COMBATING ECOSYSTEM DEGRADATION AND DEFORESTATION IN TANZANIA: PROPAGATION METHODS FOR BRIDELIA CATHARTICA G. BERTOL, LONCHOCARPUS BUSSEI HARMS AND PSEUDOLACHNOSTYLIS MAPROUNEIFOLIA PAX, MIOMBO TREES, MOROGORO, TANZANIA.

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Combating ecosystem degradation and deforestation in Tanzania: Propagation methods for *Bridelia cathartica* G. Bertol*,* *Lonchocarpus bussei* Harms *and Pseudolachnostylis maprounefolia* Pax, miombo trees, Morogoro, Tanzania

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Preface

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Abstract

Harvesting of miombo woodlands for subsistence living is very extensive in Tanzania. Regeneration of many tree species on degraded woodlands depends on seeds which are scarce in some tree species of these woodlands. Ecological restoration of degraded and harvested areas is the key issue for ensuring existence of most useful and low seed producing tree species in miombo woodlands. Testing propagation feasibility of miombo trees is a stage towards fulfilling the goal of reforesting and ensuring sustainable management of future forests. The aim of this study was to test propagation regeneration of moimbo tree species which have low seed production, had become rare in degraded areas, and which were most used by local people in Tanzania. *Bridelia cathartica*, *Lonchocarpus bussei* and *Pseudolachnostylis maprouneifolia* were selected for the tests in Kitulanghalo forest reserve (Sokoine University of Agriculture- training forest), Morogoro, Tanzania. A total of 550 air layering experiments were placed on 210 trees to test propagation feasibility of selected tree species in their natural ecosystem. A number of factors, such as: tree size, air-layering method, necessity of rooting hormone, rooting media, and height on which the experiments were placed on the tree were also tested. The experiments were, when possible, conducted as a pair-wise comparison between methods on the same individual tree for each repeat. Recorded observations were combined into three main categories (A, B, and C) for measuring success and failure of the experiments. These categories represented different stages of root development. Propagation of smaller trees had good results in *L. bussei* and *P. maprouneifolia* while larger trees had better results for *B. cathartica*. The study suggests that air layers using Eco-Caps can be successful if the method is improved. *Cyprus* saw dust is not useful in some species, but could be used in two tested species (*P. maprouneifolia* and *L. bussei*). Hormone appeared to be not necessary for root development for all three tested species. The level of success of heights on which the air layers were placed on the trees were variable for two tested species. *B. cathartica* had best results with experiments placed high, while *P. maprouneifolia* showed good success in both high and low branches. Generally, the results showed that it is possible to propagate the three tested tree species by air layering in their natural ecosystem for restoration of degraded areas around the reserve where the study was performed and grow them in the villages. Better results are expected if air layers were to be fitted on branches between the end of dry season and start of the rain seasons around November.

Keywords: Air layering, ecological restoration, miombo, propagation regeneration.

Sammendrag

Hogst av trær i miombo skog for lokalt brukt er veldig intensiv i Tanzania. Regenerering av mange treslag i degradert miombo avhenger av frø som er uvanlige hos noen av artene. Økologisk restaurering av degradert og hogget miombo er en nøkkelfaktor for fortsatt eksistens av de fleste nyttige trearter som produserer lite frø. Utprøving av formeringsmetoder for miombo trær er et viktig trinn på veien for å nå målet om reetablering av skog og bærekraftig forvaltning av framtidige skoger. Målet for denne studie var å teste formeringsmetoder for miombo treslag som hadde lite frøproduksjon, var uvanlige i degraderte områder og var nyttige for lokalbefolkningen. *Bridelia cathartica, Lonchocarpus bussei* og *Pseudolachnostylis maprouneifolia* ble valgt ut og ble testet i Kitulanghalo forest reserve (Sokoine University of Agriculture- training forest), Morogoro, Tanzania. Totalt 550 vegetative formerings eksperimenter ble plassert ut på 210 trær for å teste muligheten for å formere dem i deres naturlige miljø. En rekke faktorer som: Træstørrelse, formeringsmetode, betydningen av rotningshormon, media for rotning og hvor høy på treet det har mest ideelt å gjøre formeringen ble testet. Eksperimentene ble, når det var mulig, gjort som parvise sammenligninger på same treindivid for hvert gjentak. Observasjonene ble kombinert i tre kategorier (A, B og C) for måling av suksess og misslått rotning. Disse kategoriene representerer ulike stadier i rotutviklingen. Formeringen av mindre trær ga gode resultater for *L. bussei* og *P. maprouneifolia* mens større trær hadde bedre resultater for *B. cathartica*. Resultatene tyder på at Eco-Cap kan være egnet om metoden blir modifisert. *Cyprus* flis er ikke anvendbart for noen arter, men kunne brukes for to av de testede arter (*P. maprouneifolia* og *L. bussei*). Hormon var ikke nødvendig for noen av de testede artene. Hvor høyt på treet eksperimentet ble gjort ga ulike resultater for to testede arter. *B. cathartica* hadde best resultater på høyere greiner, mens *P. maprouneifolia* var ikke sensitive for høyde på treet. Generelt viste resultatene at det er mulig å formere de tre testede artene i deres naturlige miljø for restaurering av degraderte skoger rundt reservatet hvor studien ble gjort og å gro dem i landsbyer. Bedre resultater kan forventes dersom eksperimentet hadde blitt gjort mellom avslutningen av den tørre sesong og begynnelsen på regntiden omkring november måned.

Nøkkelord: vegetative formering, økologisk restaurering, miombo.

1 Introduction

Forest degradation and altering ecosystems for livelihood purposes have been occurring on a large scale in whole world for many years now. It is estimated that 70% of deforestation in sub-Saharan Africa is caused by clearing for agriculture, harvesting of timber, charcoal, fuel wood, and poles (Luoga *et al.* 2000b, Geist and Lambin 2002, Luoga *et al.* 2005). In the miombo woodlands of Tanzania, clearing of natural forests for shifting cultivation is very extensive (Luoga *et al.* 2005). Moreover, 90% of rural people depend on firewood or charcoal production, harvesting of medicinal trees, and fruits as income generating activities and for food. (Luoga *et al.* 2000b, Luoga *et al.* 2000d). While firewood is particularly used as a means of energy in villages, the cleaner charcoal is produced there and sold along the roads leading to cities for income purposes among rural people. Charcoal production in communal land surrounding Kitulanghalo forest reserve is estimated to influence more than 1671 ha per year which covers 13% of the area (Luoga *et al.* 2000b). The impact of harvest is ecosystem change and biodiversity loss through habitat loss, degradation, and fragmentation (Ramadhani *et al.* 2002). Because 70% of miombo tree species are able to regenerate vegetatively, the destruction is particularly strong if the area harvested is then burned – as is often the case if the area is also being used for grazing by pastoralists (Obiri *et al.* 2002). Possible solutions and methods to slow down deforestation, degradation, and loss of biodiversity is a challenge today, especially in developing countries including Tanzania. Increase in human population, combined with higher costs of using other sources of fuel (such as electricity and gas), causes an accelerating increase in the demand for fuel wood in rural areas and charcoal in urban areas (Luoga *et al.* 2000d). However, miombo forest degradation in Tanzania is caused by local people's multiple use of trees for subsistence living (Figure 1), not by large scale commercial clear cuttings. In addition to the need for energy, the increasing need for agricultural fields and settlements areas, as well as pressure from pastoralists, adds to the speed of deforestation in Tanzania (Luoga *et al.* 2005, Piiroinen *et al.* 2008). Adding to the problems, property rights and user rights to forest resources are neither well defined nor implemented by Tanzanian governmental institutions (Luoga *et al.* 2005).

