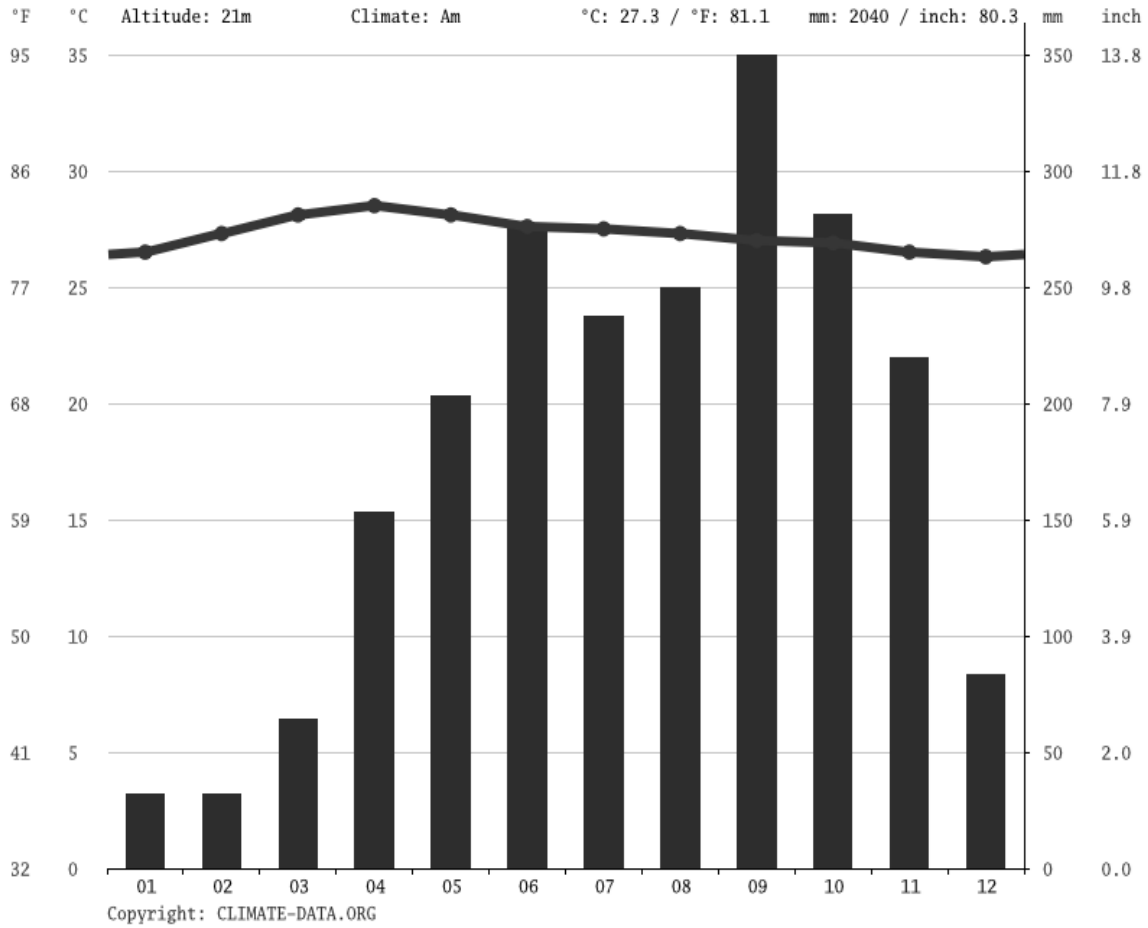


Figure 2.1 (b.) Krabi climate graph-average monthly rainfall (solid bars), mean temperatures (solid lines) in 1982-2012 from CLIMATE-DATA.

Figure 2.2 Location of study site at (a) Doi Suthep-Pui National Park, Chiang Mai Province and (b) Khlong Thom District, Krabi Province, Thailand.

2.2 Methodological strategy

2.2.1 Species selected

Ten framework species (Table 2.1), proven effective at restoring tropical forest ecosystems were selected for this study-five typical of southern forests and five typical of northern forests, according to seed availability. The experiments were carried out simultaneously at both locations.

The five northern species were:

1) *Adenanthera microsperma* (Fabaceae)
2) *Ficus racemosa* (Moraceae)
3) *Terminalia nigrovenulosa* (Combretaceae)
4) *Xantolis cambodiana* (Sapotaceae)
5) *Podocarpus neriifolius* (Podocarpus)

The five southern species were:

6) *Saraca indica* (Fabaceae)
7) *Sandoricum koetjape* (Meliaceae)
8) *Cleistocalyx operculatus* (Myrtaceae)
9) *Lepisanthes rubiginosa* (Sapindaceae)
10) *Garcinia speciosa* (Guttiferae)

Table 2.1: Flowering and fruiting period of the species studied.

Species	**Family**	**Habitat**	**Flowering**	**Fruiting**
Adenanthera microsperma	Fabaceae	dof	ap-jl	jl-oc
Ficus racemosa	Moraceae	dof bb/dof mxf	nv-jl	ja-dc
Terminalia nigrovenulosa	Combretaceae	dof mxf	ap-ma	fb-ma
Xantolis cambodiana	Sapotaceae	egf mxf	mr-ap	oc-dc
Podocarpus neriifolius	Podocarpus	egf	ja - ap	mr-ag
Saraca indica	Fabaceae	egf mxf	jl-oc	oc-nv
Sandoricum koetjape	Meliaceae	egf	mr-ap	ap-ag
Cleistocalyx operculatus	Myrtaceae	egf	-	-
Lepisanthes rubiginosa	Sapindaceae	dof	dc-fb	mr-ap

Garcinia speciosa	Guttiferae	egf	dc-ag	jn-oc

(Modified from "FORRU Database" and The Vegetation and Vascular Flora of Doi Suthep-Pui National Park Northern Thailand", by Maxwell and Elliott, 2001).

Note: Habitat

dof bb	degraded teak & bamboo+ deciduous forest
egf	primary evergreen forest
eg/bb	evergreen forest with bamboo
eg/pine	evergreen forest with pine
dof	deciduous forest
mfx	mixed evergreen + deciduous seasonal, 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

2.2.2 Seed collection

About 500 seeds were collected of each tree species from natural forests, surrounding both nurseries. A floatation test was used, to discard non-viable seeds. The remaining seeds were germinated that were sown in germination trays in the nursery. Seed germination was monitored every week for 2 months. After that, seeds were sown into seed germination trays. Once seedlings had grown two true leaves, at the 2-node stage (usually about 10 cm tall), they were potted into plastic bags 2.5 inches in diameter and 9 inches in deep. The potting mixture comprised forest soil, peanut husk, and coconut husk mixed in the ratio of 2:1:1. Seedlings were shaded in the nursery, under a plastic roof (approximately 20% sunlight), for about 2-4 weeks. After that, they were moved out of the nursery to experimental plots and placed under shade netting called “slan”.

Table 2.2 Seed collection data in each area.

Species	Date of seed collection	Seed collection location	Date of seed sowing	Date of potting up	Specimen number & location of specimen used to confirm identification of the species.
Sandoricum koetjape	13/9/18	Sa Morakot (Emerald Pool)	15/9/18	25/9/18	Preeyaphat 2018_001. CMUB Herbarium
Cleistocalyx operculatus	15/9/18	Sa Morakot (Emerald Pool)	17/9/18	25/9/18	Preeyaphat 2018_002. CMUB Herbarium
Saraca indica	15/9/18	Ton Teo Waterfall	17/9/18	25/9/18	Preeyaphat 2018_003. CMUB Herbarium
Lepisanthes rubiginosa	20/9/18	Khao Pra-Bang Kram Wildlife Sanctuary	22/9/18	29/9/18	Preeyaphat 2018_004. CMUB Herbarium
Garcinia speciosa	20/9/18	Khao Pra-Bang Kram Wildlife Sanctuary	22/9/18	29/9/18	Preeyaphat 2018_005. CMUB Herbarium
Adenanthera microsperma	05/11/18	Phra That Doi Suthep Temple	07/11/18	15/11/18	S118b1 CMUB Herbarium
Ficus racemosa	05/11/18	Road to Doi-Pui	07/11/18	15/11/18	S365b1 CMUB Herbarium
Terminalia nigrovenulosa	09/11/18	Road to Doi-Pui	11/11/19	18/11/18	Preeyaphat 2018_006. CMUB Herbarium
Xantolis cambodiana	05/11/18	Road to Doi-Pui	07/11/18	15/11/18	Preeyaphat 2018_007. CMUB Herbarium
Podocarpus neriifolius	09/11/18	Kawk Mah	11/11/19	18/11/18	S23b2 CMUB Herbarium

2.3 Treatment used in the experiment

For each of the ten-selected species, batches of 48 seedlings were randomly selected and assigned to a randomized complete block design (RCBD), consisting of three treatments and three replicates (432 seedlings per species). The experiment was divided into three treatments, as follows (Figure 2.3 (a, b))

1. Control (CON): standard nursery practices; containers stood down on a plastic sheet on the ground.

2. Crate with air-pruning (CAP) (raised on benches) + crate: seedling containers placed in twelve-cavity plastic crates, measuring 25.5 x 33.5 x 14.5 cm on a wire-mesh bench, measuring 2 x 2.5 m, 60 cm above the ground.

3. Crate on ground (COG): seedling containers placed in twelve-cavity plastic crates, measuring 25.5 x 33.5 x 14.5 cm and arranged on a plastic sheet on the ground.

Figure 2.3 (a.) The experiment in Doi Suthep-Pui National Park, Chiang Mai.

Figure 2.3 (b.) The experiment in Khlong Thom district, Krabi province, Southern.

Note: The experiment was divided into three treatments and arranged in RCBD.

T = Treatment; T.1 = Control, T.2 = Air-pruning (bench) + crate, T.3 = Crate

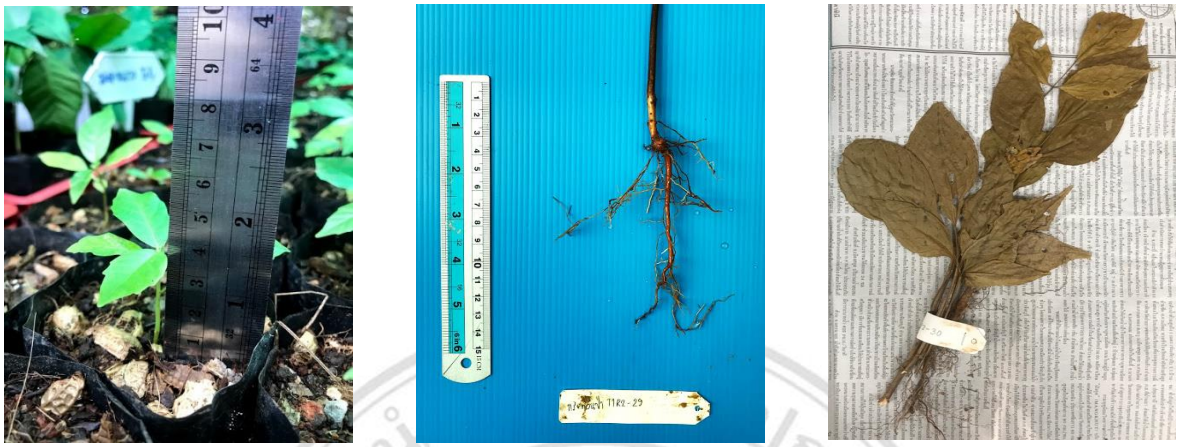
R = Replicate

2.4 Measurement data in seedlings trials

The seedlings were taken care of by standard nursery practices such as watering, fertilizing which about 10 granules of "Osmocote" slow-release fertilizer (14-14-14) were placed on the media surface every 3 months, and grading i.e. arrangement of the plants in order of size-an effective method of quality control (Elliott et al., 2006). Height and stem diameter are the two characteristics most commonly examined on forest seedling stock. Therefore, relative growth rate of height and root collar diameter was measured of all seedlings and health was monitored monthly for six months.

Seedling height was measured by a ruler from the cotyledon scar to the base or tip of the terminal bud (or end of growing tip if no bud formed). Root collar diameter (RCD) was measured by Vernier calipers that below the cotyledon scar (it's important to ensure that the calipers are perpendicular to the stem during measurement) (Haase, 2008) and a health score of 0 to 3 was assigned to each plant (0=appears dead, 1=very unhealthy (widespread discoloration or insect damage), 2=moderate health (moderate discoloration or insect damage) and 3=near perfect (none or minimal insect damage).

After sixth months, nine seedlings per replicate were harvested for biomass determination. The seedlings were dried at 70ºC for 72 hours and biomass dry weight was determined (Peìrez et al., 2013). Root morphology was also compared among treatments, including root length which measured with taproot by a ruler from the base of taproot to the tip of the terminal root (Figure 2.4). Root branch count to hand-measured branch number. The branch number is a count of the number of primary roots branches from taproot. While the root area were record by the Image J Program.



(a.) (b.) (c.)

Figure 2.4 photo of some method for measurement seedling growth: (a.) measured high (b.) measured root length (c.) biomass dry weight of seedlings sample.

2.5 Seedling Production Costs

The cost for different seedling production processes was separated into

1. Establishment cost-purchase of equipment, soil and compound preparation, potting, etc.
2. Maintenance cost - labor, transports, nursery care, etc.

Costs were calculated based on six months of seedling production and on the number of seedlings survival at each study sites. It was assumed that materials for the nursery establishment would last at least 5 years. The total cost was compared with those of conventional seedling production to evaluate the economically feasible of each production process. Moreover, the calculation of seedling production cost used Microsoft Excel based on the time value of money by 2018.

3. Data analysis

Data were analyzed by R Programming language, version 3.4.1 (R Core Team, 2018) was used to compare the seedling growth among treatment. The biomass of seedlings and the seedling production cost was calculated which culture in the nursery for six months. In this study, the data separated 2 groups: 1.) Binomial data, which variables that have only two states consist of mortality and root grew out of plastic bag. 2.) Continuous data, which have any value e.g. relative growth rate of height, RCD, root dry weight and root data. Thus, the binomial data, arcsine transform the data for statistical reasons before carrying out the analysis of variance (ANOVA) while analyzing continuous data straight to an analysis of variance. Mean relative growth rate (height and RCD), root dry weight, root length, root area, and root branching were compared among treatments for each species. For Linear Mixed-Effects Models (lme4) and ANOVA that fixed factor is treatments and species while random factor is replicated without replication was performed to detect any significant differences (alpha level of 0.05) in growth performances in both nurseries. After that, Turkey's HSD was performed when linear mixed-effects models results showed any significant differences in growth performances, root dry weight, root length, % root area, and root branching.

Relative growth rates (RGR) (RGR-H or RGR-RCD) was calculated as

$$RGR = \frac{(\ln Size2 - \ln Size1)}{(t2 - t1)} \times 365 \times 100$$

Size1 was an initial size measurement (height or RCD) on date t1 and Size2 the final size of the plants on date t2: t2-t1 is the number of days between the two measurements (Evans, 1972.)

The root area were record by Image J Program. Image J is a public domain Java image processing and analysis program inspired by of the National Institute of Health (NIH), Maryland, United States of America. It can be downloaded from public website https://imagej.nih.gov/ij/download.html. It can display, edit, analyze, process, save and print 8-32 bit images. It can be used to measure area, mean, centroid, perimeter, etc. of user-

defined regions of interest. Thus, it can be used to measure density and area on digitals photos, related by numbers of pixel or unit to know measurement. This project used the digital photographs of roots into Image J software which applied of black and white color, and the color threshold filter was applied, saturated and brightness sliders until all root area of each seedling turned red. After that, the information is processed in numerical form (Figure 2.5).

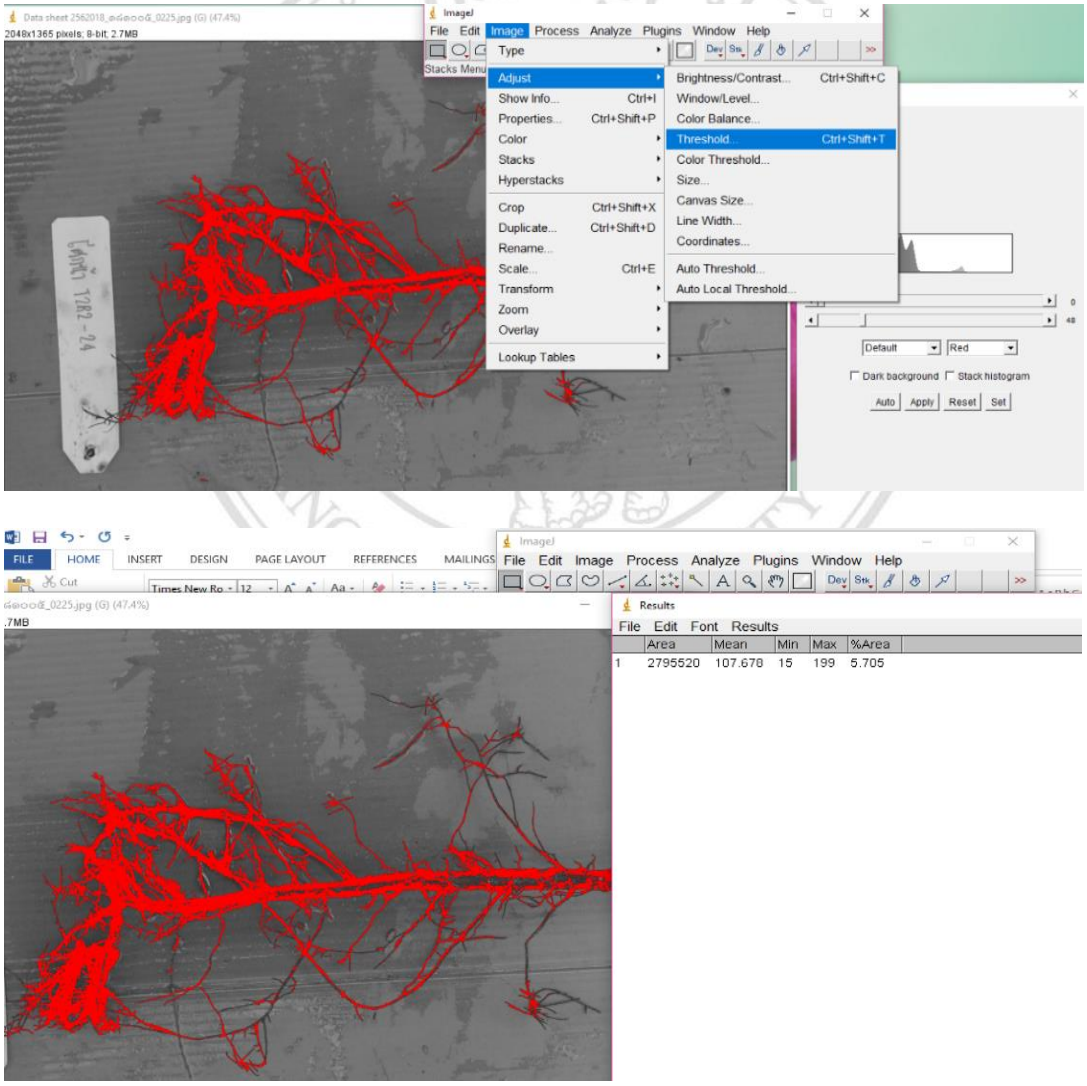


Figure 2.5 Root area measurement by Image J program.