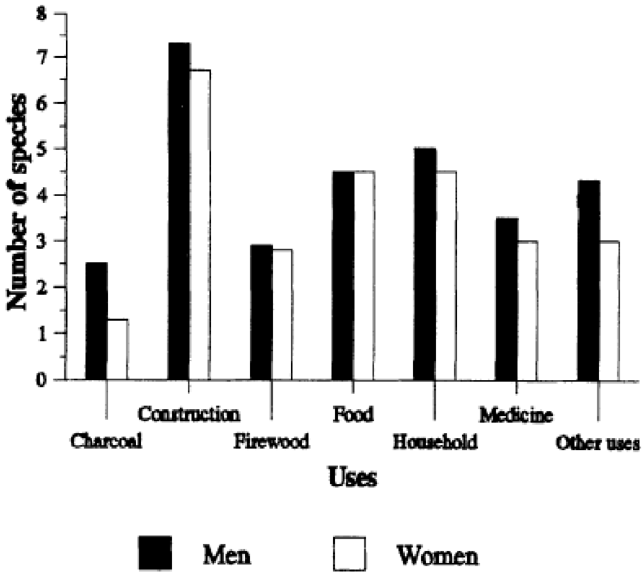

Figure 1 Uses of miombo trees by men and women of the villages surrounding Kitulanghalo forest reserve, Morogoro, Tanzania (source: Luoga *et al.* 2000b)

It is known that tree planting is one of the solutions for replenishing diminishing forest resources (MEA 2005). However, the knowledge of restoration and applied methods for regeneration of different indigenous tree species is lacking (Beck and Dunlop 2001). It should be pointed out that indigenous tree species have a good capacity to be propagated, have higher survival rate in the field, and are more pests resistant compared with many exotic species (Haggar *et al.* 1998). In addition to that, miombo trees are important for ecosystem functions and use for most human needs in local areas and in the region (Butterfield 1995, Luoga *et al.* 2000b, MEA 2005). Among the challenges with planting indigenous tree species is the specialized ecological demands of the different species. Most of miombo tree species do not perform well in either monoculture plantations or out of their natural ecosystem (Haggar *et al.* 1998). There is evidence that, management of indigenous miombo trees can be sustainable in communal land by coppicing management (Luoga *et al*. 2000b, Piiroinen *et al.* 2008). However, seedling establishment and survival is difficult both in the forest reserves and on communal land due to number of factors of which seed predation, seedling mortality, low seed production, and limited seed dispersal are among the most important ((Luoga *et al*. 2004, Kanschik & Becker 2001).

Testing regeneration methods for native tree species would give way to possibilities for local planting and biodiversity conservation through restoration of degraded areas. However, the challenge is high costs involved in seed propagation of low seed producing miombo trees. It is predicted that, low seed producing miombo tree species will become extinct in high pressure areas in a few years to come due to increasing demand on woodlands (Brooks *et al.* 2002). This demand calls for alternative regeneration methods of miombo trees rather than depending on soil seed bank.

Previous studies have shown that regeneration methods used for many tree species was based on seeds and thus through sexual propagation (Beck and Dunlop 2001, Kanschik & Becker 2001). Many of studied tree species were used for large scale commercial purposes (Beck and Dunlop 2001). However, there is a limitation of species diversity in terms of soil seed bank (Butler and Chazdon 1998) for indigenous tree species and very little is known for Tanzanian forests and woodlands (Luoga *et al*. 2004).

The aim of this study was to provide practical information on propagation regeneration of miombo trees which do not regenerate easily from seeds and in addition are among the most used tree species by local people in Tanzania. The site chosen was Kitulanghalo forest reserve in Morogoro region, in Tanzania. Kitulanghalo forest reserve is known to have 133 tree species from 30 different families (Luoga *et al.* 2000b). Regeneration of this forest is mainly natural with high human disturbance. The area outside the reserve is highly degraded which calls for fast and efficient ecological restoration. The main goals for this study are to contribute to:

1. Reducing degradation impact on the natural miombo ecosystem by providing easy regeneration techniques for restoration of degraded areas around the study area.
2. Developing easy and cheap methods of propagating selected tree species that may be used by local people as a means to increase livelihoods.

2 Material and Methods

2.1 Study area

Data were collected between July 2009 and January 2010 in the SUA-Kitulanghalo forest reserve (600ha) which is part of Kitulanghalo forest reserve (2452ha). The reserve was leased to Sokoine University of Agriculture (SUA) from the Ministry of natural resources and tourism for conservation and research purposes in 1993 (Temu *et al.* 2008). It is located about 50km east of Morogoro town towards Dar es salaam. It is situated between 6^0 39^1 28.54^{11} – 6^0 41^1 35.95^{11} S and 37^0 36^1 52.11^{11}- 38^0 00^1 29.66^{11} E in Morogoro region, Tanzania (Figure 2). The altitude ranges from 300m to 350m above sea level. The reserve is characterised by miombo forest trees with *Brachystegia* spp, *Julbernardia globiflora, J. paniculata, Isoberlinia angolensis, Pterocarpus angolensis* and *Afzelia quanzensis* (Luoga *et al*. 2000b) among the most common species. The precipitation of this area is 900mm annually, with wet seasons between November and May, leaving the dry season between June and October (Luoga *et al*. 2004). November and December has slight rainfall - called "small rains", while March to May has more rain - called "Big rains". Mean annual temperature is 25.5^0C with the minimum of 18.6^0C and maximum of 32.4^0C. The maximum temperatures were observed inside the reserve in October 2009 (Personal observation). Miombo woodlands are characterized by nutrient–poor soils (Campbell *et al*. 1996, Kanschik & Becker 2001). Geologically, the area is "Precambrian Usagaran metasedimentory rocks consisting of garnet biotite gneiss" (Luoga *et al*. 2004). The soils are well drained, red, sandy clay loams with brown top soil covered with patches of decomposing litter (Msanya *et al*. 1995, Luoga *et al*. 2004).

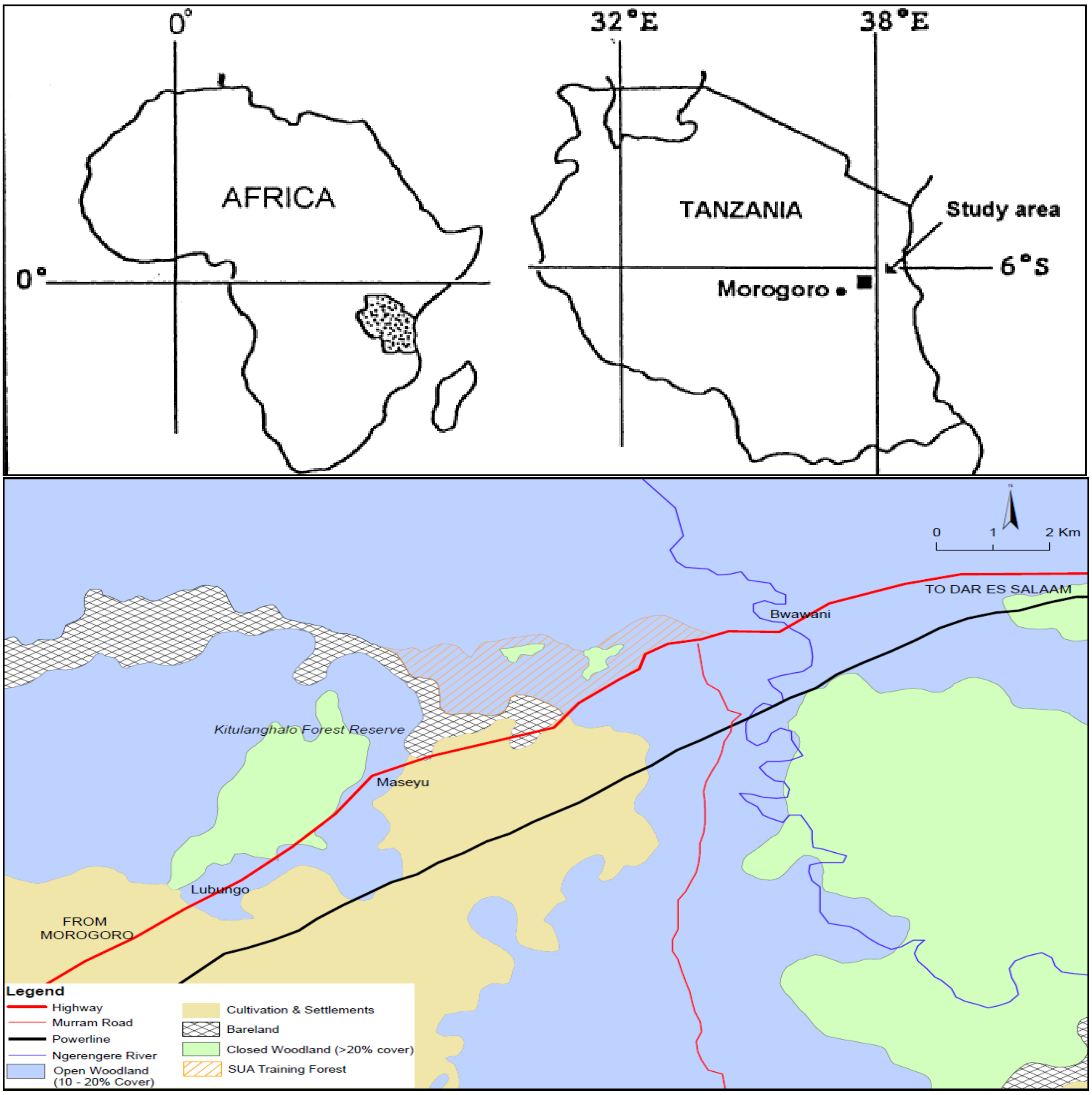

Figure 2. The location of SUA-Kitulanghalo forest reserve (Sokoine University of Agriculture -Training forest) in Morogoro, Tanzania.

2.2 Species selection

Three different miombo tree species were selected based on their importance to the livelihoods around the forest reserve, regeneration capacity from seeds, and availability of enough individual trees for propagation experiments. Information about these factors was gathered by consulting Tanzania Tree Seeds Agency (TTSA) and local people in the villages around the study area. A total of seven tree species were suggested. *Bridelia cathartica* and *Lonchocarpus bussei* had perishable seeds, while *Pterocarpus angolensis* and *Dalbergia melanoxylon* had difficult seed extraction, and *Combretum molle*, *Zahna africana*, *Pseudolachnostylis maprouneifolia* were among the used and valuable tree species around the reserve (Table 1). *Bridelia cathartica*, *Pseudolachnostylis maprouneifolia* and *Lonchocarpus* *bussei* were selected for propagation experiments. Selection was completed in the field by preliminary survey, where, the tested tree species were found to have enough individuals for tests replicates. Other mentioned species were rarely seen in the forest reserve.

Table 1. Suggested tree species for propagation in Kitulanghalo forest reserve 2009, Morogoro, Tanzania. (Uses: Ca = carvings, Cha = Charcoal, Fi = Firewood, Me = Medicinal and Ri = rituals)

Species	**Local Name (s)**	**Family**	**Main Use (s)**	**Propagation reasons**
Bridelia Cathartica	Msinzila	Euphobiaceae	Me	Perishable seeds
Combretum molle	Mlama-mweusi	Combretaceae	Ch, Fi	Highly harvested
Lonchocarpus bussei	Mfumbili	Fabaceae	Ch, Fi	Perishable seeds
Pterocarpus angolensis	Mninga	Papilionoideae	Ti	Difficult seed extraction
Pseudolachnostylis maprouneifolia	Msolo	Euphobiaceae	Ch, Fi, Ri	Highly used
Dalbergia melanoxylon	Mpingo	Papilionoideae	Me, Ca	Difficult seed extraction
Zahna Africana	Mdaula	Sapindaceae	Me	Highly harvested

2.2.1 Preliminary survey

The preliminary survey took place in mid August to identify suggested tree species in the study area. It was aiming at selecting three tree species for propagation from the possible seven (Table 1). Most of these tree species were rarely found in the reserve. For example, *Z. africana* was only occurring in very few individuals while *D. melanoxylon* and *P. angolensis* had few individuals. The remaining four species had enough individuals for experiments. *B. cathartica*, *P. maprouneifolia* and *L. bussei* were randomly selected out of the remaining four species.

2.2.1.1 *Bridelia cathartica* G. Bertol

B. cathartica is a hardwood miombo tree which is mainly used for medicine around the study area (Luoga *et al*. 2000d). The tree was growing to a maximum of 6m height with 10cm maximum diameter at breast height (DBH) in the study area. The species was abundantly found in the forest reserve despite of it having problems with seed germination. This was because it produced pungent smell when burnt as firewood (Luoga *et al.* 2000d), which made it less harvested in the reserve.

2.2.1.2 *Pseudolachnostylis maprouneifolia* Pax

P. maprouneifolia is a big tree found in Miombo woodlands. It is only found on the African continent and is mainly used for charcoal making, firewood and spiritual purposes in the study area. Seeds germinate when the hard coat have been through fire or in the stomach of the browsers. The tree was growing to 23m height and maximum DBH of 35cm in the study area. Despite of having charcoal and firewood values, the tree was found abundantly in the reserve probably because it was respected for spiritual purposes (Luoga *et al.* 2000d).

2.2.1.3 *Lonchocarpus bussei* Harms

L. bussei is miombo hardwood tree species found in open miombo woodlands. The tree was mainly used for charcoal and firewood around the study area. The tree has green leaves and green seed pods during the dry season. The tree was growing up to the maximum height of 8m and maximum DBH of 10cm in the study area.

2.3 Tree measurement and marking

Grouping in age classes was based on tree diameter as an indicator of age. Three diameter classes were allocated differently for each tree species (Table 2). The largest stem diameters and heights were found in *P. maprouneifolia* which made it appropriate to have three diameter classes for this species.