CHAPTER 3

Results

1. Seedling growth rate

Differences in RGR-H among treatments were significant (P<.05) for all species tested except *Saraca indica*, *Terminalia nigrovenulosa* and *Xantolis cambodiana*. The COG treatment significantly increased RGR-H of all species tested (P<.05), compared with the CAP treatment and the control (Figures 3.1). Furthermore, the difference in RGR-H among species was also most significant that *Ficus racemosa* had the highest RGR-H 228 % (Appendix1) which difference effect estimate between COG and CON had 36 %. While *Xantolis cambodiana* had the lowest of RGR-H. (Figures 3.1)

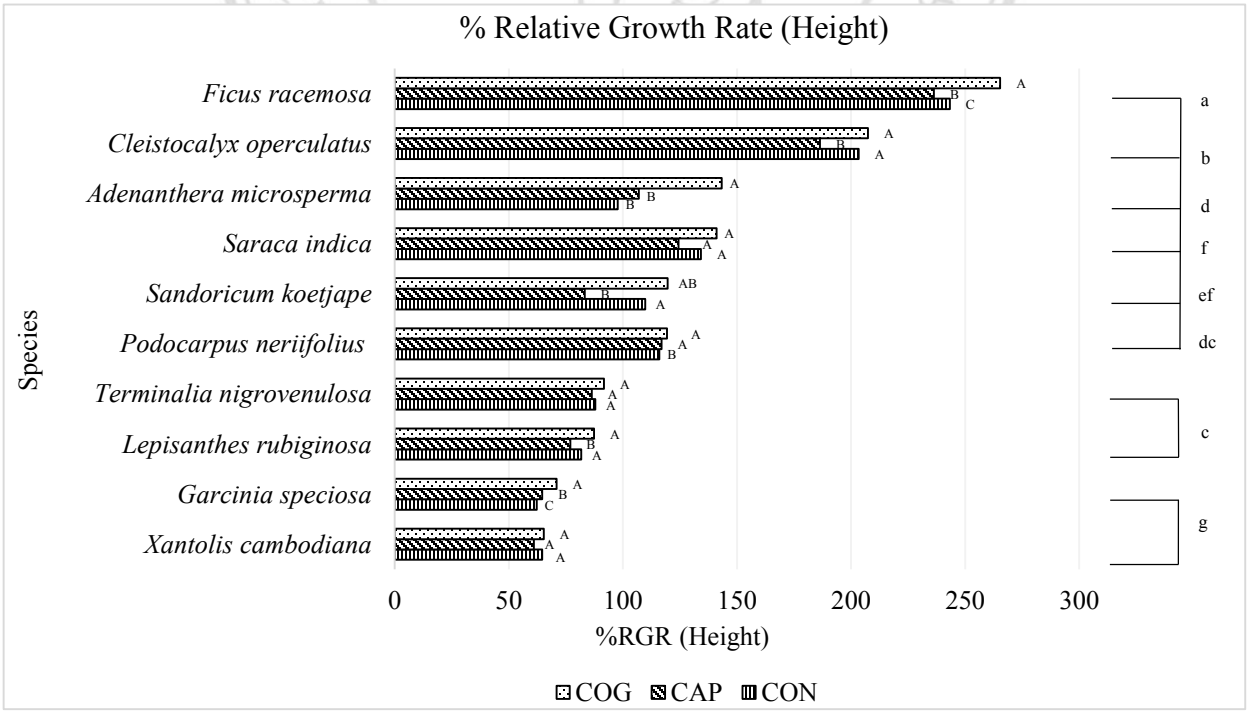


Figure 3.1 Mean RGR-H of ten selected species (N=4320) %/y. (COG = Crate on ground treatment, CAP = Crate with air-pruning treatment and CON = Control treatment). Bars not sharing the same

capitalized superscripts indicate significant differences among treatments within a species; species not sharing the same lowercase superscript indicate significant difference among species.

The COG treatment resulted in significantly the highest RGR-RCD for eight species while *Saraca indica* and *Lepisanthes rubiginosa* (*P*>.05) for the effects estimates of *Lepisanthes. rubiginosa* indicated that CAP higher than CON about 25 % (Appendix 3).

The top 4 fastest growing species (in terms of both RGR-H and RGR-RCD) were *Cleistocalyx operculatus, Ficus racemosa, Adenanthera microsperma, Saraca indica.* Whilst the slowest growing species was the gymnosperm *Podocarpus neriifolius*. (Figures 3.2)

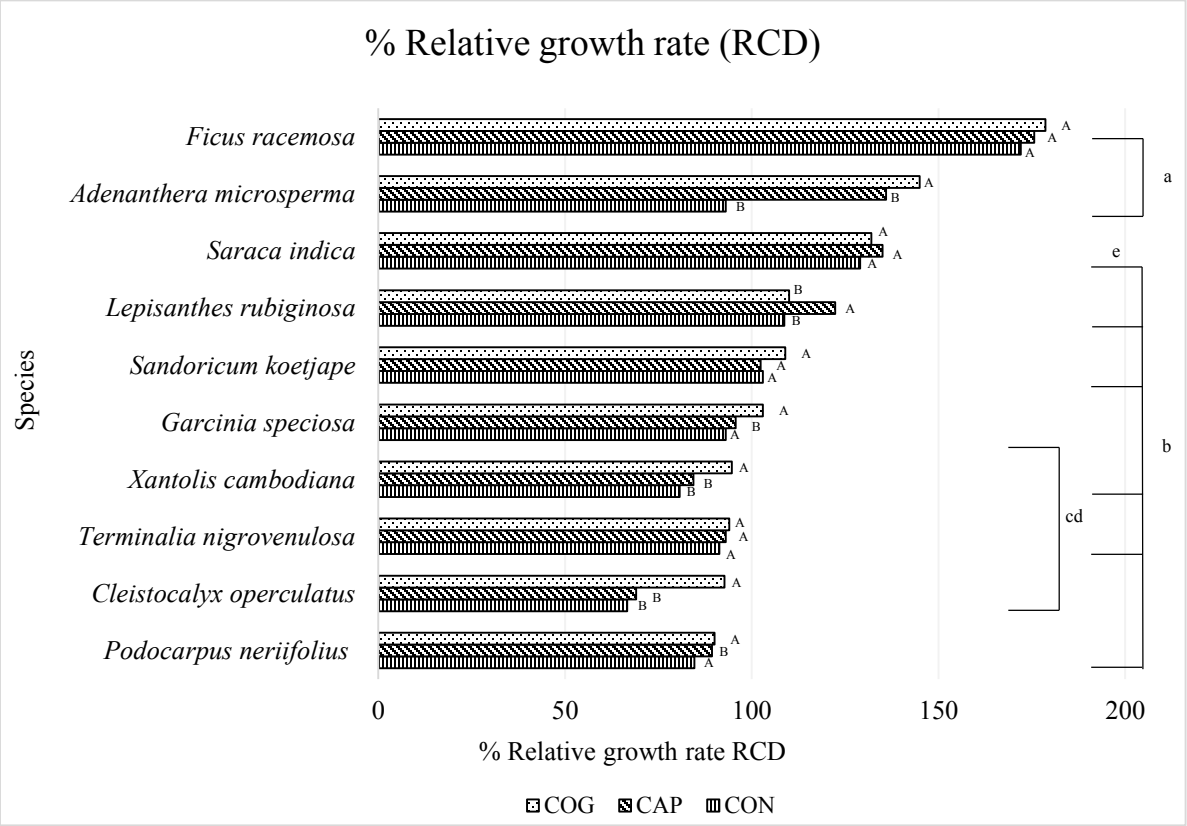


Figure 3.2 Mean RGR-RCD (%/y) of ten selected species (N=4320). (COG = Crate on ground treatment, CAP = Crate with air-pruning treatment and CON = Control treatment). Bars not sharing the same capitalized superscripts indicate significant differences among treatments within a species; species not sharing the same lowercase superscript indicate significant difference among species.

After 6 months, differences in root dry weight within each species were insignificant (P>.05) except *Cleistocalyx operculatus* and *Terminalia nigrovelunosa.* (*P*<.05). The COG treatment resulted in the highest mean root dry mass of *Saraca indica* with 4.35 g ± 0.61 (Appendix 4). Meanwhile, effects estimates of *Saraca indica* and *Sandoricum Koetjape* showed the effect estimates are strong between CON and COG about 87% and 82% respectively. Moreover, averaging over all species, the COG treatment remarkably increased root dry mass compared with both the CAP treatment and the controls. Nevertheless, the shoot-root ratio among treatments were small significant between CON and COG (P<.05) while the shoot-root ratio among species were insignificant (P>.05) (Appendix 4).

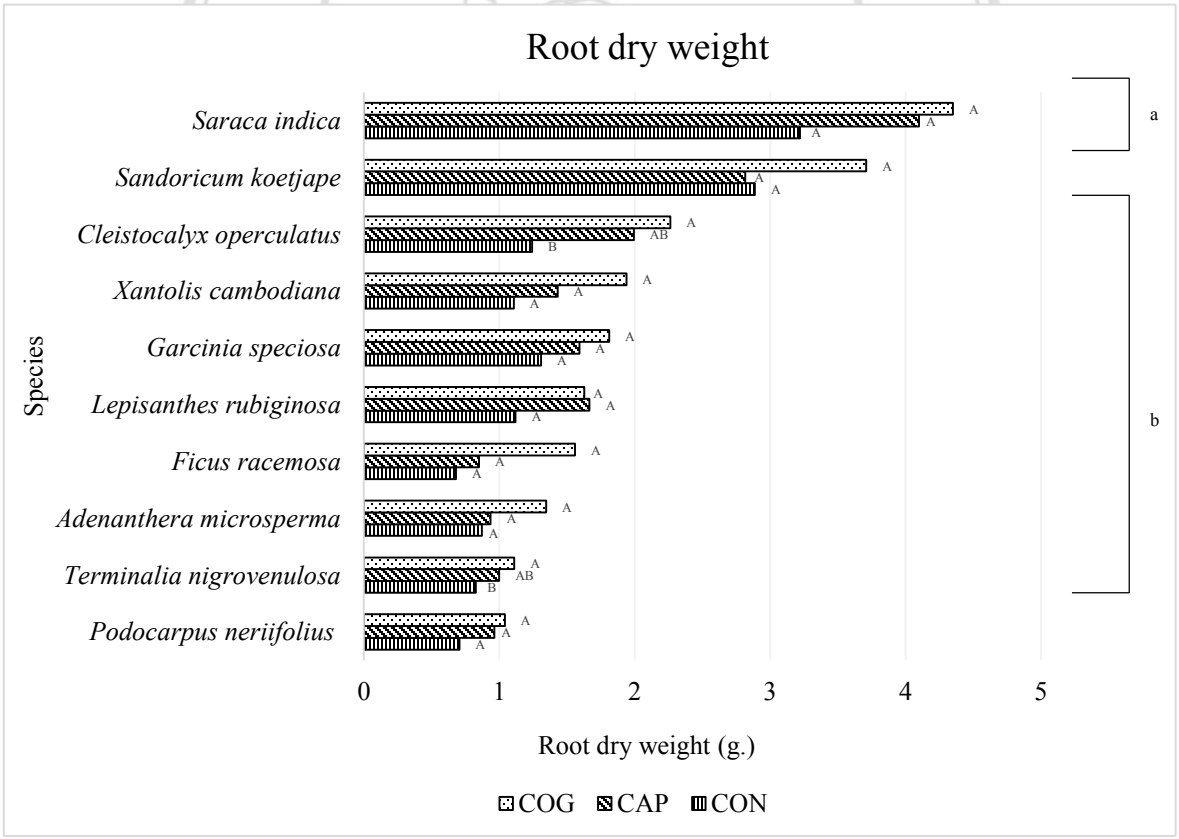


Figure 3.3 Mean root dry weight (g) of individual seedlings (N=270) of ten species with three treatments. (COG = Crate on ground treatment, CAP = Crate with air-pruning treatment and CON

= Control treatment). Bars not sharing the same capitalized superscripts indicate significant differences among treatments within each species; species not sharing the same lowercase superscript indicate significant difference among species.

The mean health score averaged over all saplings, at the end of the monitoring, was 2.86 (out of a maximum of 3). Differences in health scores among treatments were insignificant (ANOVA, $P>.05$).

Mortality rates were large significantly $P<.05$ among species. Differences in percent mortality among treatments were medium significant ($P<.05$) (Appendix B). Figure 3.4 shows that the end of monitoring in 6 months, *Terminalia nigrovenulosa* seedlings had the highest mean mortality rate, compared with other species. The overwhelming majority of the mortality rate of *Terminalia nigrovenulosa* occurred in the control group (11.11 %). In contrast, *Garcinia speciosa* and *Sandoricum koetjape* did not the saplings died.

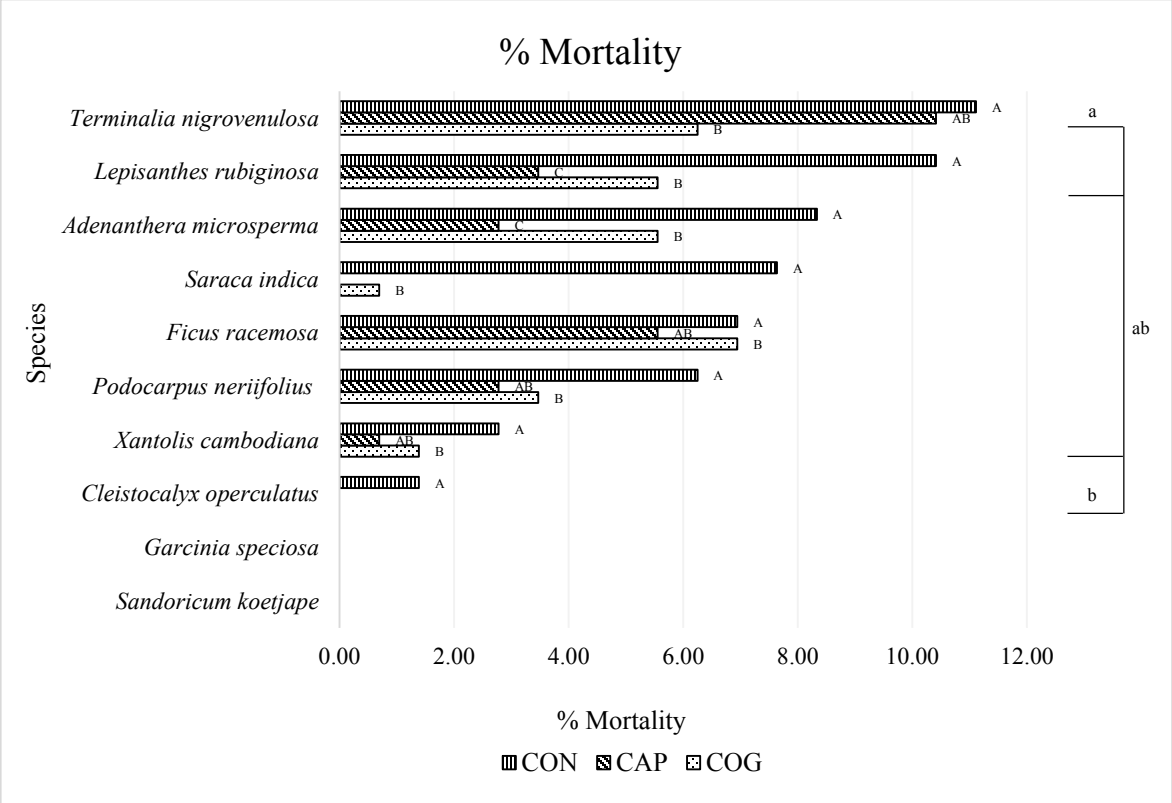


Figure 3.4 Mean percent seedling mortality (N=4230) in six months of ten tree species among the three treatments. (CON = Control treatment, CAP = Crate with air-pruning treatment and COG =

Crate on ground treatment). Bars not sharing the same capitalized superscripts indicate significant differences among treatments within each species; species not sharing the same lowercase superscript indicate significant differences among species.

2. Root architecture and quality

Differences root length among the treatment of five species were significant (P<.05) whilst five species were not significant (P>.05) (Figure 3.5). While an analysis of variance showed a significant (P<.05) interaction between species and root length. Figure 3.5 showed the highest of taproot length was *Xantolis cambodiana* which effects estimates were large significant between CON and GOG 85 % follow with *Ficus racemosa* by COG treatment while *Cleistocalyx operculatus* had the lowest of root length by 10.69 (Appendix 5, 7).

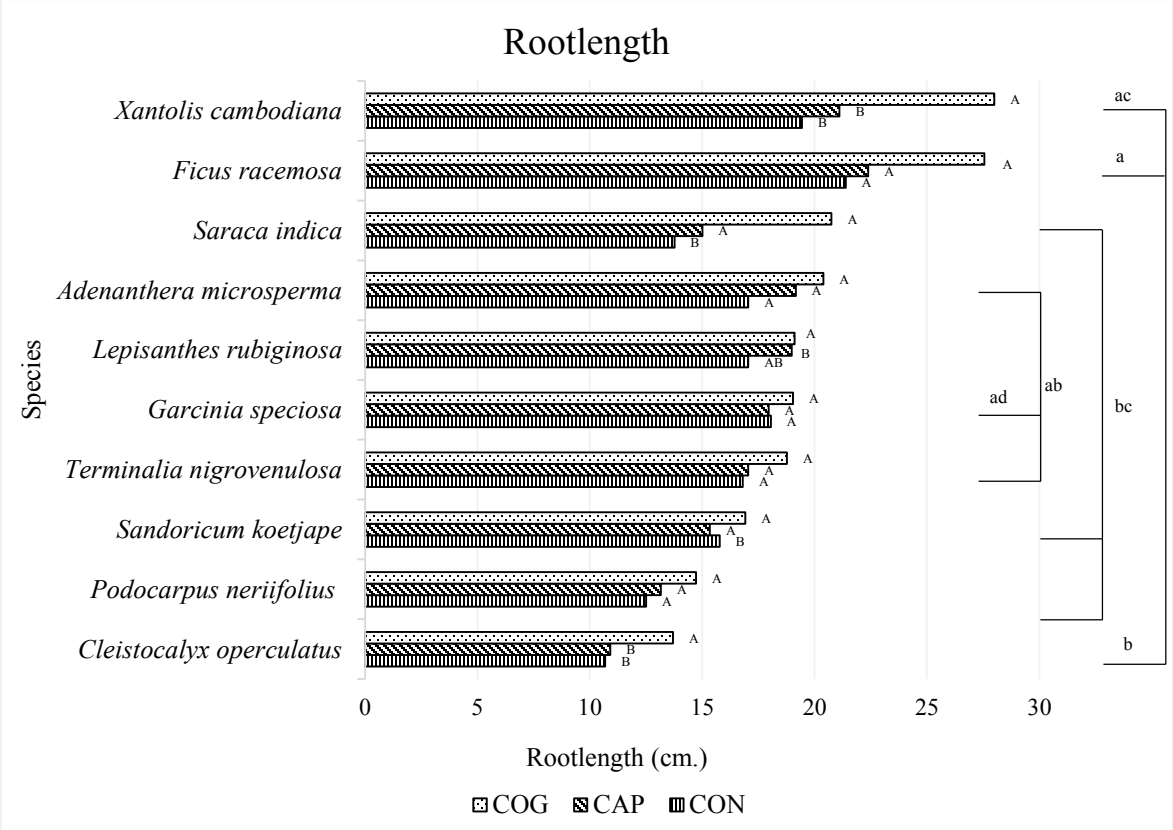


Figure 3.5 Root length of ten seedlings of selected framework species with three treatments. (N=270) (COG = Crate on ground treatment, CAP = Crate with air-pruning treatment and CON = Control treatment). Bars not sharing the same capitalized superscripts indicate significant

differences among treatments within each species; species not sharing the same lowercase superscript indicate significant difference among species.

An analysis of variance showed a significant (P<.05) interaction between species and root area. And also differences among the treatment of four species were small significant. *Ficus racemosa* by 92.48% (Appendix 6, 7) with the COG treatment had the highest percent root area while *Cleistocalyx operculatus* with control treatment had the lowest percent root area (Figure 3.6).

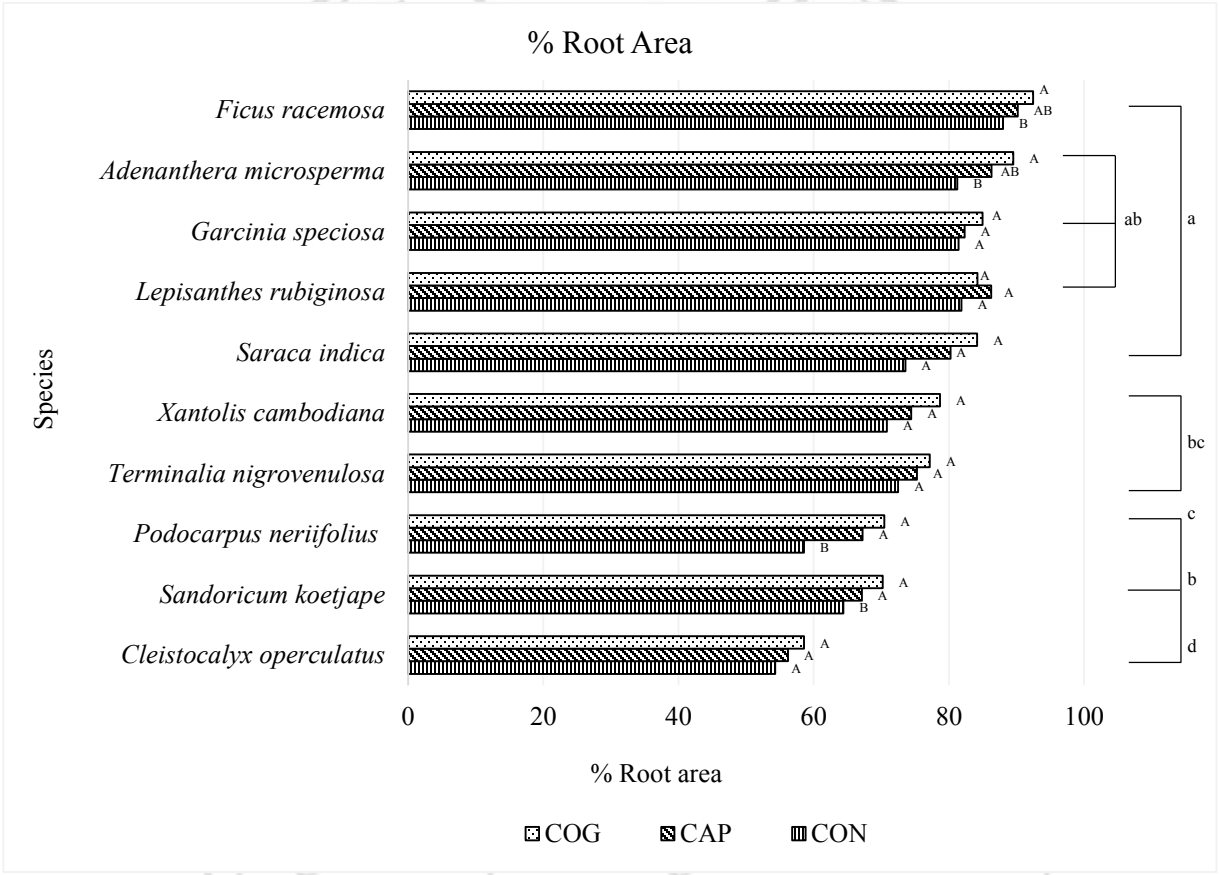


Figure 3.6 Mean percent root areas of ten seedlings selected framework species with three treatments. (N=270) (COG = Crate on ground treatment, CAP = Crate with air-pruning treatment and CON = Control treatment). Bars not sharing the same capitalized superscripts indicate significant differences among treatments within each species; species not sharing the same lowercase superscript indicate significant difference among species.

Root branching of ten seedlings species after six months were different ways depending on species is revealed in figure 3.8. An analysis by Tukey HSD showed insignificant differences among the treatments (P>.05) except *Ficus racemosa*, *Lepisanthes rubiginosa* and *Podocarpus neriifolius* were small significant between CON and COG (P<.05). Ranking by root branching, the species with the highest number of root branching was *Ficus racemosa* (Appendix 7), while *Podocarpus neriifolius* had the lowest root branching (Figure 3.7).

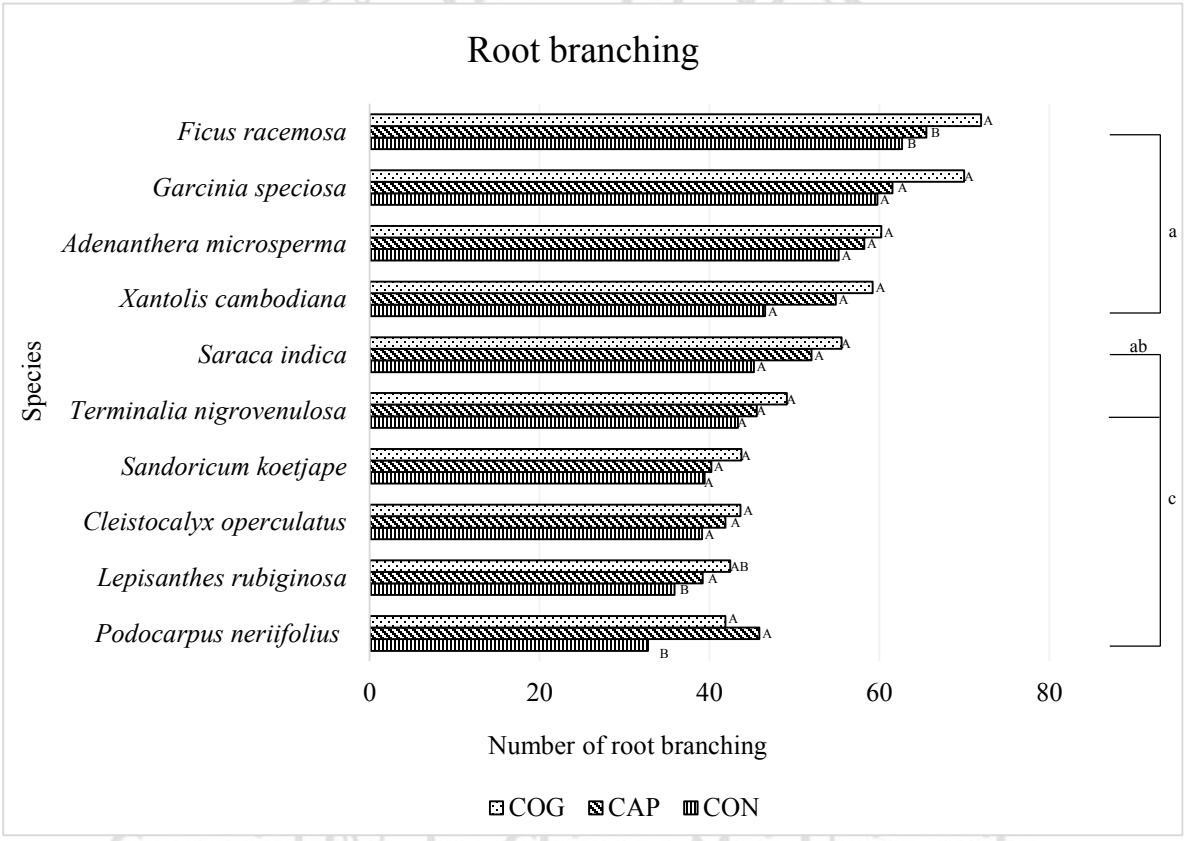
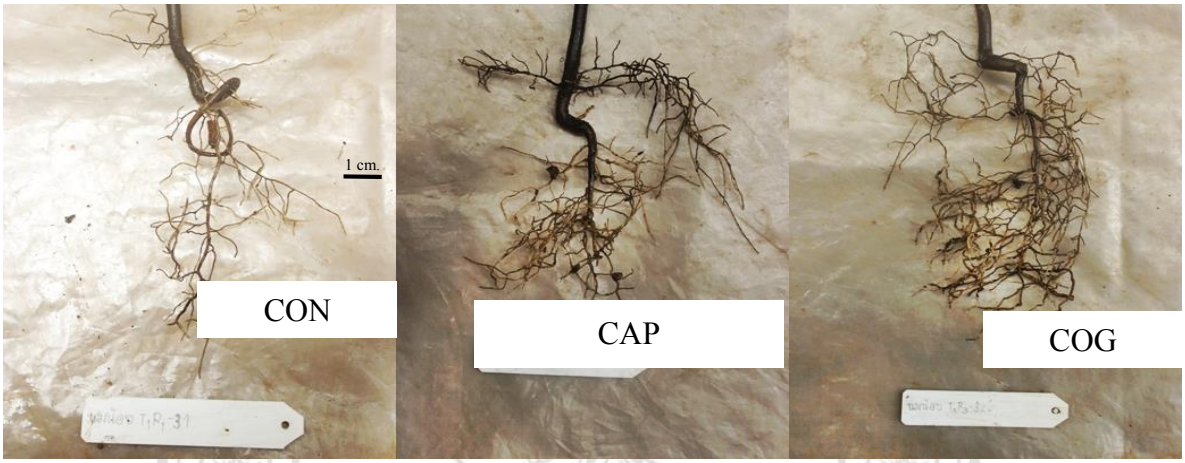


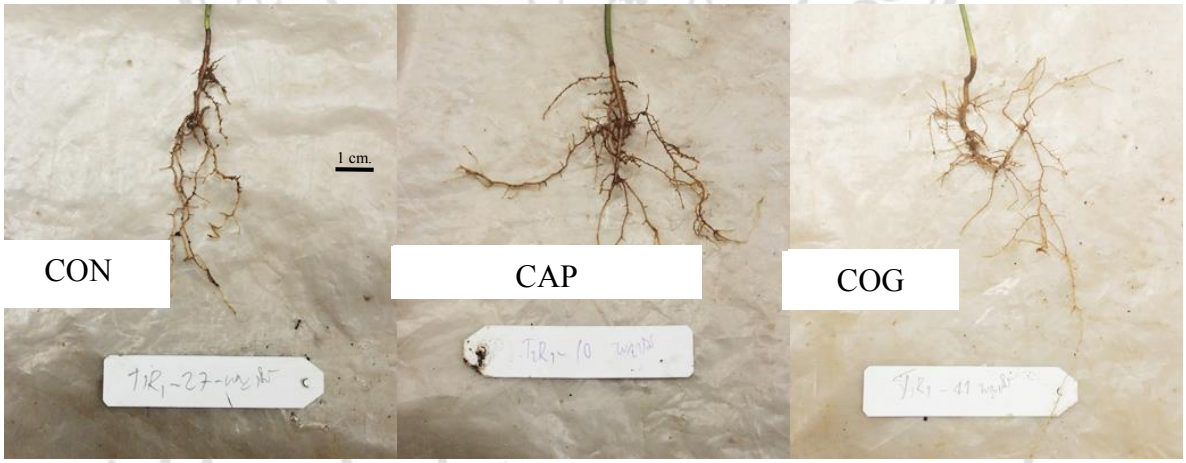
Figure 3.7 Number of root branches of ten seedlings of selected framework species with three treatments after six months. (N=270) (COG = Crate on ground treatment, CAP = Crate with air-pruning treatment and CON = Control treatment). Bars not sharing the same capitalized superscripts indicate significant differences among treatments within each species; species not sharing the same lowercase superscript indicate significant difference among species.

Figure 3.8 Root branching after six months.

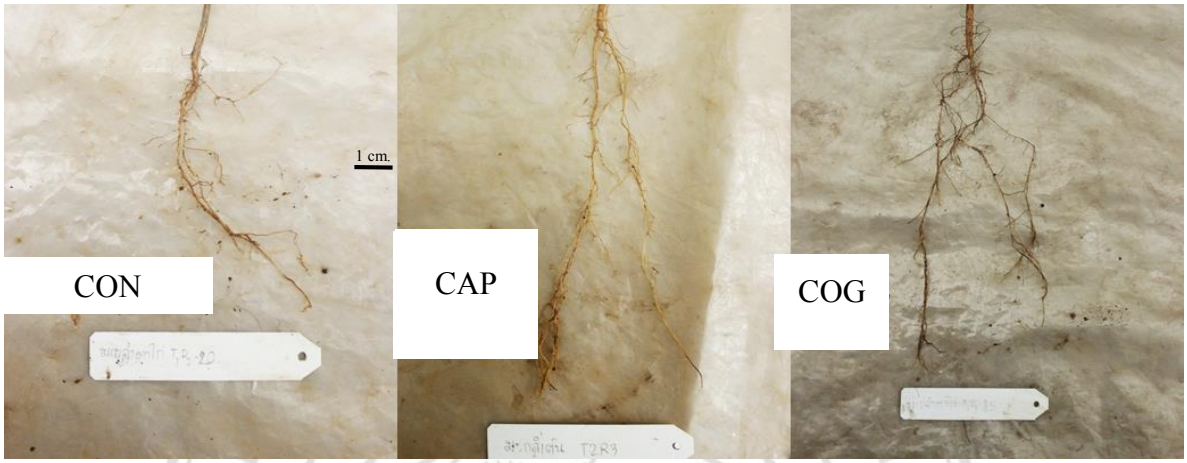
a.) *Xantolis cambodiana* (Sapotaceae)



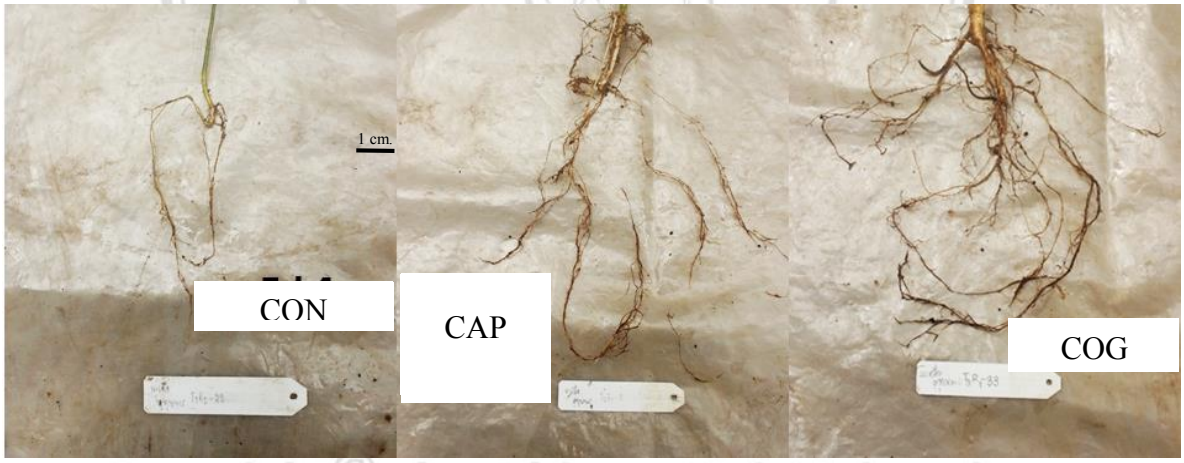
b.) *Podocarpus neriifolius* (Podocarpus)



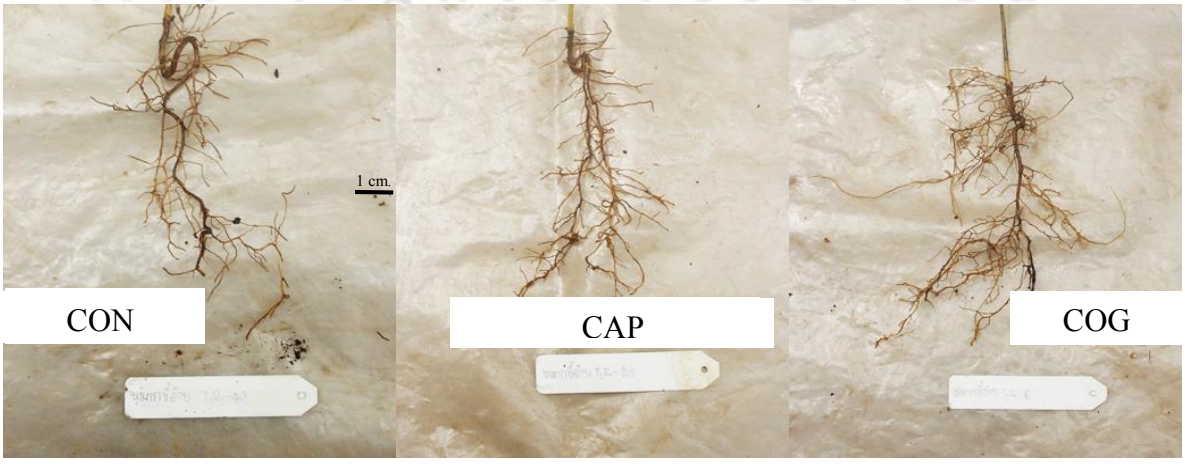
c.) *Adenanthera microsperma* (Fabaceae)



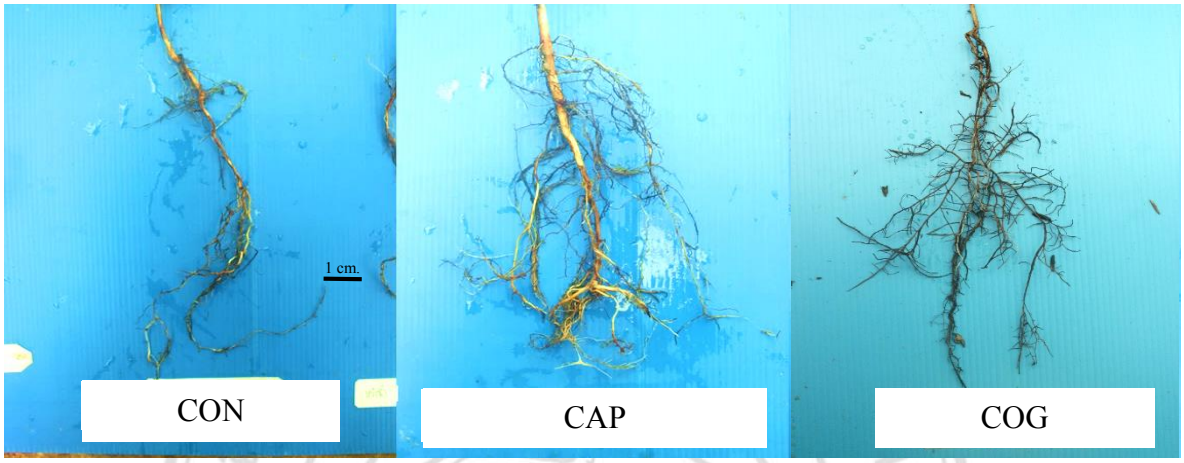
d.) *Ficus racemosa* (Moraceae)



e.) *Terminalia nigrovenulosa* (Combretaceae)