Table 2. Allocated diameter classes to three propagated tree species of Kitulanghalo forest reserve, Morogoro, Tanzania in August 2009 (DBH = Diameter at breast height, D1 = Diameter class 1, D2= Diameter class 2 and D3 = Diameter class 3)

Species	**DBH range (cm)**	**D1 (cm)**	**D2 (cm)**	**D3 (cm)**
Bridelia cathartica	0-10	0-5	5.1-10	_
Lonchocarpus bussei	0-10	0-5	5.1-10	_
Pseudolachnostylis maprouneifolia	0-35	0-11	11.1-21.9	22-35

Trees were given numbers to identify each individual, and a coloured tag was placed on each tree diameter class for easy field differentiation. Diameter class 1 (D1) was marked with yellow tag, Diameter class 2 (D2) was marked with red tag and Diameter class 3 (D3) was marked with blue tag. A total of 210 trees were marked in the forest reserve. All trees found were grouped in their respective diameter classes and the marking was stopped when the chosen maximum numbers of experimental trees were reached (Table 2).

2.4 Experimental setup

Pair-wise propagation experiments were set on 5th, 6th, and 7th of September 2009 to avoid high variation of days between onsets. D2 trees were assumed to reflect most of the studied properties and had an average size suitable for the main experiments. Therefore, it had five different pairs of experiments while D1 and D3 trees had one experiment each. Experiments were placed on tree branches at about 2-3m high for *B. cathartica*, 3-4m high for *L. bussei* and 4-5m high for *P. maprouneifolia*. This difference reflects the height of the lower appropriate branches for the experiment. The height measurements were taken from the ground to the first branches of each tree, except for one experiment which was placed 1 meter higher than other experiments in D2 in order to test the effects of this increase in height.

Figure 3. Eco-cap (Left) and Plastic sheet (right), air layers of miombo tree species in Kitulanghalo forest reserve, Morogoro, Tanzania.

2.4.1 Treatment combinations

A total of five different pair of experiments were set to test the Eco-Cap and plastic sheet methods, rooting hormone, rooting media, height in which the experiments was placed on the tree, and diameter classes (see description below). The combinations included, (1) Plastic sheet + coconut fibre + hormone * 2 diameter classes *3Spp (* 1diameter class*1Spp), (2) Eco-Cap +coconut fibre + hormone *3Spp, (3) Plastic sheet + coconut fibre *3Spp, (4) Plastic sheet + saw dust + hormone * 3Spp and (5) Plastic sheet + coconut fibre + hormone + 1m higher *2Spp. Experiment one was a control to all other tests. Combination two was testing if Eco-Cap material was more efficient in air layering than locally used plastic sheets (Figure 3). Combination three was used to test if hormone was necessary to stimulate roots of the tested species. Floramon $C_{4\%}$ from Novotrade was used as a rooting stimulating agent to the experiments. Experiment four was used to test if saw-dust of *Cyprus* trees was suitable as rooting media compared to coconut fibre (Figure 4). Experiment five was used to test the effect of height on the tree on which the experiments were placed. All other factors such as soil, elevation, direction from the sun and climate were assumed constant. Each pair of experiments was conducted on the same individual tree and there were a total of 30 replicates (trees) for each experiment. Totally, 550 experiments were fixed on the branches of three tree species.

Figure 4. Moist coconut fibre (dark brown) and Cyprus saw dust (light brown) used for air layering experiments of *B. cathartica, L. bussei* and *P. maprouneifolia*, at Kitulanghalo forest reserve, Tanzania.

2.4.2 Experiment monitoring

Experiments were monitored from the first day they were fixed. After seven days of monitoring, many of the experiments had lost 50- 70% of the applied water. The main reasons were two; (1) Insects, such as beetles, and the miombo genet (*Genetta angolensis*) were sucking water from the experiments. The Angolan or miombo genet, as it is named in Tanzania, is a nocturnal miombo woodland carnivore. It lives in moist moimbo woodlands and vegetations along the river banks. Water sources around the study area were dried out at the time of the experiment, which forced the miombo genet and insects to suck water from the experiments. However, all experiments with holes were covered with a new plastic sheet once they were found. Daily check up of the experiments was done to ensure that all experiments were tightly fixed on branches. A proportional amount of about 30cc and 50cc of water were added to plastic sheets and Eco-Cap respectively by using a syringe to moist the rooting media every seven days until the start of rain season. (2) The season in which the tests were set was very dry. Most of water sources were drying out around the study area. Eco-Caps showed high percentage of water loss due to many openings. They were not tightly fixed on branches due to fitting problems of the closing buttons (an industrial production problem with the batch used) and water collecting cap was not closing tightly (Figure 5).

Figure 5. Plastic sheet (left) and Eco-Cap (right) propagation methodology in miombo ecosystem around September 2009 at Sokoine University of Agriculture- Kitulanghalo forest reserve, Tanzania.

Water loss from experiments (up to 50-70% per week) contributed to failure of many experiments in the whole study. Together with that, higher temperatures in the forest reserve during the study period contributed to higher percentages of failure to many experiments.

2.5 Field data collection and analyses

Data were collected based on success and failure of pair wise experiments within and between species. Four different sets of observations were recorded from 10th to 12th of January 2010. Recorded information were dead branches, branches with dead callus, branches with living callus, and branches with roots. For each branch with roots, root length was measured and recorded. Measure of success and failure were combined to three different categories (Table 3). The main reason for categories was to take into consideration factors other than treatments, which could affect roots development. The most important factors in this case were the season of the year which air layering was done and time of harvesting experiments. Dry season was assumed to have caused death of branches which developed callus (branches with dead callus), that would otherwise have developed further, and delayed root formation for branches with living callus. Data were analysed in each category and each tree species.

Table 3. Category division for measure of success and failure of each pair of experiments within and between species.

Categories	**Failure**	**Success**
A	Dead branches	Branches with dead callus or branches with living callus or branches with roots
B	Dead branches or branches with dead callus	Branches with living callus or branches with roots
C	Dead branches or branches with dead callus or branches with living callus	Branches with roots

2.6 Statistical tests

Fisher exact tests were performed to compare diameter class and species differences (Lowry, 2010). ANOVA and Logistic regression were performed on the Minitab 14 to compare root length and each pair of experiment respectively. All significant results were given at $\alpha \leq 0.05$. Bar graphs were indicated with standard errors.

3 Results

Percentage results for combined species were summarized in Table 4, for general overview of the failure and success of each pair of experiments. Generally, there was a possibility of getting better propagation results for the tested three species by using air layering method (Figure 6).

Table 4. Summary of percentages of failure and success of the tests in categories; dead branches =failure and branches with dead callus or branches with living callus or branches with roots = success (A), dead branches or branches with dead callus = failure and branches with living callus or branches with roots = success (B), and dead branches or branches with dead callus or brances with living callus =failure and branches with roots= success (C).