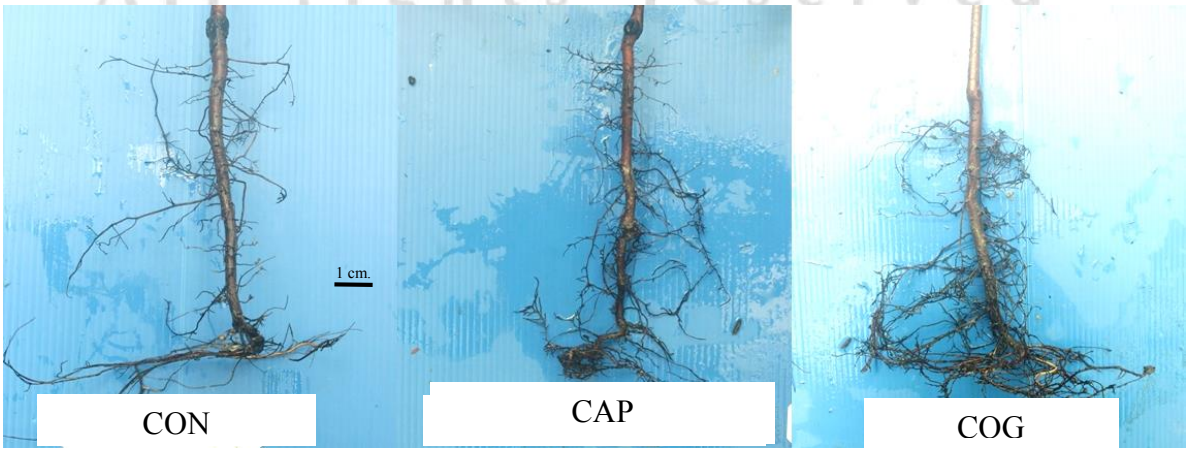


f.) *Cleistocalyx operculatus* (Myrtaceae)

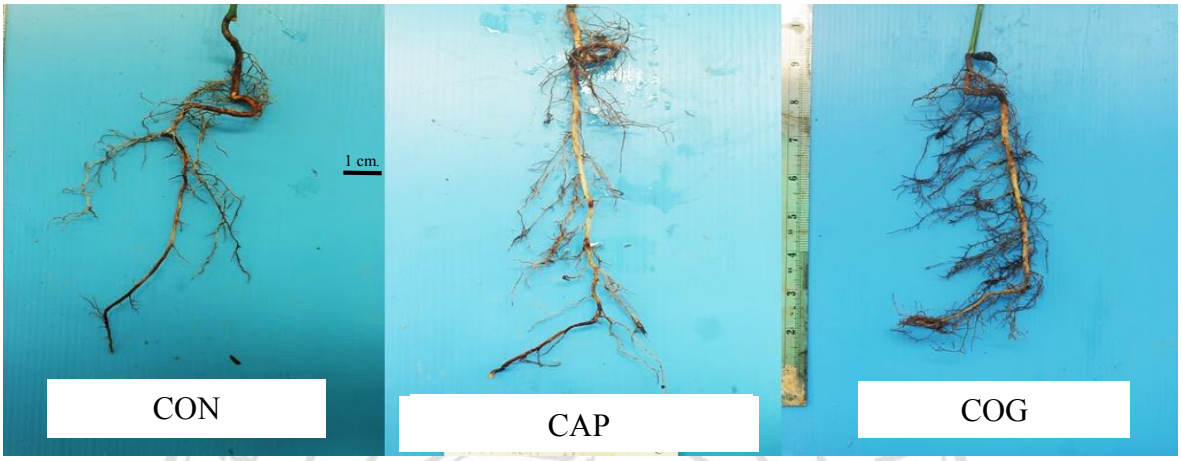


g.) *Sandoricum koetjape* (Meliaceae)

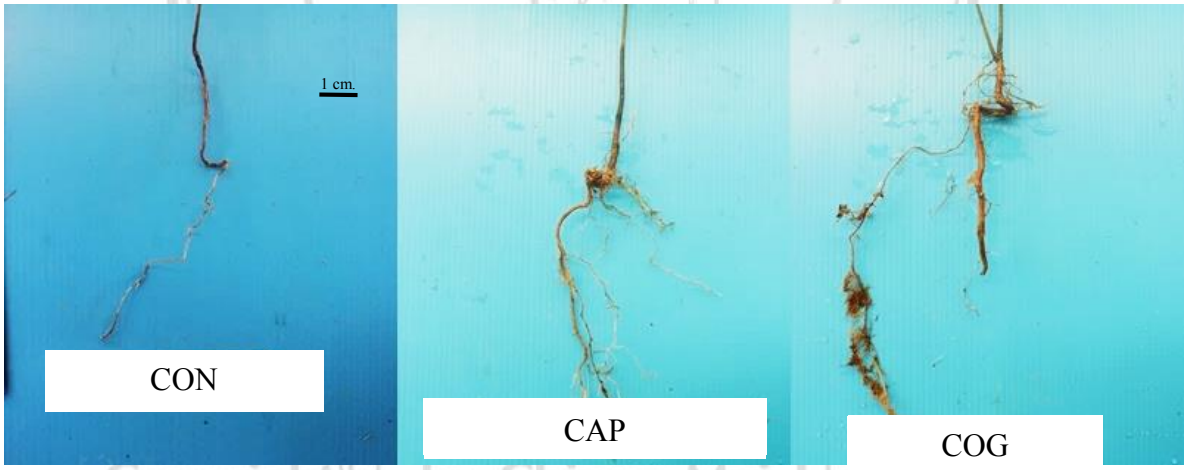
h.) *Saraca indica* (Fabaceae)



i.) *Garcinia speciosa* (Clusiaceae)



j.) *Lepisanthes rubiginosa* (Sapindaceae)



Some seedlings had various primary root deformities such as kinks and spiraling (Figure 3.9). The COG and CAP treatments reduced root deformations compared with controls.

The roots of some saplings grew out from their containers (Figure 3.10). Differences in root grew out among the treatment of all species were significant ($P<.05$). The percentage of saplings with roots growing out from plastic bags was highest in the CON group, particularly for *Xantolis cambodiana* with 32.64% followed by COG treatment and CAP treatment. (Figure 3.11).

Figure 3.9 Examples of spiraling roots and other root abnormalities by control treatment.

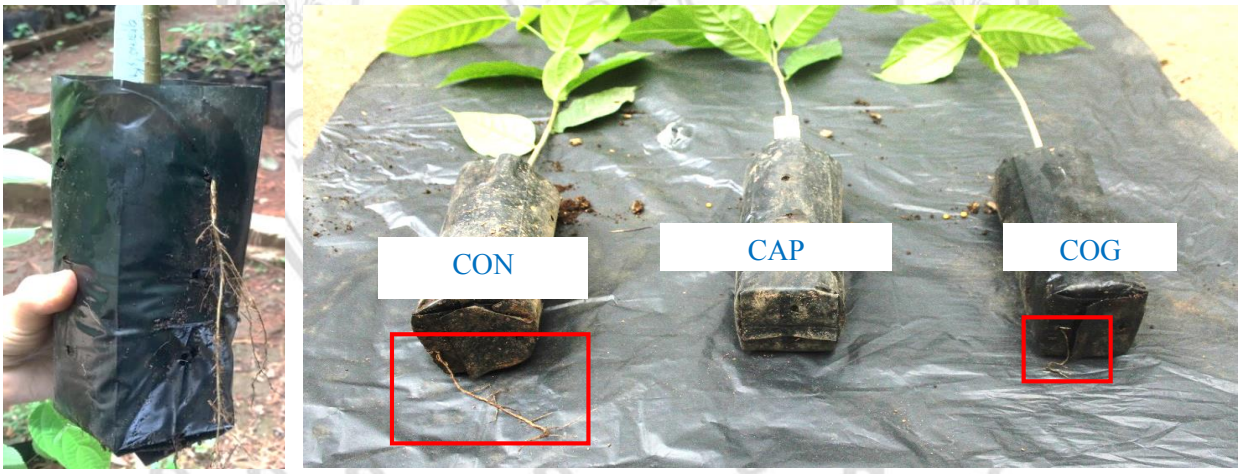


Figure 3.10 Some of the roots (*Sandoricum koejape*) grew out of the plastic bags of seedlings ten framework species in the nursery.

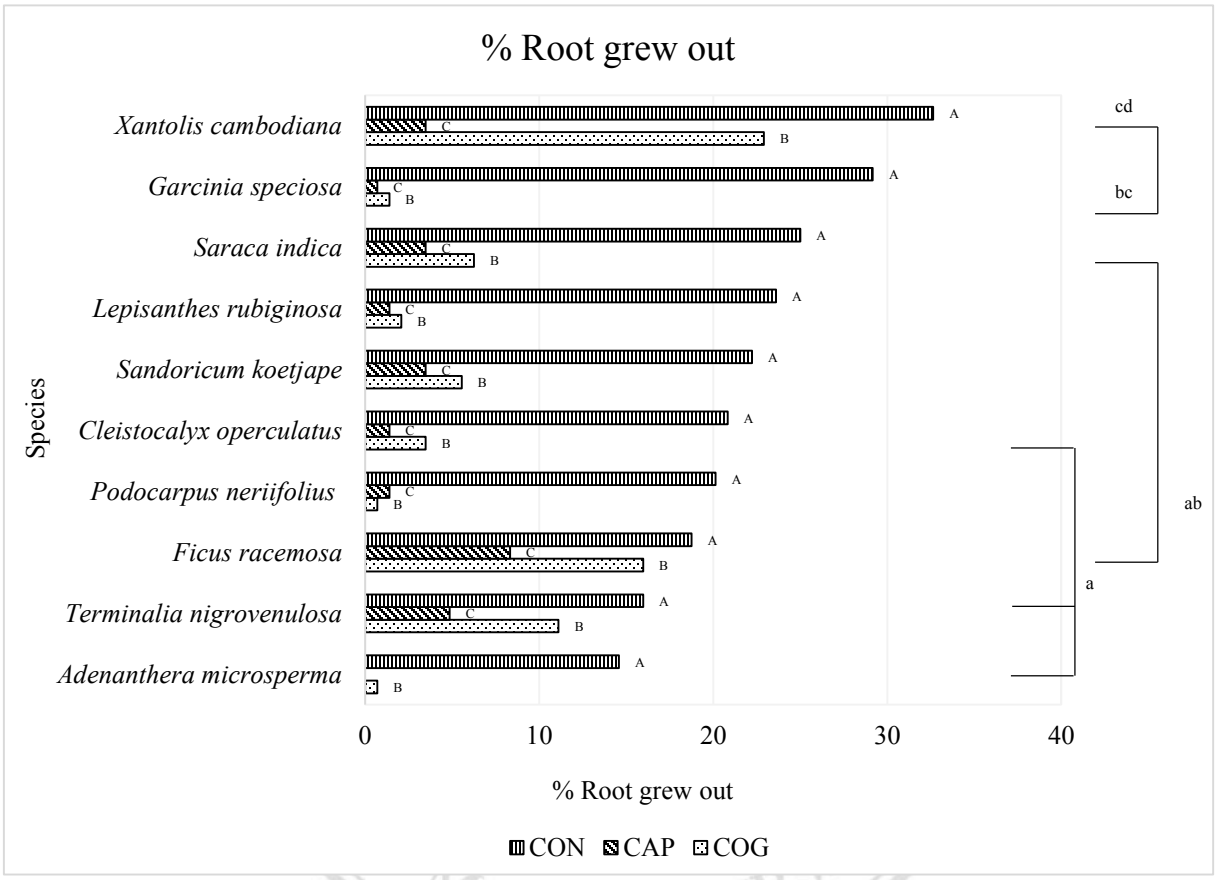


Figure 3.11 Percent of seedlings (N=144 per species) with roots growing out of plastic bags after six months of ten framework species in the nursery. Bars not sharing the same capitalized superscripts indicate significant differences among treatments within each species; species not sharing the same lowercase superscript indicate significant difference among species.

3. Cost effectiveness

For the cost effectiveness, The CAP treatment was the most expensive (19.63 and 20.66 baht per seedling in Chiang Mai and Krabi respectively). Followed by the controls 18.95 and 20.28 baht per seedling. The cheapest treatment was the crate method on the ground with the cost was about 18.08 and 19.11 baht per seedling. (Table 3.1).

The seedling production cost was calculated based on the number of survival seedlings consisting of CON 2,135 seedlings, CAP 2,144 seedlings, and COG 2,143 seedlings in Chiang Mai while CON 2,146 seedlings, CAP 2,158 seedlings, and COG 2,156 seedlings in Krabi, grown in nurseries for six months. In addition, it was assumed that materials would last for five years before requiring replacement. Costs were divided into establishment costs and maintenance costs. The most expensive treatment was the air-root pruning treatment (about 42,094.44 bath and 44,586.80 baht at the Chiang Mai and Krabi nurseries respectively). For the controls and COG treatment the cost were 40,467.24 bath, 43,526.16 baht and 38,748.84 bath, 41,208.00 baht respectively (Table 3.1).

Whereas establishment costs did not differ among treatments maintenance costs did, with labor accounting for 85-95 percent of total costs. Maintenance costs for the control group were 39,600 and 41,999.76 baht in Chiang Mai and Krabi respectively higher compared with those for the CAP and COG treatments.

Table 3.1 Establishment and maintenance costs for seedling production of five species in each area for the six months of study and assume that material for experiment set up will last for five years.

Order	**Chiang Mai nursery**			**Krabi nursery**		
	Prices (baht)			Prices (baht)		
	CON	CAP	COG	CON	CAP	COG
Crate	-	881.6	881.6	-	1,500.00	1,500.00
Material[1]	-	4521.20	1175.6	-	3,378.80	-
Soil	-	-	-	518.40	518.4	518.4
Plastic bag	360.2	360.2	360.2	518.40	518.4	518.4
Coconut husk	216.1	216.1	216.1	345.60	345.60	345.60
Rice husk	115.3	115.3	115.3	144.00	144.00	144.00
Labor cost[2] (1person)	39,600	36,000	36,000	41,999.76	38,181.6	38,181.6
Total costs	**40,467.24**	**42,094.44**	**38,748.84**	**43,526.16**	**44,586.80**	**41,2080**
*Seedlings survival	2,135	2,144	2,143	2,146	2,158	2,156
Cost per seedling	**18.95**	**19.63**	**18.08**	**20.28**	**20.66**	**19.11**

[1]Material cost include material for setup such as iron tubes, wire bench.

[2] Labor cost calculated by averaged of the CON 22 working days per month differs from the CAP and COG treatments 20 working days per month.

CHAPTER 4

Discussion

1. Finance of Nursery cultivation

In Thailand, it is estimated that 5.28 million hectares of degraded land should be restored to forest. However, few studies of the economics of producing framework tree species in nurseries have been performed.

In this study, three production systems were compared: control (CON), air root pruning (CAP), and crate treatment (COG). Seedling production costs were calculated, based on 2,160 seedlings, grown in the nursery over six months (2019 costs). Cost range between 18.08 – 20.66 baht per seedling. Seedling production by the CAP method was the most expensive, followed by CON and COG treatment in descending order of cost. Nevertheless, Interstate Commission on the Potomac River Basin, United States reported costs to range between $0.50 and $1.50 per seedling (around 15.45 – 46.35 baht, 2020) for the smallest seedling orders (generally 100 seedlings). At the same time, Mangueira and Rodrigues (2019) demonstrated cost comparisons used in experiments of degraded forest fragments in Brazil. The costs from a local nursery calculated for planting 835 seedlings/ha. They showed the cost of small seedlings (average height of 8.3 cm) 0.17 $ / seedling while 0.5 $ / seedling for large seedlings (26.7 cm.). Thus, the cost of trees planting depends on area size and restoration strategy. However, if you are planting a large area or your budget is limited, seedling tree plantings can be effective.

The control treatment required 22 days of labor per month (8 hours per day). The work was mostly maintenance of the seedlings and nursery, which includes transplanting, root pruning and grading. The highest cost was for labor (85-95 percent of the total cost). The working time and hourly pay may differ with different nursery operations. In addition,

control treatment used equipment for root cutting such as scissors, glove, etc. that increased establishment cost. Meanwhile, Van et.al, 2020 indicate real costs of establishing plantations vary according to fluctuations in several component costs. Wage rates accounted for around 40% of the total costs of planting. Contractor rates for labor in Australia for maintenance were as high as AU$50 h^{-1} and for supervisors AU$57 h^{-1}.

Crating reduced the labor costs by two days per month (the time needed to do a conventional root pruning by hand). The high cost of the CAP treatment was due to the cost of the wire benches and crates. They were assumed to have a lifespan of 5 years. Accordingly, in the long term, air root pruning could reduce labor costs and therefore reduce the total production cost.

COG was the cheapest treatment since it had the same labor savings, without the bench costs. In addition, this method also promotes the growth of some species. Thus, crate treatment is particularly recommended as a cost-effective and efficient method for tree seedlings production for forest restoration in the long term.

In addition, a vital consideration, when planning a forest restoration project, is obtaining high-quality trees for planting. Consequently, all aspects of tree production, including species selection, quality, and quantity of trees produced and production costs should be controlled. However, the variation of seedling growth among tree species is influenced by individual plant characteristics.

2. Seedlings growth and Culture Technique

In this study, the seedlings of the ten species grew well under nursery conditions. However, growth rates varied among species. *Ficus racemosa* in the COG treatment achieved the highest RGR-H. *Ficus racemosa* is a fast-growing species that thrives in semi-shade (light woodland) or no shade, the very dense root systems enable them to survive and grow well under the harshest of conditions and to grow back rapidly after burning or slashing (Elliott, 2006). Moreover, seedling height at planting can influence subsequent growth, because taller

seedlings tend to keep their height advantage over time (Grossnickle 2005b; Pinto 2011; Pinto et al. 2015).

Moreover, *Terminalia nigrovenulosa* of control treatment had a low percentage of survival probably the seedlings suffered from damping-off diseases such as fungal diseases (Figure 4.1), leave diseases and dieback diseases (Figure 4.2). Thus, to prevent disease spread, check seedlings that the plants are adequate drainage within and beneath the containers and that the plants are well spaced to allow air movement around them and to prevent direct transfer of pathogens from plants to their neighbors. Space the containers can a few centimeters apart, to prevent neighboring seedlings from shading each other. Remove infected leaves of diseased plants including remove harmful animals or their eggs by hand, or spray the saplings with a mild disinfectant (Elliott et al, 2006). Furthermore, have to use the grading method for quality control that arranging the growing trees in order of size, help to removing stunted, diseased, or weak saplings.

Figure 4.1 Some seedlings were compressed due to an unregulated arrangement on the ground and infected with fungus.

a.) b.)

c.) d.)

Figure 4.2 a. and b.) leaves disease of a *Sandoricum koetjape* seedlings.

c.) leaves disease of a *Cleistocalyx operculatus* seedlings.

d.) fungus disease of a *Terminalia nigrovenulosa* seedlings.

I found that the crate treatments on ground (COG) reduced mortality and diseases, leading to higher survival saplings compared with control treatment. In this case, these probably of the effect of air pruning which also occurred in crate treatment. The crates were put on the ground and there was a small gap between seedling containers and ground when the root grows out of the containers, the root growth was limited by dry air in the gap and air-pruning process could occur. This promotes a better root system and hence increased in dry weight in some seedlings species. Also, the crate treatment showed the highest root length because of the air root pruning by crate advocate strong taproot, encourages new roots to sprout that it also increased root branch and root areas included that prevents roots from spiraling (Walker, 2006). Thus, The COG increased the small gap between seedlings and stimulated the branches of the taproot.

Likewise, the root dry weight was indicative of the overall growth performance of the trees. In this study, the different species responded differently to treatments in terms of root dry weight. However, air root-pruning with a crate on the ground resulted in the highest fibrous root. As well both of air root pruning treatments tended to increase seedling mass. Consequently, the air root pruning technique is known to increase fibrous root mass (A.M.A, 2012) and stimulates the plants to constantly produce new and healthy branched roots. Similarly, the work of Wu (2013) reported the hazelnut seedlings plant in three treatments: grown in outdoor environmental, a retractable roof greenhouse, and air root pruning. The results showed there was no significant difference in root dry weight between the retractable roof greenhouse and the air pruning treatment. However, the root pruning technology had the highest fine root ratio on the dry weight.

High quality seedlings are essential for the success of forest restoration. For forest restoration, growing trees in community nurseries may be the best option. The seedlings in nurseries to grow on until they grow large enough to be planted out. But one of the main problems in the nursery is the poor root structure such as root ball, tangled up, root

deformities and root to grow out of the container. This problem affects plant health and may cause a seedling shock when transport to the planting site. Consequently, the nursery staffs must produce high quality seedlings in which the shoot and root systems should be healthy. This reduced transplantation stress, tree mortality. In addition, for successful out planting, high quality seedlings should be secured at an affordable cost.

Abnormal root growth can cause trees to fall prematurely later in life (Elliott et.al, 2006). Thus, a strong root system will make a plant better able to establish itself when installed in a restoration project.

This study showed the control treatment, coil, or spiral roots around the bottom of the plastic bag were found in some seedlings. Seedlings were compressed due to an unregulated arrangement on the ground. Seedlings in the control treatment grew slowest, compared with the crate treatment and had lower lateral and fine roots. Roots of some seedling grew out from the container and reached to the soil (Figure 4.3). The roots could be damaged. This causes planting shock as roots break when trees are lifted for transporting to the field. Damaged root systems also cause leaves to turn yellow or brown, shrivel, or drop. Moreover, plants were arranged pot-thick on the ground (no space in between). This caused seedling easy to infect with the disease. It can be prevented by lifting container frequency and prune back any roots seen growing outside including standing containers on concrete to inhibit root growing out. However, the cost of this treatment was higher than the crate treatment which consumes labor-intensive and expensive. Lifting and hand-pruning roots of trees in the control group took time and required a lot of labor that need the labor for cutting roots, sometimes every 15 days.

a.) b.) c.)

Figure 4.3 a.) Root grew out the plastic bag by control treatment. b. and c.) The roots spiral, twist and kink of some seedlings in control treatment.

The crate treatment accelerated the growth of ten seedlings in two areas. This agreed with the work of Van Sambeek et al. (2013) and Loppe et al. (1992). They reported that the air root pruning resulted in larger fibrous root systems and faster growth of height, diameter, and biomass, compared with conventional manual root pruning. This study found several root responses to crate treatments. The crate treatment may due to the effect of air pruning, because seedlings had a small gap between the bottom of the crate and the ground (around 1 cm), in which roots were exposed to air (Figure 4.4). Trees that have lots of roots, branching at the stem-root junction, outgrew those with fewer large roots at this location. In addition, the roots are effectively burnt off, causing the plant to constantly produce new and healthy branching roots (Walker, 2005). This study found crate treatments produced more lateral and fibrous roots more than other treatments did such as *Ficus racemosa*, which was also found with *Pyracantha* hybrid (Whitcomb, 1981). Also, Dey et al. (2003) and Lovelace (1998)

indicated that with root production method (RPM^{TM}) in oak. Oak seedlings grew faster treated with RPM^{TM}. RPM^{TM} is a trademark for the Root Production Method, an air root pruning process developed by Forrest Keeling Nursery in Elsberry, MO to accelerate plant growth rate. In the same way, with Devine, 2006 studied improving the root growth of Oregon white oak seedlings they found it responded to air-pruning with increased lateral root growth and minimal circling of roots. Similarly to this study that most of ten species in the nursery responded to crate treatments with increased lateral roots, and seedlings grew faster in terms of height and RCD. Consequently, seedlings with large, healthy fibrous root systems are better able to supply shoots with water. Moreover, The COG has put the seedling in twelve-cavity plastic crates which make seedlings transfers easier this will be move convenient seedlings transports (steam lining). The seedling can move to plant directly instead of move seedling one by one to the truck.

However, after six months, total seedling root dry weight did not differ significantly among all three treatments except *Cleistocalyx operculatus* and *Terminalia nigrovelunosa*. The average of root dry weight of lateral roots was greater with the COG and CAP treatments, however, indicating that air pruning increased root growth. Lateral root growth was not at the expense of taproot growth, as taproot weight did not differ among treatments. Air root pruning with increased lateral root growth and minimal root spiraling helps to create a dense root ball (Elliott et al, 2006). Thus, pruning new radicles increased taproot branching but did not increase growth of lateral roots.

Figure 4.4 Seedlings in crate treatment had a small gap between containers and ground.

Air root pruning happens naturally, when roots are exposed to air in the absence of high humidity. This study used plastic crates on a wire bench, sixty-centimeter height above ground. This stimulated root branching, resulting in many more secondary roots. As more secondary roots develop, nutrient absorption increases, enabling plants to grow more rapidly. Marshall et al, (1998) reported that air root-pruning containers caused an increase in numbers of descending roots, compared to smooth-sided containers, probably due to the corrugated sides. In my study, air root-pruning reduced outgrowth of roots from the plastic bags, but it also resulted in shorter seedlings compared with other treatments (Figure 4.5). Smaller saplings can be kept for a long time in the nursery, when the conditions are not suitable for transplantation to the field, such as droughts, floods, and climate change.

In the same way with The ACIAR FLR project (2019) has been demonstrating low-cost simple technologies to produce high-quality seedlings. They found seedlings from nurseries of peoples organizations in Iloilo showing a good comparison of seedling quality using elevated hardening bed constructed from local materials versus the common practice of placing seedlings on the ground. Seedlings on the ground are *Acacia auriculiformis* (auri) while those on an elevated bed are *Swietenia macrophylla* (mahogany). The result showed Auri seedling showing roots growing outside the container and penetrating into the ground. Seedling of Mahogany taken from elevated bed showing no roots growing outside the polybag due to aerial root pruning. In addition, Mahogany seedling showing dense root hair mass more than Auri. Thus, the size of the seedling and number of leaves, and compare to the root volume. Large seedling generally requires more soil moisture. But fewer root hairs that absorb water prove a low chance of seedling survival and establishment. In contrast, small seedling with a high volume of root hairs has a great chance of survival in the field.

Therefore, to promote seedling growth in this treatment, more watering may be needed. Similarly, Jitlam, 2001 suggested increased watering, when using air pruning. Moreover, the height of the wire bench, at 60 cm above the ground in air pruning treatment, provided a more convenient working position for the nursery staff. In addition, crate and air root pruning treatments could save or reduce the seedlings production cost but must be weighed against the materials cost of building the wire-grid bench (Elliott et al, 2006).

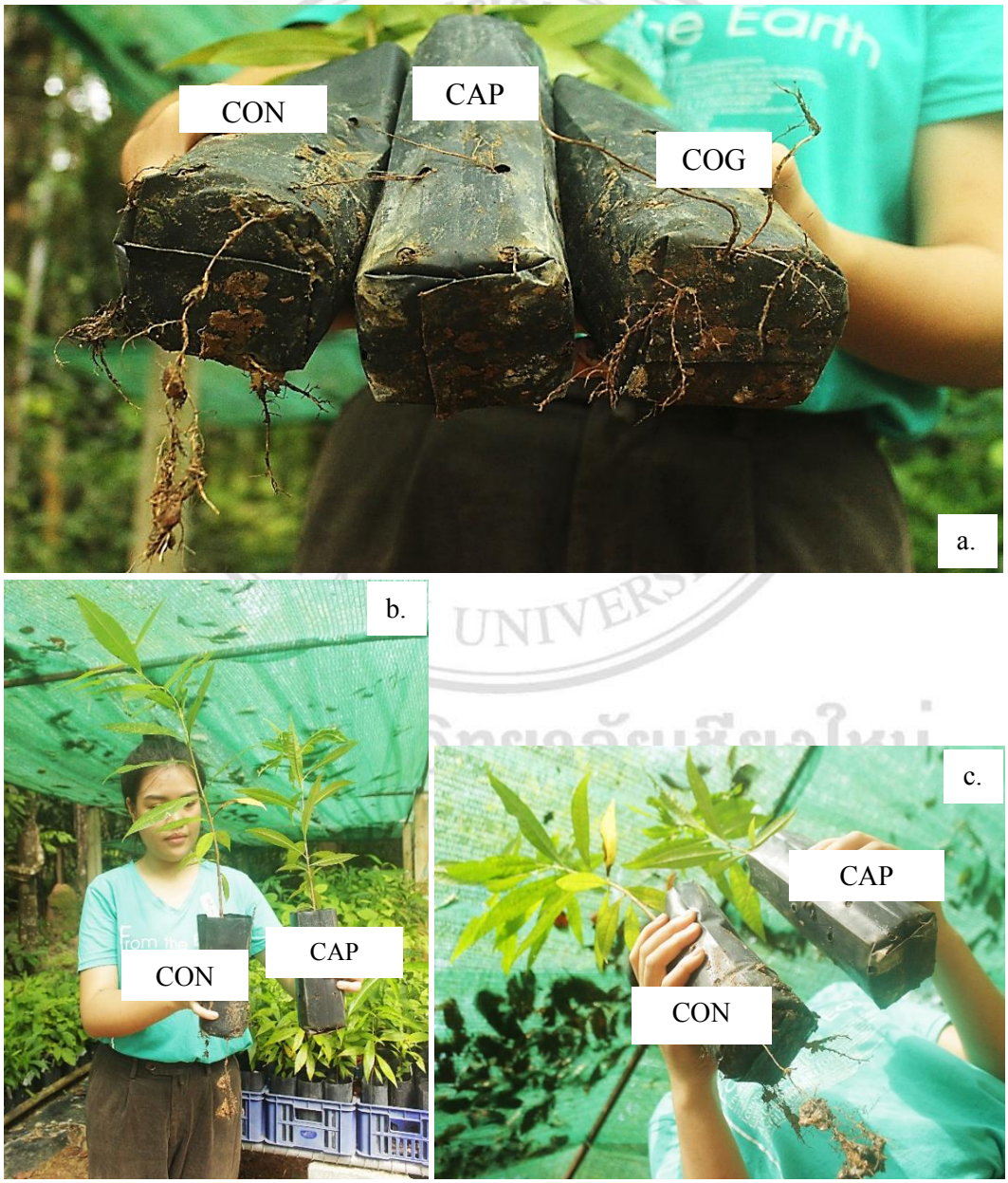


Figure 4.5 a) Comparing outgrowth of roots from plastic bags among the three treatments; b) comparing seedling height between control and air root-pruning treatment and c) comparing root outgrowth from plastic bags between control and air root pruning treatment.

In some studies found the potential of air root pruning effect on seedlings growth rate in the long term, although it did not different seedlings potential in an early stage. For example, Tolliver et al., 1980 indicated that root-pruning did not promote the survival or growth of *Quercus nigra*, *Quercus phellos* and *Carya illinoensis* in the field. A similar result was reported for Magnolia grandiflora (Gillman, 1992) and root pruning could not promote a good root system of *Artocarpus lakoocha*, *Balakata baccata* and *Horsfieldia thorelii* by REX tray root trainers (Jitlam, 2001). However, with *Picea smithiana* root pruning in the nursery prior to planting resulted in taller plants with a greater shoot dry weight after two years growing in the field (Singh et al., 1984). Although root pruning can induce water stress and reduce plant growth in the short term, plant growth appears to be unaffected or increased in the long term (Watson et al, 1987). Therefore, the trees produced by the present study should be followed after transplantation in the field to determine the long term effects of nursery treatments.

CHAPTER 5

Conclusion

The Asia-Pacific region has seen some important developments in forest restoration. In the second half of the last century, China, Japan, the Republic of Korea and Vietnam initiated massive nationwide restoration programs, which effectively doubled or tripled their forest cover. (FAO, 2016). Therefore, the demand of high-quality seedlings increased. Advanced culture techniques should be a part of the forest restoration. Crate treatment (COG) which had a small gap among the ground and seedlings that made the root at the bottom of the container desiccated by air root pruning techniques. Perhaps instead of building expensive benches, all we really need to do is to raise the crates slightly on 2-inch bricks at the edges - just enough to enhance the air pruning effect. These successfully achieved in the nursery. This was better than the control (CON) - conventional root pruning techniques for five reasons. First, seedling root systems had more lateral and fibrous roots. Second, this technique reduced root deformation. Third, the air pruning technique may potentially have long-term benefits for trees growing in the field. Fourth, the COG technique was more cost-effective than the other two techniques-producing seedling sat below 20 THB each. The technique required less labor in the nursery than CAP and CON. Finally, the COG technique has put the seedling in twelve-cavity plastic crates that move convenient seedlings transports easier. Further studies on plant acclimation and transplanting dates will make the framework species production more integrated and further reduce the cost of nursery plants.

REFERENCES

Andersen, L., Rasmussen, H. N., & Brander, P. E. (2000). Regrowth and dry matter allocation in *Quercus robur* (L.) seedlings root pruned prior to transplanting. *New Forests*, *19*(2), 205-214.

The ACIAR FLR project (2019), The National Greening Program of Commission on Audit (COA) report, Republic of Philippines. Australian Centre for International Agricultural Research (ACIAR) for Forest and Landscape Restoration project (accessed March, 2020).

A.M.A. (2012). A.M.A. Plastic Ltd. Canada. Available from http://www.amaplas.com/ellepots/ (accessed March, 2020).

Ali, H.I., Ismail, M.R., Baharudin, W.M.Z., Khiry,M.A. and Mahmoud, T.E. (2014). Effect of rootpruning on leaf expansion, leaf water potentialand stomatal conductance in mango. Universityof Kordofan Journal of Natural Resources andEnvironmental Studies 1, 71-76

Budiarto, R., Poerwanto, R., Santosa, E., & Efendi, D. (2019). A review of root pruning to regulate citrus growth. Journal of Tropical Crop Science Vol, 6(1).

Davis, A. S., & Jacobs, D. F. (2005). Quantifying root system quality of nursery seedlings and relationship to outplanting performance. *New Forests*, *30*(2-3), 295-311.

Dey, C. D., M. J. Kabrick, and A. M. Gold. (2003). Tree establishment in floodplain agroforestry practices. AFTA Conference Proceedings 102-107.

Duryea, M. L. (1984). Nursery cultural practices: impacts on seedling quality. In *Forestry Nursery Manual: Production of Bareroot Seedlings* (pp. 143-164). Springer, Dordrecht.

Elliott, S., Blakesley, D., Maxwell, J. F., Doust, S., & Suwannaratana, S. (2006). How to plant a forest: the principles and practice of restoring tropical forests. *Biology Department, University of Chiang Mai, Chiang Mai*.

FORRU. (2006). Planting trees. In: Elliott, S., Blakesley, D., Maxwell, J.F., Doust and Suwannaratana. S. How to plant a forest: the principles and practices of restoring tropical forests. Biology Department, Science Faculty, Chiang Mai University, Chiang Mai p. 103–132.

Food and Agriculture Organization of the United Nations. (2015). *Global Forest Resources Assessment 2015: How are the World's Forests Changing*. Food and Agriculture Organization of the United Nations.

Forseth, I. (2010) Terrestrial Biomes. Nature Education Knowledge 3(10):11. *Department of Biology, University of Maryland*.

Gilman, F. E. 1992. Effect of root pruning prior to transplanting on establishment of southern magnolia in the landscape. Journal of Arboriculture 18 (4): 197-200.

Grim, G.R. (1956). Preliminary investigation on dieback of young transplanted citrus trees. Proceeding of the Florida State Horticultural Society 69, 31-34.

Grossnickle SC (2005b) Seedling size and reforestation success. How big is big enough? In: Colombo SJ(compiler) The thin green line: a symposium on the state-of-the-art in reforestation. Ontario ForestResearch Institute, OMNR For Res Info Paper 160, pp 138–144

GFW, Global Forest Watch. 2018. World Resources Institute and Forest Global Forest Watch (accessed September, 2018).

IUCN: International Union for Conservation of Nature (2016). Making the Case for Forest Restoration: A guide to engaging companies. Gland, Switzerland.

IUCN: International Union for Conservation of Nature (2017). *IUCN issues briefs*: *Deforestation and Forest Degradation.* Gland, Switzerland.

Jaenicke, H. (1999). Good tree nursery practices: practical guidelines for research nurseries. World Agroforestry Centre.

Jitlam N. Effects of Container Type, Air Pruning and Fertilizer on the Propagation of Tree Seedlings for Forest Restoration. 2001. M.Sc. in Biology, Graduate School, Chiang Mai University

Harris, J.G. and Harris, M.W. (2006). "PlantIdentification Terminology: An IllustratedGlossary", Spring Lake Publishing, Utah.

Haase, D. L. (2008). Understanding forest seedling quality: measurements and interpretation. Tree Planters' Notes, 52(2), 24-30.

Kainer K.A. and Duryea M.L. 1990. Root wrenching and lifting date of slash pine: effects on morphology, survival, and growth. New Forest 4: 207–221.

Khan, Z. U.; McNeil, D. L.; Samad, A. 1998a: Effect of carbohydrate reserves on fruit yield and vegetative growth of apple trees growing in an ultra-high density planting system under Canterbury condition. Sarhad journal of agriculture: in press.

O'Connor, A. S., Klett, J. E., & Koski, A. J. (2013). Container Type and Overwintering Treatments Affect Substrate Temperature and Growth of Chanticleer® Pear (Pyrus calleryana 'Glen's Form') in the Nursery. *Journal of Environmental Horticulture*, *31*(2), 117-123.

Olave R. and McAdam J. (2003) Progress in the development of Maidenhair tree (*Gingko biloba*) using root air pruning for agroforestry. Agroforestry Forum, Scotland, UK.

Ortega, U., Majada, J., Mena-Petite, A., Sanchez-Zabala, J., Rodriguez-Iturrizar, N., Txarterina, K., & Duñabeitia, M. (2006). Field performance of Pinus radiata D. Don produced in nursery with different types of containers. *New Forests*, *31*(1), 97-112.

Lovelace, W. 1998. The root production method (RPM). System for producing container trees. Combine Proceeding International Plant Propagation Society 48: 556-557.

Louppe, D., QUATTARA, N., & Vandenbeldt, R. J. Growth of Faidherbia albida in nurseries: standard production techniques or air pruning? Proceedings. In Faidherbia albida in the West African Semi-Arid Tropics, Niamey, NIger, 22-26 Apr 1991 (No. 23587). ICRISAT, Andhra Pradesh (India) ICRAF, Nairobi (Kenia).

Mangueira, J. R. S., D. Holl, K., & Rodrigues, R. R. (2019). Enrichment planting to restore degraded tropical forest fragments in Brazil. Ecosystems and People, 15(1), 3-10.

Marshall, M. D., & Gilman, E. F. (1998). Effects of Nursery Container Type on Root Growth and Landscape Establishment of Acer rubrum L. *Journal of Environmental Horticulture*, *16*(1), 55-59.

Marler, T. E., & Willis, D. (1996). Chemical or air root-pruning containers improve carambola, longan, and mango seedling root morphology and initial root growth after transplanting. *Journal of environmental horticulture*, *14*(2), 47-49.

Maxwell, J. F., & Elliott, S. (2001). Vegetation and Vascular Flora of Doi Sutep-Pui National Park, Chiang Mai Province, Thailand. Thai Studies in Biodiversity 5, Biodiversity Research and Training Programme, Bangkok.

Mitre, V., MITRE, I., SESTRAS, A. F., & SESTRAS, R. E. (2012). Effect of Roots Pruning upon the Growth and Fruiting of Apple Trees in High Density Orchards. *Bulletin of the University of Agricultural Sciences & Veterinary Medicine Cluj-Napoca. Horticulture*, *69* (1).