Categories	**A**		**B**		**C**	
Test experiment	**Failure%**	**Success%**	**Failure %**	**Success%**	**Failure %**	**Success%**
Control test	57	43	69	31	91	9
Eco-cap	53	47	71	29	93	7
No hormone	69	31	82	18	97	3
Saw dust	81	19	89	11	99	1
1M Higher**	48	52	60	40	92	8
Diameter class 1	52	48	57	43	97	3
Diameter class 3*	67	33	67	33	100	0

*Test was performed on one tree species, ** Test was performed on two tree species 1

Figure 6. Propagules with roots from air layers of *Pseudolachnostylis maprouneifolia* (Msolo), *Lonchocarpus bussei* (Mfumbili) and *Bridelia cathartica* (Msinzila) miombo trees of Kitulanghalo forest reserve, propagated between September 2009 and January 2010.

3.1 Species difference

There was no significant difference of success and failure between *B. cathartica, L. bussei* and *P. maprouneifolia* (Fisher exact test, P= 0.318, P= 0.689 and P= 0.263) within categories

A, B and C respectively. However, there was a difference between species in terms of mean root length (Figure 7).

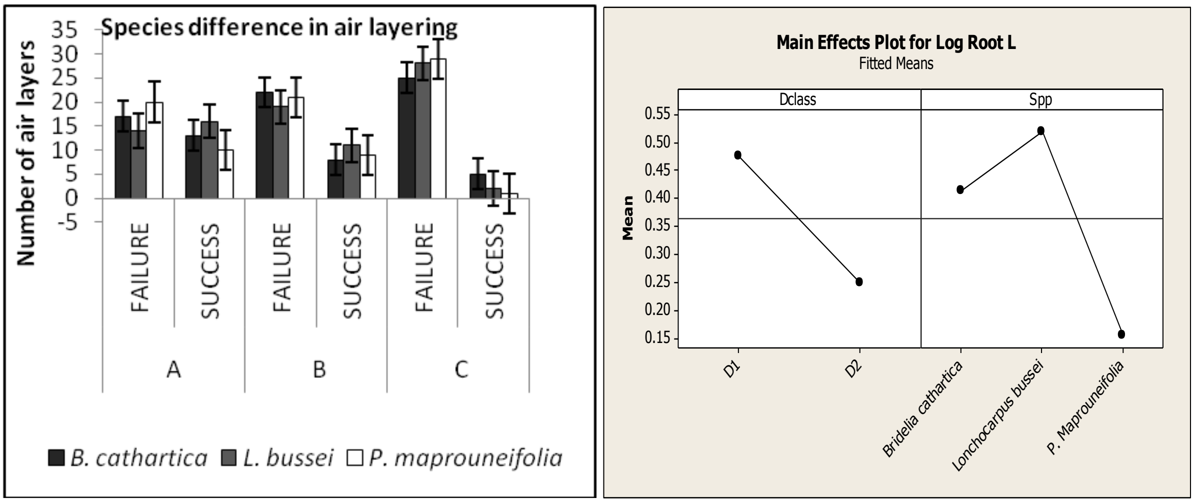

Figure 7. (Left); species failure and success within and between categories; dead branches =failure and branches with dead callus or branches with living callus or branches with roots = success (A), dead branches or branches with dead callus = failure and branches with living callus or branches with roots = success (B), and dead branches or branches with dead callus or brances with living callus =failure and branches with roots= success (C). Results are based on frequensies of failure and success within categoies of each species. (Right); mean root length between species (Spp) and between diameter classes (Dclass) (ANOVA). D1= Diameter class 1 and D2= Diameter class 2.

3.2 Diameter class

There was no significant different of diameter classes in failure or success in category A (*p* =0.37), B (*p* =0.48) and C (*p* =0.11) when all species were combined (Figure 8). However, species were significantly different in failure or success in D1 for categories A (*p*=0.001) and B (*p*= 0.001), and insignificantly different in category C (*p*=0.77), (Figure 8a, 8b and 8c). Also, species were insignificantly different in failure or success in D2 for all categories, A (*p*=0.07), B (*p*=0.14) and C (*p*=0.19), (Fisher exact test was used to all tests). Mean root length was higher in D1 than D2 (Figure 7).

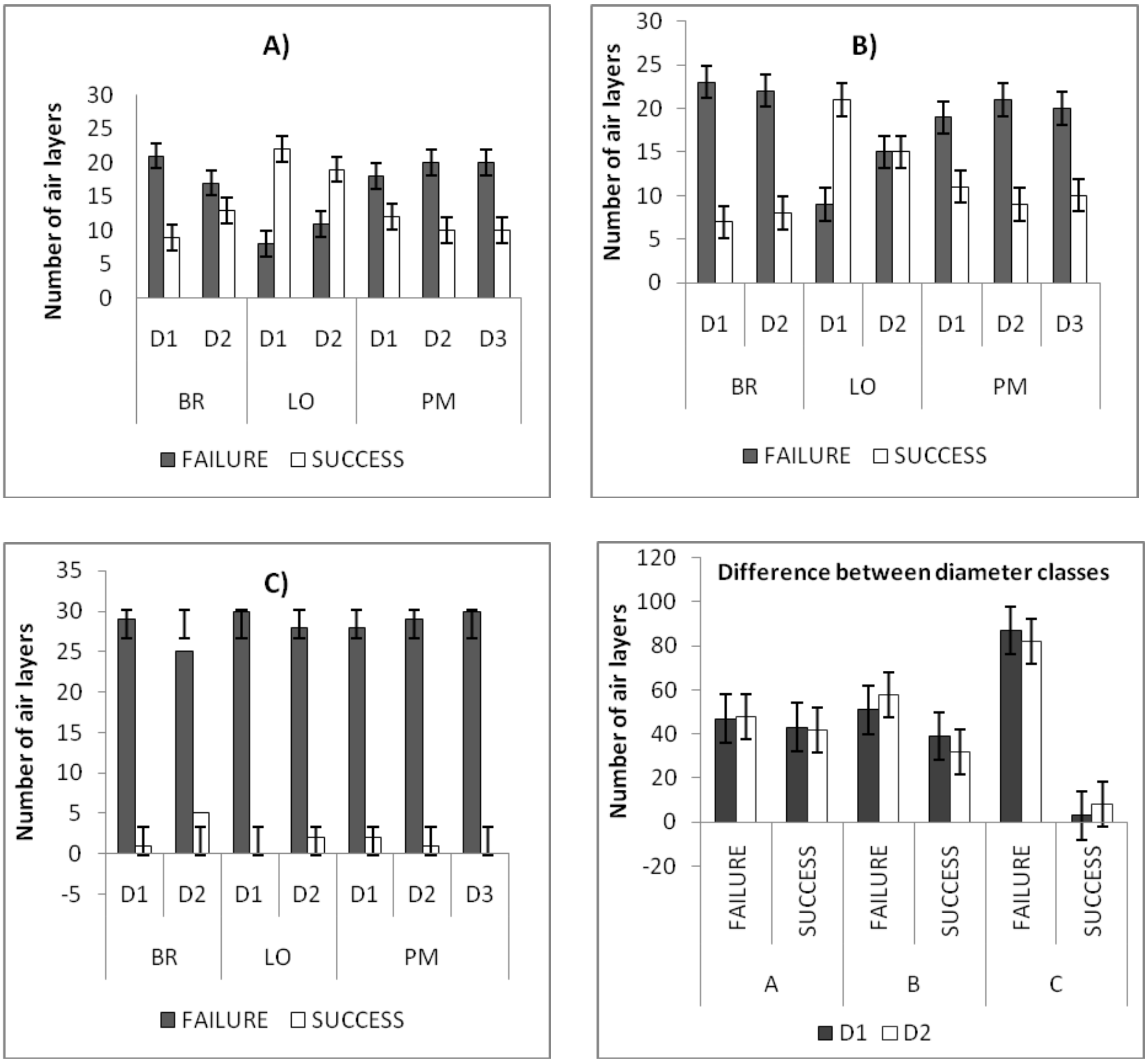

Figure 8. Diameter classes: diameter class 1 (D1), Diameter class 2 (D2) and diameter class 3 (D3) differences between species: *Bridelia cathartica* (BR), *Lonchocarpus bussei* (LO) and *Pseudolachnostylis maprouneifolia* (PM) in categories: dead branches =failure and branches with dead callus or branches with living callus or branches with roots = success (A), dead branches or branches with dead callus = failure and branches with living callus or branches with roots = success (B), and dead branches or branches with dead callus or brances with living callus =failure and branches with roots= success (C).