Mullan, G. D., & White, P. J. (2002). Seedling quality: Making informed choices. *Bushcare and the Department of Conservation and Land Management of Western Australia, Perth*, *24*.

Pérez-Harguindeguy N., Díaz S., Garnier E., Lavorel S., Poorter H., Jaureguiberry P., Bret-Harte M. S., Cornwell W. K., Craine J. M., Gurvich D. E., Urcelay C., Veneklaas E. J., Reich P. B., Poorter L., Wright I. J., Ray P., Enrico L., Pausas J. G., de Vos A. C., Buchmann N., Funes G., Quétier F., Hodgson J. G., Thompson K., Morgan H. D., ter Steege H., van der Heijden M. G. A., Sack L., Blonder B., Poschlod P., Vaieretti M. V., Conti G., Staver A. C., Aquino S. and Cornelissen J. H. C.. (2013). New handbook for standardised measurement of plant functional traits worldwide. Australian Journal of Botany, 61, 167-234.

R Core Team (2018). R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria. URL https://www.R-project.org/.

Riikonen, J., & Luoranen, J. (2018). Seedling Production and the Field Performance of Seedlings.

Meek (2019). Effects of Deforestation: How Does Agriculture Cause Deforestation?. Available from Sentient Media https://sentientmedia.org/how-does-agriculture-cause-deforestation/ (accessed October 12, 2019).

Thompson B.E. 1985. Seedling morphological evaluation: what you can tell by looking. In: Duryea M.L. (ed.), Evaluating Seedling Quality: Principles, Procedures, and Predictive Ability of Major Tests. Oregon State University, Corvallis, OR, pp. 59-71.

Tolliver, R. J., C. R. Sparks, and T. Hansbrough. 1980. Effects of trp and lateral root pruning on survival and early growth-three bottomland hardwood tree species. Tree Planters' Notes 13 .

Thaler, P. and L. Pages. 1997. Competition within the root system of39.rubber seedlings (Hevea brasiliensis) studied by root pruning and blockage.J. Expt. Bot. 48:1451–1459

Tsukahara, K., Yamane, K., Yamaki, Y., Fujishige, N.and Honjo, H. (2009). Effects of root pruningand uniconazole treatments on flower budinduction in peach seedlings of the currentyear. Horticultural Research 8, 341–346

Shevade, R. (2011). Effects of Root Pruning Containers and Traditional Containers on Growth of Roots and Shoots of Selected Landscape Plants (Doctoral dissertation).

Van Sambeek, J. W., Godsey, L. D., Walter, W. D., Garrett, H. E., & Dwyer, J. P. (2016). Field Performance of Quercus bicolor Established as Repeatedly Air-Root-Pruned Container and Bareroot Planting Stock. Open Journal of Forestry, 6, 163-176.

Van Oosterzee, P., Liu, H., & Preece, N. D. (2020). Cost benefits of forest restoration in a tropical grazing landscape: Thiaki rainforest restoration project. Global Environmental Change, 63, 1-6.

Walker, J. (2005). Development and construction of an air-pruning propagation bench, and its proper use. *Guidebook for Native Plant Propagation.* ESRM 412 – Native Plant Production, http://depts.washington.edu/propplnt/Chapters/air-pruning.htm#_edn9

Watson, G. W., & Sydnor, T. D. (1987). The effect of root pruning on the root system of nursery trees. *Journal of arboriculture (USA)*.

Whitcomb, C.E. (2003). *Plant production in containers II*. Lacebark Publ., Stillwater, Okla. 77–118.

Whitcomb, C.E. (2018). The original root pruning container system. www.rootmaker.com (accessed October 23, 2018).

Wightman K.E. 1999. Good tree nursery practices: practical guidelines for community nurseries. Nairobi: International Centre for Research in Agroforestry. 95 pp.

Woods, K., & Elliott, S. (2004). Direct seeding for forest restoration on abandoned agricultural land in northern Thailand. *Journal of Tropical Forest Science*, 248-259.

Wu, S. (2013). Nursery techniques Influence the growth of hazelnuts (Doctoral dissertation, MS thesis, University of Guelph).

WWF – World Wide Fund for Nature, Taylor, R. (2011): WWF living forests report: *Chapter 1: Forests for a living planet.* 1-35.

United Nations. ECE/FAO Forestry and Timber Section (2013). Trade and Sustainable Land Management Division United Nations Economic Commission for Europe (ISSN 1020 2269). United Nations Publications.

APPENDICES

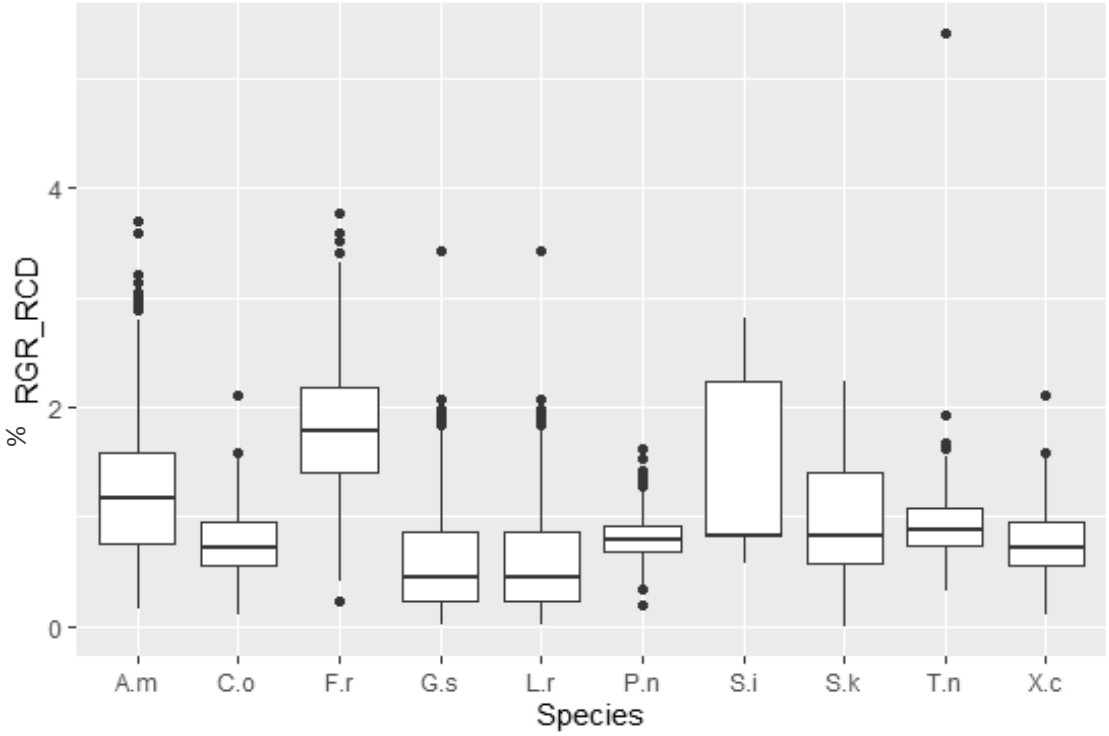
APPENDIX A

Appendix 1 Mean Relative Growth Rate (RGR) (%/year) of height of ten species with three treatments.

^{A} shows the significant difference among treatments **a** shows the significant difference among species

Species	Treatments	Height mean ± SE (%RGR/year)	Tukey HSD
X.cambodiana	Control	$64.67^{A} \pm 1.45$	**g**
	Air-root pruning	$61.00^{A} \pm 1.15$	
	Crate	$65.33^{A} \pm 5.21$	
P.neriifolius	Control	$116.00^{B} \pm 6.43$	**de**
	Air-root pruning	$117.00^{A} \pm 5.51$	
	Crate	$119.33^{A} \pm 1.20$	
A.microsperma	Control	$97.67^{A} \pm 4.70$	**cd**
	Air-root pruning	$107.00^{B} \pm 7.51$	
	Crate	$143.33^{B} \pm 5.61$	
F.racemosa	Control	$228.00^{B} \pm 43.96$	**a**
	Air-root pruning	$236.33^{C} \pm 19.15$	
	Crate	$265.33^{A} \pm 12.90$	
T.nigrovenulosa	Control	$85.67^{A} \pm 6.38$	**c**
	Air-root pruning	$86.33^{A} \pm 7.69$	
	Crate	$91.67^{A} \pm 7.88$	

Species	Treatments	Height mean ± SE (%RGR/year)	Tukey HSD
C.operculatus	Control	$203.33^{A} \pm 42.47$	**b**
	Air-root pruning	$186.33^{B} \pm 15.93$	
	Crate	$207.33^{A} \pm 32.38$	
S.koetjape	Control	$109.78^{A} \pm 14.75$	**ef**
	Air-root pruning	$83.33^{B} \pm 5.93$	
	Crate	$119.67^{AB} \pm 15.98$	
S.indica	Control	$134.22^{A} \pm 5.93$	**f**
	Air-root pruning	$124.33^{A} \pm 7.88$	
	Crate	$141.00^{A} \pm 11.00$	
G.speciosa	Control	$62.22^{C} \pm 7.00$	**g**
	Air-root pruning	$64.67^{B} \pm 9.61$	
	Crate	$71.00^{A} \pm 8.19$	
L.rubiginosa	Control	$81.78^{A} \pm 10.83$	**c**
	Air-root pruning	$77.00^{B} \pm 5.29$	
	Crate	$87.33^{A} \pm 11.89$	



Appendix 2 box plot seedling RGR of RCD of ten selected species.
(A.m=*A.microsperma*, C.o=*C.operculatus*, F.r=*F.racemosa*, G.s=*G.speciosa*, L.r=*L.rubiginosa*, X.c= *X.cambodiana,* P.n=*P.neriifolius*, S.i=*S. indica*, S.k=*S.koetjape*, and T.n=*T.nigrovelunosa*)

Appendix 3 Mean Relative Growth Rate (%/year) of root collar diameter of ten species with three treatments.

^{A} shows the significant difference among treatments, **a** shows the significant difference among species

Species	Treatments	RCD mean ± SE (%RGR/year)	Tukey HSD
X.cambodiana	Control	$80.67^{B} \pm 0.67$	**b**
	Air-root pruning	$84.33^{B} \pm 6.57$	
	Crate	$94.67^{A} \pm 0.97$	
P.neriifolius	Control	$84.67^{A} \pm 1.67$	**b**
	Air-root pruning	$89.33^{B} \pm 2.03$	
	Crate	$90.00^{A} \pm 0.58$	
A.microsperma	Control	$93.00^{A} \pm 11.00$	**b**
	Air-root pruning	$136.67^{B} \pm 39.41$	
	Crate	$145.00^{B} \pm 10.58$	
F.racemosa	Control	$172.00^{A} \pm 5.69$	**a**
	Air-root pruning	$175.67^{A} \pm 9.21$	
	Crate	$178.67^{A} \pm 2.91$	
T.nigrovenulosa	Control	$91.33^{A} \pm 6.06$	**cd**
	Air-root pruning	$93.00^{A} \pm 3.79$	
	Crate	$94.00^{A} \pm 6.81$	

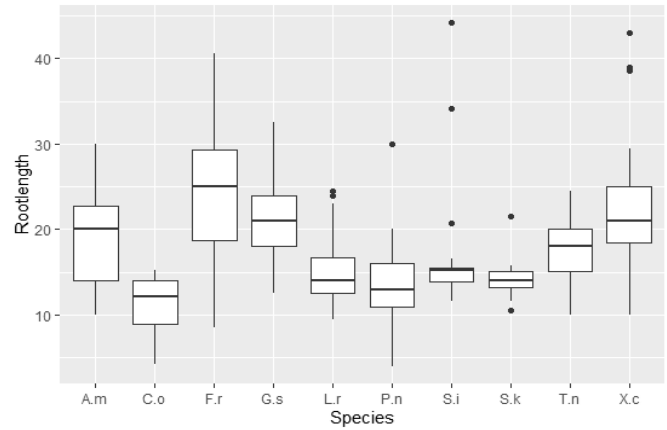
Species	Treatments	RCD mean ± SE (%RGR/year)	Tukey HSD
C.operculatus	Control	$172.00^{B} \pm 6.43$	**a**
	Air-root pruning	$193.67^{B} \pm 17.33$	
	Crate	$230.33^{A} \pm 39.33$	
S.koetjape	Control	$103.00^{A} \pm 7.54$	**cd**
	Air-root pruning	$102.33^{A} \pm 3.38$	
	Crate	$109.00^{A} \pm 4.73$	
S.indica	Control	$127.00^{A} \pm 8.08$	**e**
	Air-root pruning	$133.67^{A} \pm 13.38$	
	Crate	$147.33^{A} \pm 5.78$	
G.speciosa	Control	$93.00^{B} \pm 16.44$	**b**
	Air-root pruning	$95.67^{B} \pm 15.24$	
	Crate	$103.00^{A} \pm 2.52$	
L.rubiginosa	Control	$108.67^{B} \pm 10.48$	**b**
	Air-root pruning	$122.33^{A} \pm 14.11$	
	Crate	$110.00^{B} \pm 0.58$	

Apendix 4 Mean of root dry weight and shoot root ratio of ten species with three treatments.

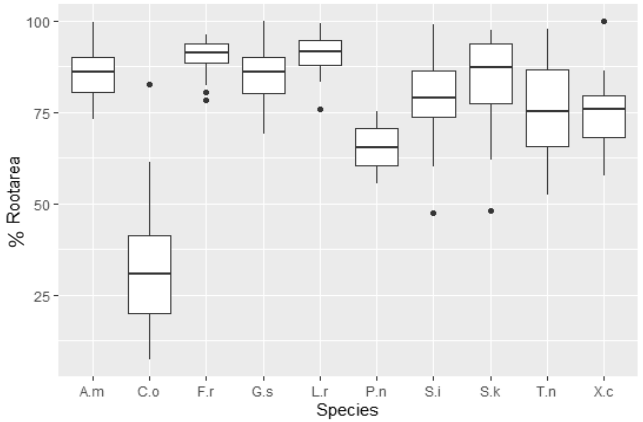
^{A} shows the significant difference among treatments, **a** shows the significant difference among species

Species	**Treatments**	**Root dry weight (g.)** Mean ± SE	Tukey HSD	**Shoot/Root (g.)** Mean ± SE	Tukey HSD
X.cambodiana	Control	$1.11^{A} \pm 0.43$	**b**	$17.20^{A} \pm 5.73$	**a**
	Air-root pruning	$1.43^{A} \pm 0.30$		$7.54^{AB} \pm 2.53$	
	Crate	$1.94^{A} \pm 0.29$		$9.29^{B} \pm 3.10$	
P.neriifolius	Control	$0.71^{A} \pm 0.04$	**b**	$15.78^{A} \pm 5.26$	**a**
	Air-root pruning	$0.96^{A} \pm 0.15$		$7.01^{AB} \pm 2.34$	
	Crate	$1.04^{A} \pm 0.22$		$4.64^{B} \pm 1.55$	
A.microsperma	Control	$0.87^{A} \pm 0.11$	**b**	$16.44^{A} \pm 5.48$	**a**
	Air-root pruning	$0.94^{A} \pm 0.10$		$14.79^{AB} \pm 4.93$	
	Crate	$1.35^{A} \pm 0.14$		$5.40^{B} \pm 1.80$	
F.racemosa	Control	$0.53^{A} \pm 0.13$	**b**	$14.53^{A} \pm 4.84$	**a**
	Air-root pruning	$0.42^{A} \pm 0.20$		$7.26^{AB} \pm 2.42$	
	Crate	$0.63^{A} \pm 0.28$		$4.73^{B} \pm 1.58$	
T.nigrovenulosa	Control	$0.83^{A} \pm 0.05$	**b**	$12.70^{A} \pm 4.23$	**a**
	Air-root pruning	$1.00^{AB} \pm 0.07$		$8.04^{AB} \pm 2.68$	
	Crate	$1.11^{B} \pm 0.05$		$4.33^{B} \pm 1.44$	

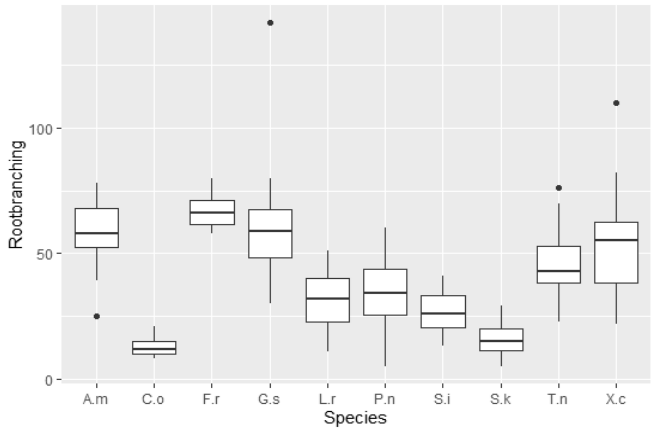
Species	Treatments	Root dry weight (g.)	Tukey HSD	Shoot/Root (g.)	Tukey HSD
		Mean ± SE		Mean ± SE	
C.operculatus	Control	$1.24^{B} \pm 0.13$	**b**	$15.39^{A} \pm 5.13$	**a**
	Air-root pruning	$1.99^{AB} \pm 0.35$		$7.92^{AB} \pm 2.64$	
	Crate	$2.26^{A} \pm 1.06$		$5.23^{B} \pm 1.74$	
S.koetjape	Control	$2.89^{A} \pm 0.34$	**a**	$15.61^{A} \pm 5.20$	**a**
	Air-root pruning	$2.82^{A} \pm 0.37$		$8.97^{AB} \pm 2.99$	
	Crate	$3.71^{A} \pm 0.51$		$5.26^{B} \pm 1.75$	
S.indica	Control	$3.64^{A} \pm 0.63$	**a**	$15.16^{A} \pm 5.05$	**a**
	Air-root pruning	$4.10^{A} \pm 0.40$		$7.55^{AB} \pm 2.52$	
	Crate	$4.35^{A} \pm 0.61$		$4.98^{B} \pm 1.66$	
G.speciosa	Control	$1.31^{A} \pm 0.19$	**b**	$16.66^{A} \pm 5.55$	**a**
	Air-root pruning	$1.59^{A} \pm 0.34$		$7.87^{AB} \pm 2.62$	
	Crate	$1.81^{A} \pm 0.22$		$9.59^{B} \pm 3.20$	
L.rubiginosa	Control	$1.12^{A} \pm 0.16$	**b**	$9.77^{A} \pm 3.26$	**a**
	Air-root pruning	$1.67^{A} \pm 0.20$		$6.91^{AB} \pm 2.30$	
	Crate	$1.63^{A} \pm 0.26$		$4.40^{B} \pm 1.47$	



a.)

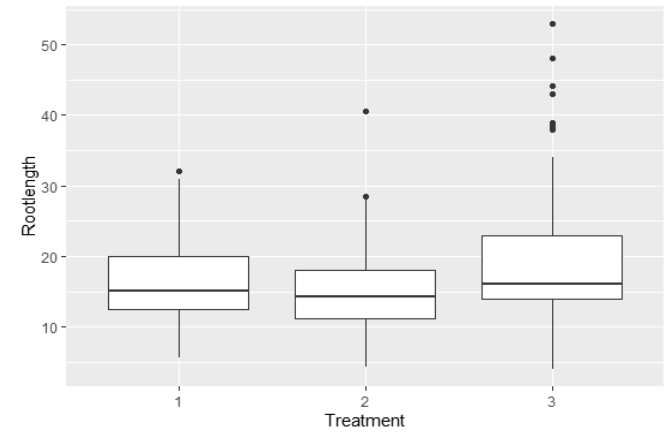


b.)

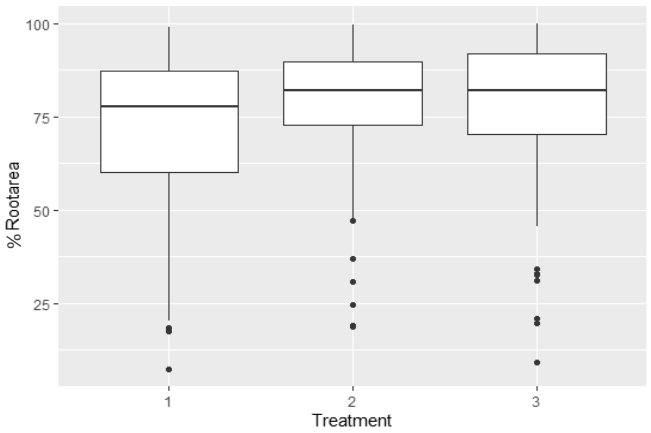


c.)

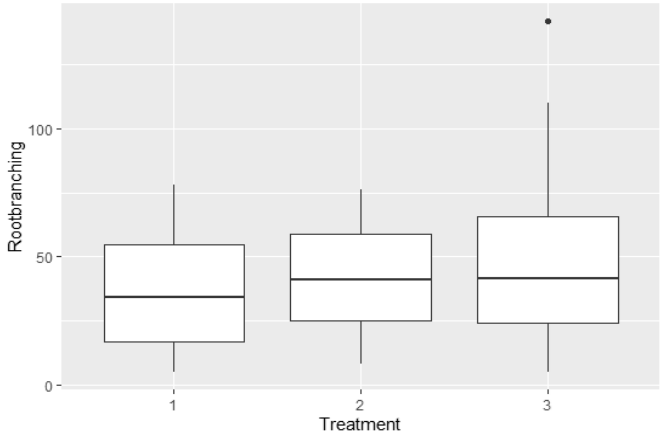
Appendix 5 a.) Box plot root length of ten seedlings selected framework species. b.) Box plot seedling percent of root area of ten selected framework species. c.) Box plot root branching of ten seedlings selected framework species. Boxplot representations of the median (thick black line), upper and lower quartiles (box).



d.)



e.)



f.)

Appendix 6 d.) Box plot root length of seedlings selected framework species, e.) Box plot percent of root area of seedlings selected framework species, f.) Box plot root branching of seedlings selected framework species treated with three different production practices. (1=Control treatment, 2=Air-root pruning treatment, 3=Crate treatment). Boxplot representations of the median (thick black line), upper and lower quartiles (box).

Appendix 7 Mean of root architecture of ten species with three treatments.

[A] shows the significant difference among treatments, **a** shows the significant difference among species

Species	Treatments	Root length (cm.) Mean ± SE	Tukey HSD	% Root area Mean ± SE	Tukey HSD	Root branching Mean ± SE	Tukey HSD
X.cambodiana	Control	19.44[B] ± 1.74	**ab**	70.86 [A] ± 3.27	**bc**	46.56 [A] ± 4.19	**a**
	Air-root pruning	21.11[B] ± 0.93		74.44 [A] ± 2.19		54.89 [A] ± 3.52	
	Crate	28.00[A] ± 3.38		78.70 ± 4.41		59.22 [A] ± 9.25	
P.neriifolius	Control	12.50 [A] ± 1.04	**bc**	58.59 [B] ± 0.83	**c**	26.11 [B] ± 6.48	**c**
	Air-root pruning	13.17 [A] ± 1.33		67.24 [A] ± 1.43		38.22 [A] ± 3.75	
	Crate	14.72 [A] ± 2.42		70.47 [A] ± 1.43		40.33 [A] ± 4.06	
A.microsperma	Control	17.06 [A] ± 2.33	**ab**	81.26 [B] ± 1.94	**ab**	55.22 [A] ± 4.63	**a**
	Air-root pruning	19.17[A] ± 1.15		86.30 [AB] ± 2.72		58.22 [A] ± 2.28	
	Crate	20.39 [A] ± 1.46		89.54 [A] ± 1.76		60.22 [A] ± 1.56	
F.racemosa	Control	21.39 [A] ± 2.12	**a**	88.10 [B] ± 1.85	**a**	62.67 [B] ± 0.68	**a**
	Air-root pruning	22.39 [A] ± 3.46		90.19[AB] ± 1.72		65.56 [B] ± 0.39	
	Crate	27.56 [A] ± 2.13		92.48 [A] ± 0.66		72.00 [A] ± 1.11	
T.nigrovenulosa	Control	16.81 [A] ± 1.26	**ab**	72.51 [A] ± 4.72	**bc**	43.33 [A] ± 1.90	**ab**
	Air-root pruning	17.06 [A] ± 0.85		75.28 [A] ± 5.88		45.56 [A] ± 4.64	
	Crate	18.78 [A] ± 1.44		77.20 [A] ± 4.42		49.11 [A] ± 3.43	

Species	Treatments	Root length (cm.) Mean ± SE	Tukey HSD	% Root area Mean ± SE	Tukey HSD	Root branching Mean ± SE	Tukey HSD
C.operculatus	Control	10.69 ^{B} ± 1.08	**c**	54.33 ^{A} ± 1.35	**d**	39.11 ^{A} ± 1.52	**c**
	Air-root pruning	10.91 ^{B} ± 0.70		56.20 ^{A} ± 3.98		41.89 ^{A} ± 1.70	
	Crate	13.70 ^{A} ± 0.29		58.58 ^{A} ± 1.92		43.67 ^{A} ± 1.42	
S.koetjape	Control	15.78^{B} ± 0.22	**b**	72.17 ^{B} ± 4.30	**b**	39.44 ^{A} ± 3.33	**c**
	Air-root pruning	15.34 ^{A} ± 0.45		73.35 ^{A} ± 1.91		40.22 ^{A} ± 2.38	
	Crate	16.92 ^{A} ± 0.62		75.90 ^{A} ± 2.38		43.78 ^{A} ± 1.57	
S.indica	Control	13.77 ^{B} ± 0.45	**b**	73.56 ^{A} ± 2.73	**ab**	45.22 ^{A} ± 0.89	**c**
	Air-root pruning	15.01 ^{A} ± 0.37		80.25 ^{A} ± 2.98		52.00 ^{A} ± 1.45	
	Crate	20.76 ^{A} ± 3.65		84.19 ^{A} ± 2.73		55.56 ^{A} ± 1.76	
G.speciosa	Control	18.06 ^{A} ± 1.15	**a**	81.47 ^{A} ± 2.04	**ab**	59.78 ^{A} ± 2.27	**a**
	Air-root pruning	17.96 ^{A} ± 0.76		82.35 ^{A} ± 2.59		61.56 ^{A} ± 3.24	
	Crate	19.04 ^{A} ± 1.67		84.99 ^{A} ± 3.16		70.00 ^{A} ± 9.81	
L.rubiginosa	Control	17.06 ^{AB} ± 0.38	**ab**	82.88 ^{A} ± 1.29	**a**	35.89 ^{B} ± 1.29	**c**
	Air-root pruning	18.99 ^{B} ± 0.30		86.29 ^{A} ± 1.12		39.22 ^{A} ± 1.65	
	Crate	19.11 ^{A} ± 1.08		84.21 ^{A} ± 1.91		42.44 ^{AB} ± 1.48	

APPENDIX B

Statistic of Relative Growth Rate of Height

Treatment :	Estimate	Std. Error	z value	Pr(>|z|)
2 - 1 == 0	4.821	6.329	0.762	0.726
3 - 1 == 0	61.173	6.374	9.597	<1e-04 ***
3 - 2 == 0	56.352	6.316	8.921	<1e-04 ***

Species :	Estimate	Std. Error	z value	Pr(>|z|)
C.operculatus - A.microsperma == 0	1.18183	0.05856	20.183	<0.01 ***
F.racemosa - A.microsperma == 0	1.65362	0.05877	28.136	<0.01 ***
G.speciosa - A.microsperma == 0	-0.46952	0.05774	-8.131	<0.01 ***
L.rubiginosa - A.microsperma == 0	-0.15632	0.05845	-2.674	0.1835
X.cambodiana - A.microsperma == 0	-0.33569	0.05866	-5.722	<0.01 ***
P.neriifolius - A.microsperma == 0	0.18381	0.05814	3.162	0.0511 .
S.indica - A.microsperma == 0	0.39957	0.05784	6.908	<0.01 ***
S.koetjape - A.microsperma == 0	0.28603	0.05774	4.953	<0.01 ***
T.nigrovenulosa - A.microsperma == 0	-0.11986	0.05934	-2.020	0.5851
F.racemosa - C.operculatus == 0	0.47179	0.05856	8.057	<0.01 ***
G.speciosa - C.operculatus == 0	-1.65136	0.05752	-28.708	<0.01 ***
L.rubiginosa - C.operculatus == 0	-1.33816	0.05823	-22.979	<0.01 ***
X.cambodiana - C.operculatus == 0	-1.51752	0.05845	-25.964	<0.01 ***
P.neriifolius - C.operculatus == 0	-0.99802	0.05792	-17.231	<0.01 ***
S.indica - C.operculatus == 0	-0.78227	0.05762	-13.576	<0.01 ***
S.koetjape - C.operculatus == 0	-0.89580	0.05752	-15.573	<0.01 ***
T.nigrovenulosa - C.operculatus == 0	-1.30170	0.05913	-22.015	<0.01 ***
G.speciosa - F.racemosa == 0	-2.12315	0.05774	-36.769	<0.01 ***
L.rubiginosa - F.racemosa == 0	-1.80995	0.05845	-30.965	<0.01 ***
X.cambodiana - F.racemosa == 0	-1.98931	0.05866	-33.910	<0.01 ***
P.neriifolius - F.racemosa == 0	-1.46981	0.05814	-25.281	<0.01 ***
S.indica - F.racemosa == 0	-1.25406	0.05784	-21.681	<0.01 ***
S.koetjape - F.racemosa == 0	-1.36759	0.05774	-23.684	<0.01 ***
T.nigrovenulosa - F.racemosa == 0	-1.77349	0.05934	-29.886	<0.01 ***
L.rubiginosa - G.speciosa == 0	0.31320	0.05742	5.455	<0.01 ***
X.cambodiana - G.speciosa == 0	0.13384	0.05763	2.322	0.3747
P.neriifolius - G.speciosa == 0	0.65334	0.05710	11.442	<0.01 ***
S.indica - G.speciosa == 0	0.86909	0.05679	15.302	<0.01 ***
S.koetjape - G.speciosa == 0	0.75556	0.05670	13.327	<0.01 ***
T.nigrovenulosa - G.speciosa == 0	0.34966	0.05832	5.995	<0.01 ***
X.cambodiana - L.rubiginosa == 0	-0.17936	0.05834	-3.074	0.0647 .
P.neriifolius - L.rubiginosa == 0	0.34013	0.05781	5.883	<0.01 ***
S.indica - L.rubiginosa == 0	0.55589	0.05751	9.665	<0.01 ***
S.koetjape - L.rubiginosa == 0	0.44235	0.05742	7.704	<0.01 ***
T.nigrovenulosa - L.rubiginosa == 0	0.03646	0.05902	0.618	0.9998
P.neriifolius - X.cambodiana == 0	0.51950	0.05803	8.952	<0.01 ***

S.indica - X.cambodiana == 0	0.73525	0.05773	12.736	<0.01 ***
S.koetjape - X.cambodiana == 0	0.62172	0.05763	10.787	<0.01 ***
T.nigrovenulosa - X.cambodiana == 0	0.21582	0.05924	3.643	<0.01 **
S.indica - P.neriifolius == 0	0.21575	0.05720	3.772	<0.01 **
S.koetjape - P.neriifolius == 0	0.10222	0.05710	1.790	0.7418
T.nigrovenulosa - P.neriifolius == 0	-0.30367	0.05871	-5.172	<0.01 ***
S.koetjape - S.indica == 0	-0.11354	0.05679	-1.999	0.5991
T.nigrovenulosa - S.indica == 0	-0.51943	0.05842	-8.892	<0.01 ***
T.nigrovenulosa - S.koetjape == 0	-0.40589	0.05832	-6.960	<0.01 ***

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Statistic of Relative Growth Rate of Root Collar Diameter

Treatment :	Estimate	Std. Error	z value	Pr(>|z|)
2 - 1 == 0	40.336	5.264	7.662	<0.001 ***
3 - 1 == 0	54.593	5.302	10.297	<0.001 ***
3 - 2 == 0	14.257	5.244	2.719	0.018 *

Species :	Estimate	Std. Error	z value	Pr(>|z|)
C.operculatus - A.microsperma == 0	0.790411	0.055059	14.356	<0.001 ***
F.racemosa - A.microsperma == 0	0.788014	0.055262	14.259	<0.001 ***
G.speciosa - A.microsperma == 0	-0.001542	0.054294	-0.028	1.000
L.rubiginosa - A.microsperma == 0	0.011527	0.054959	0.210	1.000
X.cambodiana - A.microsperma == 0	-0.127967	0.055161	-2.320	0.375
P.neriifolius - A.microsperma == 0	-0.088343	0.054667	-1.616	0.841
S.indica - A.microsperma == 0	0.338329	0.054386	6.221	<0.001 ***
S.koetjape - A.microsperma == 0	0.046583	0.054294	0.858	0.998
T.nigrovenulosa - A.microsperma == 0	-0.010110	0.055797	-0.181	1.000
F.racemosa - C.operculatus == 0	0.002397	0.055060	-0.044	1.000
G.speciosa - C.operculatus == 0	-0.791953	0.054088	-14.642	<0.001 ***
L.rubiginosa - C.operculatus == 0	-0.778884	0.054756	-14.225	<0.001 ***
X.cambodiana - C.operculatus == 0	-0.918377	0.054956	-16.711	<0.001 ***
P.neriifolius - C.operculatus == 0	-0.878753	0.054462	-16.135	<0.001 ***
S.indica - C.operculatus == 0	-0.452082	0.054179	-8.344	<0.001 ***
S.koetjape - C.operculatus == 0	-0.743828	0.054088	-13.752	<0.001 ***
T.nigrovenulosa - C.operculatus == 0	-0.800521	0.055595	-14.399	<0.001 ***
G.speciosa - F.racemosa == 0	-0.789556	0.054295	-14.542	<0.001 ***
L.rubiginosa - F.racemosa == 0	-0.776487	0.054959	-14.128	<0.001 ***
X.cambodiana - F.racemosa == 0	-0.915981	0.055161	-16.606	<0.001 ***
P.neriifolius - F.racemosa == 0	-0.876357	0.054667	-16.031	<0.001 ***
S.indica - F.racemosa == 0	-0.449685	0.054386	-8.268	<0.001 ***
S.koetjape - F.racemosa == 0	-0.741431	0.054295	-13.656	<0.001 ***
T.nigrovenulosa - F.racemosa == 0	-0.798124	0.055798	-14.304	<0.001 ***
L.rubiginosa - G.speciosa == 0	0.013069	0.053986	0.242	1.000
X.cambodiana - G.speciosa == 0	-0.126425	0.054191	-2.333	0.368

P.neriifolius - G.speciosa == 0	-0.086801	0.053689	-1.617	0.840
S.indica - G.speciosa == 0	0.339870	0.053402	6.364	<0.001 ***
S.koetjape - G.speciosa == 0	0.048125	0.053309	0.903	0.996
T.nigrovenulosa - G.speciosa == 0	-0.008568	0.054838	-0.156	1.000
X.cambodiana - L.rubiginosa == 0	-0.139494	0.054858	-2.543	0.246
P.neriifolius - L.rubiginosa == 0	-0.099870	0.054360	-1.837	0.711
S.indica - L.rubiginosa == 0	0.326802	0.054079	6.043	<0.001 ***
S.koetjape - L.rubiginosa == 0	0.035056	0.053986	0.649	1.000
T.nigrovenulosa - L.rubiginosa == 0	-0.021637	0.055497	-0.390	1.000
P.neriifolius - X.cambodiana == 0	0.039624	0.054565	0.726	0.999
S.indica - X.cambodiana == 0	0.466295	0.054283	8.590	<0.001 ***
S.koetjape - X.cambodiana == 0	0.174550	0.054191	3.221	0.042 *
T.nigrovenulosa - X.cambodiana == 0	0.117857	0.055697	2.116	0.516
S.indica - P.neriifolius == 0	0.426671	0.053781	7.933	<0.001 ***
S.koetjape - P.neriifolius == 0	0.134926	0.053689	2.513	0.262
T.nigrovenulosa - P.neriifolius == 0	0.078233	0.055207	1.417	0.922
S.koetjape - S.indica == 0	-0.291745	0.053402	-5.463	<0.001 ***
T.nigrovenulosa - S.indica == 0	-0.348438	0.054928	-6.344	<0.001 ***
T.nigrovenulosa - S.koetjape == 0	-0.056693	0.054838	-1.034	0.990

Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Statistic of Root dry weight

Species : Estimate	Std. Error	z value	Pr(>|z|)
C.operculatus - A.microsperma == 0	3.744e-01	3.903e-01	0.959	0.994
F.racemosa - A.microsperma == 0	-1.878e-01	3.903e-01	-0.481	1.000
G.speciosa - A.microsperma == 0	2.867e-01	3.903e-01	0.734	0.999
L.rubiginosa - A.microsperma == 0	-1.500e-01	3.903e-01	-0.384	1.000
X.cambodiana - A.microsperma == 0	-4.444e-02	3.903e-01	-0.114	1.000
P.neriifolius - A.microsperma == 0	-1.656e-01	3.903e-01	-0.424	1.000
S.indica - A.microsperma == 0	2.771e+00	3.903e-01	7.100	<0.001 ***
S.koetjape - A.microsperma == 0	2.350e+00	3.903e-01	6.021	<0.001 ***
T.nigrovenulosa - A.microsperma == 0	-4.444e-02	3.903e-01	-0.114	1.000
F.racemosa - C.operculatus == 0	-5.622e-01	3.903e-01	-1.440	0.915
G.speciosa - C.operculatus == 0	-8.778e-02	3.903e-01	-0.225	1.000
L.rubiginosa - C.operculatus == 0	-5.244e-01	3.903e-01	-1.344	0.943
X.cambodiana - C.operculatus == 0	-4.189e-01	3.903e-01	-1.073	0.987
P.neriifolius - C.operculatus == 0	-5.400e-01	3.903e-01	-1.384	0.933
S.indica - C.operculatus == 0	2.397e+00	3.903e-01	6.141	<0.001 ***
S.koetjape - C.operculatus == 0	1.976e+00	3.903e-01	5.062	<0.001 ***
T.nigrovenulosa - C.operculatus == 0	-4.189e-01	3.903e-01	-1.073	0.987
G.speciosa - F.racemosa == 0	4.744e-01	3.903e-01	1.216	0.970
L.rubiginosa - F.racemosa == 0	3.778e-02	3.903e-01	0.097	1.000