3.3 Eco-Cap and plastic sheets

There was no significant difference between Eco-Cap and plastic sheet methods in categories A, B and C when all species were combined (Logistic regression coefficient Z= -0.28, p = 0.77, Z = 0.56, p = 0.57 and Z = 0.51, p = 0.60) respectively (Figure 9). However, the individual species were significantly different in failure or success when Eco-Cap and plastic sheet were used in categories A and B (Logistic regression coefficient Z = 2, p = 0.04 and Z = 2.38, p = 0.01) respectively, while there was no significant difference in category C (Logistic regression coefficient Z= -1.64, p = 0. 10), (Figure 9a, 9b and 9c).

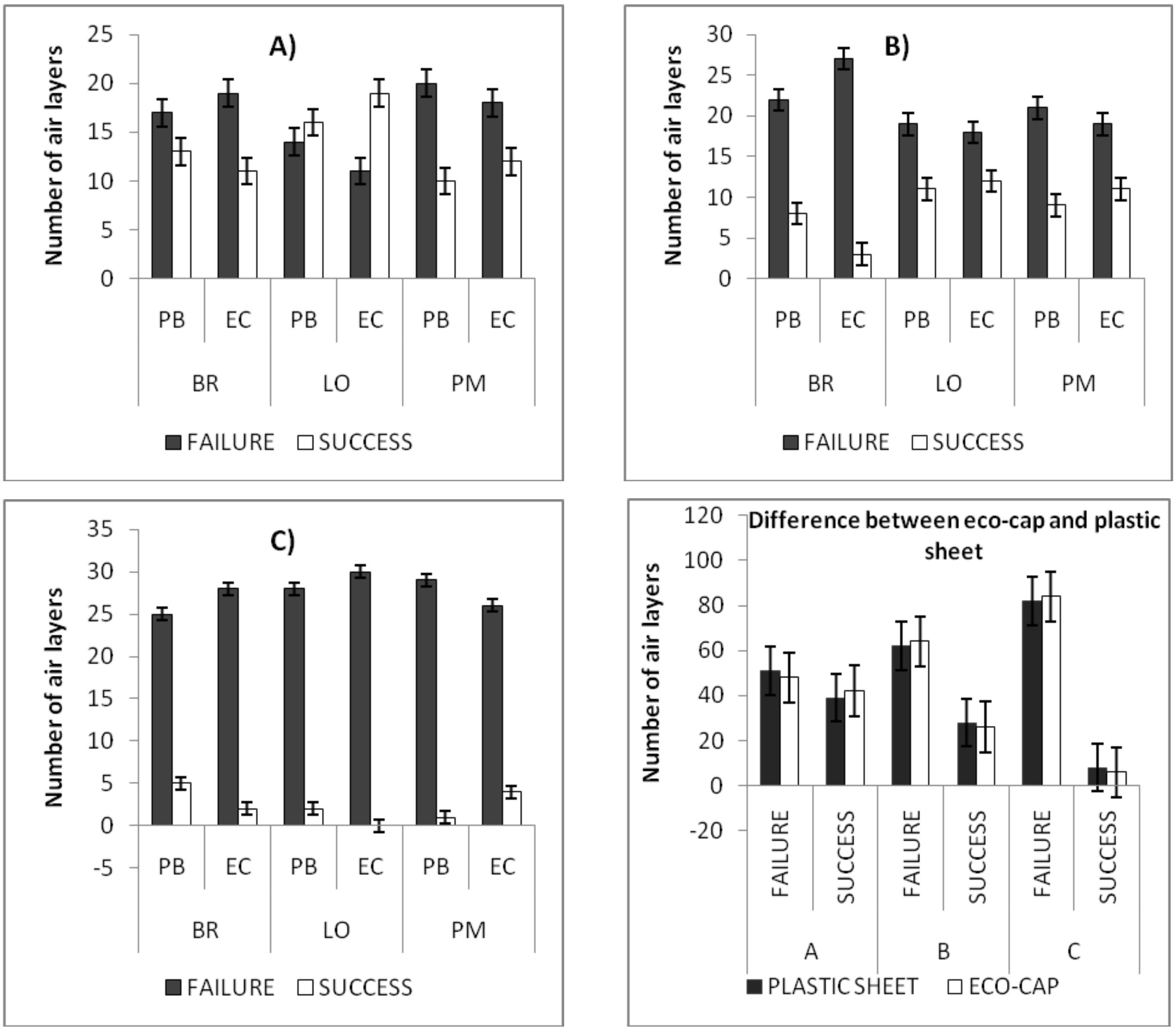

Figure 9. Failure and success between Eco-Cap (EC) and plastic sheet (PB) methods in *Bridelia cathartica* (BR), *Lonchocarpus bussei* (LO) and *Pseudolachnostylis maprouneifolia* (PM) in categories; dead branches =failure and branches with dead callus or branches with living callus or branches with roots = success (A), dead branches or branches with dead callus = failure and branches with living callus or branches with roots = success (B), and dead branches or branches with dead callus or brances with living callus =failure and branches with roots= success (C).

3.4 Rooting hormone

There was no significant difference of failure or success between hormone and no hormone experiments in category A and C (Logistic regression coefficient Z= -1.69, *p*= 0.090 and Z= 1.5, *p*= 0.133 respectively), while there was a significant difference of failure and success between hormone and no hormone experiments in category B when all tree species were combined (Logistic regression coefficient Z= -2.22, *p*= 0.026) (Figure 10). Individual species failure and success were significantly different in categories A and B (Logistic regression coefficient Z= 2.62, *p*= 0.009 and Z= 2.33, *p*= 0.020 respectively) (Figure 10a and 10b). However, there was no significant difference of failure and success of hormone and no hormone experiments between species in category C (Logistic regression coefficient Z= -1.4, *p*= 0.159), (Figure 10c).

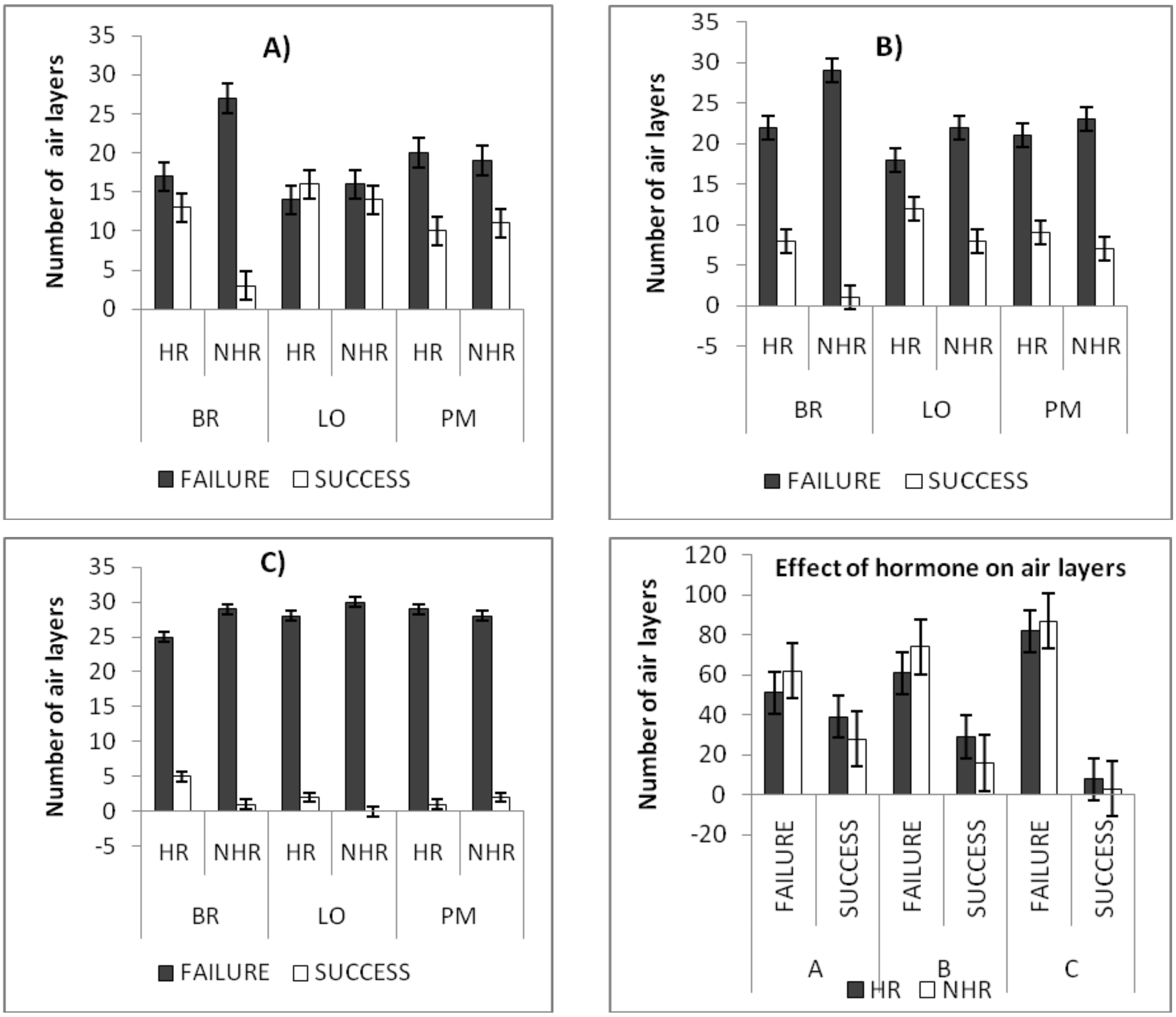

Figure 10. Success and failure of hormone (HR) and no hormone (NHR) experiments within and between tree species *Bridelia cathartica* (BR), *Lonchocarpus bussei* (LO) and *Pseudolachnostylis maprouneifolia* (PM) in categories; dead branches =failure and branches with dead callus or branches with living callus or branches with roots = success (A), dead branches or branches with dead callus = failure and branches with living callus or branches with roots = success (B), and dead branches or branches with dead callus or brances with living callus =failure and branches with roots= success (C).

3.5 Rooting media

There was a significant difference of failure and success between coconut fibre and saw dust in category A, B and C when all species were combined (Logistic regression coefficient Z= 3.43, *p*= 0.001, Z= 3.33, *p*= 0.001 and Z = 2.04, *p* = 0.042 respectively), (Figure 11). However, individual species failure and success were not significantly different in categories A, B and C (Logistic regression coefficient Z= 1.83, P= 0.067, Z= 1.85, *p*= 0.064 and Z = -0.74, *p*= 0.459 respectively) (Figure 11a, 11b and 11c).