X.cambodiana - F.racemosa == 0	1.433e-01	3.903e-01	0.367	1.000
P.neriifolius - F.racemosa == 0	2.222e-02	3.903e-01	0.057	1.000
S.indica - F.racemosa == 0	2.959e+00	3.903e-01	7.581	<0.001 ***
S.koetjape - F.racemosa == 0	2.538e+00	3.903e-01	6.502	<0.001 ***
T.nigrovenulosa - F.racemosa == 0	1.433e-01	3.903e-01	0.367	1.000
L.rubiginosa - G.speciosa == 0	-4.367e-01	3.903e-01	-1.119	0.983
X.cambodiana - G.speciosa == 0	-3.311e-01	3.903e-01	-0.848	0.998
P.neriifolius - G.speciosa == 0	-4.522e-01	3.903e-01	-1.159	0.978
S.indica - G.speciosa == 0	2.484e+00	3.903e-01	6.365	<0.001 ***
S.koetjape - G.speciosa == 0	2.063e+00	3.903e-01	5.287	<0.001 ***
T.nigrovenulosa - G.speciosa == 0	-3.311e-01	3.903e-01	-0.848	0.998
X.cambodiana - L.rubiginosa == 0	1.056e-01	3.903e-01	0.270	1.000
P.neriifolius - L.rubiginosa == 0	-1.556e-02	3.903e-01	-0.040	1.000
S.indica - L.rubiginosa == 0	2.921e+00	3.903e-01	7.484	<0.001 ***
S.koetjape - L.rubiginosa == 0	2.500e+00	3.903e-01	6.405	<0.001 ***
T.nigrovenulosa - L.rubiginosa == 0	1.056e-01	3.903e-01	0.270	1.000
P.neriifolius - X.cambodiana == 0	-1.211e-01	3.903e-01	-0.310	1.000
S.indica - X.cambodiana == 0	2.816e+00	3.903e-01	7.214	<0.001 ***
S.koetjape - X.cambodiana == 0	2.394e+00	3.903e-01	6.135	<0.001 ***
T.nigrovenulosa - X.cambodiana == 0	3.816e-16	3.903e-01	0.000	1.000
S.indica - P.neriifolius == 0	2.937e+00	3.903e-01	7.524	<0.001 ***
S.koetjape - P.neriifolius == 0	2.516e+00	3.903e-01	6.445	<0.001 ***
T.nigrovenulosa - P.neriifolius == 0	1.211e-01	3.903e-01	0.310	1.000
S.koetjape - S.indica == 0	-4.211e-01	3.903e-01	-1.079	0.987
T.nigrovenulosa - S.indica == 0	-2.816e+00	3.903e-01	-7.214	<0.001 ***
T.nigrovenulosa - S.koetjape == 0	-2.394e+00	3.903e-01	-6.135	<0.001 ***

Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Statistic of Shoot root ratio

Treatment :	Estimate	Std. Error	z value	Pr(>|z|)
2 - 1 == 0	-4.778	5.013	-0.953	0.6066
3 - 1 == 0	-12.294	5.013	-2.453	0.0377 *
3 - 2 == 0	-7.517	5.013	-1.500	0.2911

Species : insignificant

Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Statistic of percent of Mortality

Species :	Estimate	Std. Error	z value	Pr(>|z|)	
C.operculatus - A.microsperma == 0	-3.0000	1.5173	-1.977	0.4952	
F.racemosa - A.microsperma == 0	-0.6667	1.3571	-0.491	0.9997	
L.rubiginosa - A.microsperma == 0	1.0000	1.3571	0.737	0.9958	
P.neriifolius - A.microsperma == 0	-2.0000	1.5173	-1.318	0.8913	
S.indica - A.microsperma == 0	-0.3333	1.3571	-0.246	1.0000	
T.nigrovenulosa - A.microsperma == 0	1.3333	1.3571	0.982	0.9767	
X.cambodiana - A.microsperma == 0	0.5000	1.5173	0.330	1.0000	
F.racemosa - C.operculatus == 0	2.3333	1.5173	1.538	0.7855	
L.rubiginosa - C.operculatus == 0	4.0000	1.5173	2.636	0.1417	
P.neriifolius - C.operculatus == 0	1.0000	1.6621	0.602	0.9989	
S.indica - C.operculatus == 0	2.6667	1.5173	1.758	0.6470	
T.nigrovenulosa - C.operculatus == 0	4.3333	1.5173	2.856	0.0808	*
X.cambodiana - C.operculatus == 0	3.5000	1.6621	2.106	0.4086	
L.rubiginosa - F.racemosa == 0	1.6667	1.3571	1.228	0.9231	
P.neriifolius - F.racemosa == 0	-1.3333	1.5173	-0.879	0.9878	
S.indica - F.racemosa == 0	0.3333	1.3571	0.246	1.0000	
T.nigrovenulosa - F.racemosa == 0	2.0000	1.3571	1.474	0.8202	
X.cambodiana - F.racemosa == 0	1.1667	1.5173	0.769	0.9946	
P.neriifolius - L.rubiginosa == 0	-3.0000	1.5173	-1.977	0.4949	
S.indica - L.rubiginosa == 0	-1.3333	1.3571	-0.982	0.9767	
T.nigrovenulosa - L.rubiginosa == 0	0.3333	1.3571	0.246	1.0000	
X.cambodiana - L.rubiginosa == 0	-0.5000	1.5173	-0.330	1.0000	
S.indica - P.neriifolius == 0	1.6667	1.5173	1.098	0.9569	
T.nigrovenulosa - P.neriifolius == 0	3.3333	1.5173	2.197	0.3520	
X.cambodiana - P.neriifolius == 0	2.5000	1.6621	1.504	0.8041	
T.nigrovenulosa - S.indica == 0	1.6667	1.3571	1.228	0.9231	
X.cambodiana - S.indica == 0	0.8333	1.5173	0.549	0.9994	
X.cambodiana - T.nigrovenulosa == 0	-0.8333	1.5173	-0.549	0.9994	

Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

Statistic of Root length

Species :	Estimate	Std. Error	z value	Pr(>|z|)
C.operculatus - A.microsperma == 0	-6.4778	2.4431	-2.651	0.2096
F.racemosa - A.microsperma == 0	4.3333	2.4431	1.774	0.7818
G.speciosa - A.microsperma == 0	5.4444	2.4431	2.228	0.4656
L.rubiginosa - A.microsperma == 0	-1.2222	2.4431	-0.500	1.0000
X.cambodiana - A.microsperma == 0	2.3889	2.4431	0.978	0.9961
P.neriifolius - A.microsperma == 0	-4.5556	2.4431	-1.865	0.7249
S.indica - A.microsperma == 0	-3.2889	2.4431	-1.346	0.9565
S.koetjape - A.microsperma == 0	-3.6778	2.4431	-1.505	0.9110
T.nigrovenulosa - A.microsperma == 0	-0.2444	2.4431	-0.100	1.0000
F.racemosa - C.operculatus == 0	10.8111	2.4431	4.425	<0.01 ***
G.speciosa - C.operculatus == 0	11.9222	2.4431	4.880	<0.01 ***
L.rubiginosa - C.operculatus == 0	5.2556	2.4431	2.151	0.5218
X.cambodiana - C.operculatus == 0	8.8667	2.4431	3.629	0.0117 *
P.neriifolius - C.operculatus == 0	1.9222	2.4431	0.787	0.9994
S.indica - C.operculatus == 0	3.1889	2.4431	1.305	0.9647
S.koetjape - C.operculatus == 0	2.8000	2.4431	1.146	0.9862
T.nigrovenulosa - C.operculatus == 0	6.2333	2.4431	2.551	0.2596
G.speciosa - F.racemosa == 0	1.1111	2.4431	0.455	1.0000
L.rubiginosa - F.racemosa == 0	-5.5556	2.4431	-2.274	0.4330
X.cambodiana - F.racemosa == 0	-1.9444	2.4431	-0.796	0.9993
P.neriifolius - F.racemosa == 0	-8.8889	2.4431	-3.638	0.0114 *
S.indica - F.racemosa == 0	-7.6222	2.4431	-3.120	0.0628 .
S.koetjape - F.racemosa == 0	-8.0111	2.4431	-3.279	0.0383 *
T.nigrovenulosa - F.racemosa == 0	-4.5778	2.4431	-1.874	0.7188
L.rubiginosa - G.speciosa == 0	-6.6667	2.4431	-2.729	0.1754
X.cambodiana - G.speciosa == 0	-3.0556	2.4431	-1.251	0.9739
P.neriifolius - G.speciosa == 0	-10.0000	2.4431	-4.093	<0.01 **
S.indica - G.speciosa == 0	-8.7333	2.4431	-3.575	0.0138 *
S.koetjape - G.speciosa == 0	-9.1222	2.4431	-3.734	<0.01 **
T.nigrovenulosa - G.speciosa == 0	-5.6889	2.4431	-2.329	0.3957
X.cambodiana - L.rubiginosa == 0	3.6111	2.4431	1.478	0.9206
P.neriifolius - L.rubiginosa == 0	-3.3333	2.4431	-1.364	0.9525
S.indica - L.rubiginosa == 0	-2.0667	2.4431	-0.846	0.9988
S.koetjape - L.rubiginosa == 0	-2.4556	2.4431	-1.005	0.9951
T.nigrovenulosa - L.rubiginosa == 0	0.9778	2.4431	0.400	1.0000
P.neriifolius - *X.cambodiana* == 0	-6.9444	2.4431	-2.842	0.1323
S.indica - *X.cambodiana* == 0	-5.6778	2.4431	-2.324	0.3992
S.koetjape - *X.cambodiana* == 0	-6.0667	2.4431	-2.483	0.2978
T.nigrovenulosa - *X.cambodiana* == 0	-2.6333	2.4431	-1.078	0.9914
S.indica - P.neriifolius == 0	1.2667	2.4431	0.518	1.0000
S.koetjape - P.neriifolius == 0	0.8778	2.4431	0.359	1.0000
T.nigrovenulosa - P.neriifolius == 0	4.3111	2.4431	1.765	0.7875

S.koetjape - S.indica == 0	-0.3889	2.4431	-0.159	1.0000
T.nigrovenulosa - S.indica == 0	3.0444	2.4431	1.246	0.9746
T.nigrovenulosa - S.koetjape == 0	3.4333	2.4431	1.405	0.9422

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Statistic of Number of root branching

Species :	Estimate	Std. Error	z value	Pr(>|z|)
C.operculatus - A.microsperma == 0	-42.1111	5.6943	-7.395	< 0.001***
F.racemosa - A.microsperma == 0	7.4444	5.6943	1.307	0.95226
G.speciosa - A.microsperma == 0	-5.0000	5.6943	-0.878	0.99711
L.rubiginosa - A.microsperma == 0	-30.6667	5.6943	-5.385	< 0.001***
X.cambodiana - A.microsperma == 0	-8.6667	5.6943	-1.522	0.88386
P.neriifolius - A.microsperma == 0	-29.1111	5.6943	-5.112	< 0.001***
S.indica - A.microsperma == 0	-31.1111	5.6943	-5.464	< 0.001***
S.koetjape - A.microsperma == 0	-39.7778	5.6943	-6.986	< 0.001***
T.nigrovenulosa - A.microsperma == 0	-11.8889	5.6943	-2.088	0.53600
F.racemosa - C.operculatus == 0	49.5556	5.6943	8.703	< 0.001***
G.speciosa - C.operculatus == 0	37.1111	5.6943	6.517	< 0.001***
L.rubiginosa - C.operculatus == 0	11.4444	5.6943	2.010	0.59229
X.cambodiana - C.operculatus == 0	33.4444	5.6943	5.873	< 0.001***
P.neriifolius - C.operculatus == 0	13.0000	5.6943	2.283	0.40043
S.indica - C.operculatus == 0	11.0000	5.6943	1.932	0.64736
S.koetjape - C.operculatus == 0	2.3333	5.6943	0.410	0.99999
T.nigrovenulosa - C.operculatus == 0	30.2222	5.6943	5.307	< 0.001***
G.speciosa - F.racemosa == 0	-12.4444	5.6943	-2.185	0.46680
L.rubiginosa - F.racemosa == 0	-38.1111	5.6943	-6.693	< 0.001***
X.cambodiana - F.racemosa == 0	-16.1111	5.6943	-2.829	0.12649
P.neriifolius - F.racemosa == 0	-36.5556	5.6943	-6.420	< 0.001***
S.indica - F.racemosa == 0	-38.5556	5.6943	-6.771	< 0.001***
S.koetjape - F.racemosa == 0	-47.2222	5.6943	-8.293	< 0.001***
T.nigrovenulosa - F.racemosa == 0	-19.3333	5.6943	-3.395	0.02364*
L.rubiginosa - G.speciosa == 0	-25.6667	5.6943	-4.507	< 0.001***
X.cambodiana - G.speciosa == 0	3.6667	5.6943	-0.644	0.99976
P.neriifolius - G.speciosa == 0	-24.1111	5.6943	-4.234	0.00107**
S.indica - G.speciosa == 0	-26.1111	5.6943	-4.585	< 0.001***
S.koetjape - G.speciosa == 0	-34.7778	5.6943	-6.107	< 0.001***
T.nigrovenulosa - G.speciosa == 0	-6.8889	5.6943	-1.210	0.97104
X.cambodiana - L.rubiginosa == 0	22.0000	5.6943	3.863	0.00441 **
P.neriifolius - L.rubiginosa == 0	1.5556	5.6943	0.273	1.00000
S.indica - L.rubiginosa == 0	-0.4444	5.6943	-0.078	1.00000
S.koetjape - L.rubiginosa == 0	-9.1111	5.6943	-1.600	0.84854
T.nigrovenulosa - L.rubiginosa == 0	18.7778	5.6943	3.298	0.03250 *
P.neriifolius - *X.cambodiana* == 0	-20.4444	5.6943	-3.590	0.01229 *

S.indica - *X.cambodiana* == 0	-22.4444	5.6943	-3.942	0.00320 **
S.koetjape - *X.cambodiana* == 0	-31.1111	5.6943	-5.464	< 0.001***
T.nigrovenulosa - *X.cambodiana* == 0	-3.2222	5.6943	-0.566	0.99992
S.indica - P.neriifolius == 0	-2.0000	5.6943	-0.351	1.00000
S.koetjape - P.neriifolius == 0	-10.6667	5.6943	-1.873	0.68711
T.nigrovenulosa - P.neriifolius == 0	17.2222	5.6943	3.024	0.07494 .
S.koetjape - S.indica == 0	-8.6667	5.6943	-1.522	0.88385
T.nigrovenulosa - S.indica == 0	19.2222	5.6943	3.376	0.02563 *
T.nigrovenulosa - S.koetjape == 0	27.8889	5.6943	4.898	< 0.001***

Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1

Statistic of percent of root grew out

Treatment :	Estimate	Std. Error	z value	Pr(>|z|)
2 - 1 == 0	-14.000	1.729	-8.096	<0.001 ***
3 - 1 == 0	-6.300	2.457	-2.564	0.0259 *
3 - 2 == 0	7.700	3.004	2.563	0.0255 *

Species :	Estimate	Std. Error	z value	Pr(>|z|)
C.operculatus - A.microsperma == 0	3.0000	1.7293	1.735	0.7751
F.racemosa - A.microsperma == 0	2.0000	1.7293	1.157	0.9786
G.speciosa - A.microsperma == 0	7.0000	1.7293	4.048	<0.01 **
L.rubiginosa - A.microsperma == 0	4.3333	1.7293	2.506	0.2648
P.neriifolius - A.microsperma == 0	2.6667	1.7293	1.542	0.8753
S.indica - A.microsperma == 0	5.0000	1.7293	2.891	0.1076
S.koetjape - A.microsperma == 0	3.6667	1.7293	2.120	0.5133
T.nigrovenulosa - A.microsperma == 0	0.6667	1.7293	0.386	1.0000
X.cambodiana - A.microsperma == 0	8.6667	1.7293	5.012	<0.01 ***
F.racemosa - C.operculatus == 0	-1.0000	1.7293	-0.578	0.9999
G.speciosa - C.operculatus == 0	4.0000	1.7293	2.313	0.3811
L.rubiginosa - C.operculatus == 0	1.3333	1.7293	0.771	0.9990
P.neriifolius - C.operculatus == 0	-0.3333	1.7293	-0.193	1.0000
S.indica - C.operculatus == 0	2.0000	1.7293	1.157	0.9786
S.koetjape - C.operculatus == 0	0.6667	1.7293	0.386	1.0000
T.nigrovenulosa - C.operculatus == 0	-2.3333	1.7293	-1.349	0.9419
X.cambodiana - C.operculatus == 0	5.6667	1.7293	3.277	0.0347 *
G.speciosa - F.racemosa == 0	5.0000	1.7293	2.891	0.1086
L.rubiginosa - F.racemosa == 0	2.3333	1.7293	1.349	0.9419
P.neriifolius - F.racemosa == 0	0.6667	1.7293	0.386	1.0000
S.indica - F.racemosa == 0	3.0000	1.7293	1.735	0.7758
S.koetjape - F.racemosa == 0	1.6667	1.7293	0.964	0.9942
T.nigrovenulosa - F.racemosa == 0	-1.3333	1.7293	-0.771	0.9990
X.cambodiana - F.racemosa == 0	6.6667	1.7293	3.855	<0.01 **
L.rubiginosa - G.speciosa == 0	-2.6667	1.7293	-1.542	0.8754
P.neriifolius - G.speciosa == 0	-4.3333	1.7293	-2.506	0.2650

S.indica - G.speciosa == 0	-2.0000	1.7293	-1.157	0.9786
S.koetjape - G.speciosa == 0	-3.3333	1.7293	-1.928	0.6500
T.nigrovenulosa - G.speciosa == 0	-6.3333	1.7293	-3.662	<0.01 **
X.cambodiana - G.speciosa == 0	1.6667	1.7293	0.964	0.9942
P.neriifolius - L.rubiginosa == 0	-1.6667	1.7293	-0.964	0.9942
S.indica - L.rubiginosa == 0	0.6667	1.7293	0.386	1.0000
S.koetjape - L.rubiginosa == 0	-0.6667	1.7293	-0.386	1.0000
T.nigrovenulosa - L.rubiginosa == 0	-3.6667	1.7293	-2.120	0.5125
X.cambodiana - L.rubiginosa == 0	4.3333	1.7293	2.506	0.2649
S.indica - P.neriifolius == 0	2.3333	1.7293	1.349	0.9421
S.koetjape - P.neriifolius == 0	1.0000	1.7293	0.578	0.9999
T.nigrovenulosa - P.neriifolius == 0	-2.0000	1.7293	-1.157	0.9786
X.cambodiana - P.neriifolius == 0	6.0000	1.7293	3.470	0.0185 *
S.koetjape - S.indica == 0	-1.3333	1.7293	-0.771	0.9990
T.nigrovenulosa - S.indica == 0	-4.3333	1.7293	-2.506	0.2656
X.cambodiana - S.indica == 0	3.6667	1.7293	2.120	0.5129
T.nigrovenulosa - S.koetjape == 0	-3.0000	1.7293	-1.735	0.7756
X.cambodiana - S.koetjape == 0	5.0000	1.7293	2.891	0.1075
X.cambodiana - T.nigrovenulosa == 0	8.0000	1.7293	4.626	<0.01 ***

Signif. codes: 0 ‘***’ 0.001 ‘**’ 0.01 ‘*’ 0.05 ‘.’ 0.1 ‘ ’ 1

CURRICULUM VITAE

Author's Name	Ms. Preeyaphat Chaiklang
Date/Year of Birth	December 15, 1992
Education	2007-2012 Chak Kham Khanathon School. 20012-2015 B.Sc. in Biology, faculty of Science, Chiang Mai University. 2017-2019 Master Degree of Environmental Science, Chiang Mai University, Chiang Mai, Thailand.
Publication	Preeyaphat Chaiklang, Sutthathorn Chairuangsri, Pimonrat Tiansawat (2019). Quality and production cost of some framework tree species seedlings grown with different root pruning techniques. Proceedings of the 5th Environment Asia International Conference. II 213-225.