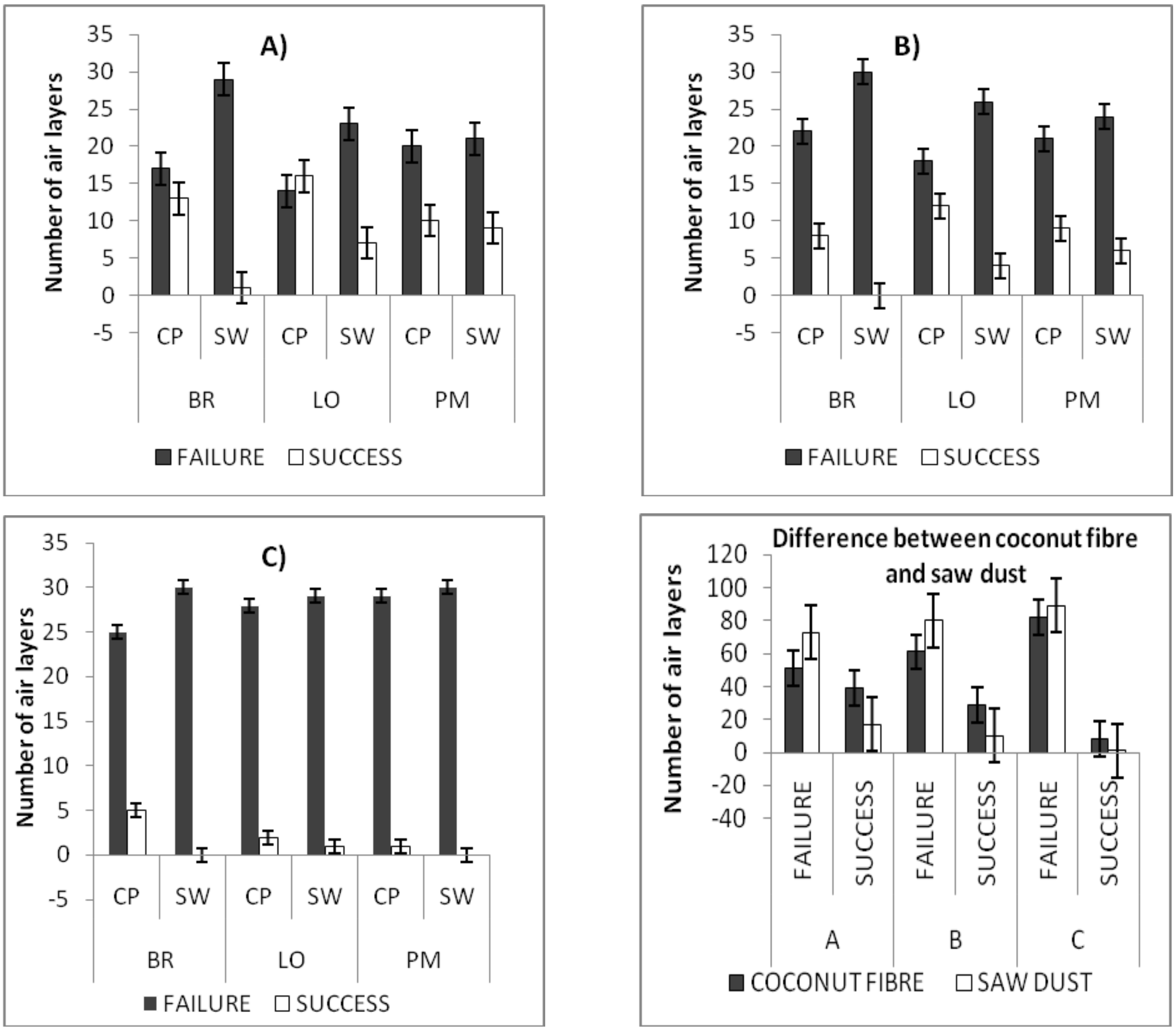

Figure 11. Failure and success between coconut fibre and *Cyprus* saw dust (SW) in *Bridelia cathartica* (BR), *Lonchocarpus bussei* (LO) and *Pseudolachnostylis maprouneifolia* (PM) in categories; dead branches =failure and branches with dead callus or branches with living callus or branches with roots = success (A), dead branches or branches with dead callus = failure and branches with living callus or branches with roots = success (B), and dead branches or branches with dead callus or brances with living callus =failure and branches with roots= success (C).

3.6 Height of branches used for experiments

There was no significant difference of failure and success between first branch and 1meter experiment above it, in category A, B and C when *B. cathartica* and *P. maprouneifolia* were combined (Logistic regression coefficient Z= 0.48, *p*= 0.138, Z= 1.35, *p*= 0.176 and Z = -0.33, *p* = 0.743 respectively) (Figure 12). Failure and success of *B. cathartica* was not significantly different from *P. maprouneifolia*, in categories A and B (Logistic regression coefficient Z= -1.84, *p*= 0.066 and Z= 1.35, *p*= 0.176 respectively), while in category C, *B. cathartica* was significantly different from *P. maprouneifolia* (Logistic regression coefficient Z= -2.32, *p*= 0.021), (Figure 12a, 12b and 12c).

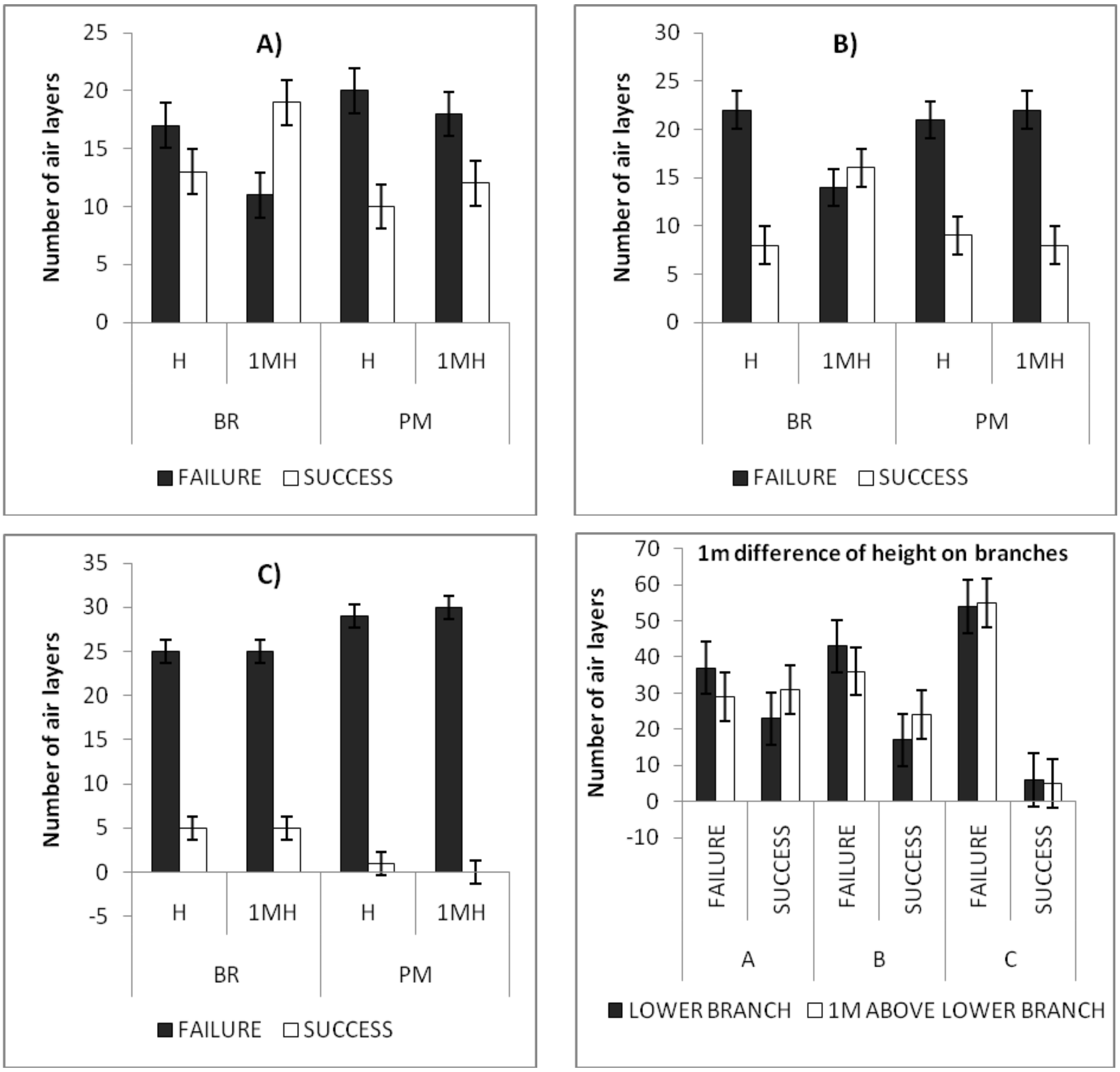

Figure 12. Failure and success between lower branch (H) and 1 meter above it (1MH) in *Bridelia cathartica* (BR), and *Pseudolachnostylis maprouneifolia* (PM) in categories; dead branches =failure and branches with dead callus or branches with living callus or branches with roots = success (A), dead branches or branches with dead callus = failure and branches with living callus or branches with roots = success (B), and dead branches or branches with dead callus or brances with living callus =failure and branches with roots= success (C).

4 Discussion

Tropical forests and woodlands are known to have high potential for biological diversity (Kanschik & Becker 2001). In the East African miombo woodlands this diversity is facilitated by more than 130 tree species of which many are highly in human demand (Luoga *et al.* 2002). Many of these species do not regenerate easily from seeds, but set sprouts from roots or stumps (Luoga *et al*. 2004). With increased and continued human pressure, including the burning of cut, regenerating areas, these natural regenerations fail (Mwase *et al*. 2007, Obiri *et al.* 2002). Deforestation and degradation of ecosystems creates thus a high risk of disappearance of some tree species in the future (Brooks *et al*. 2002, Mwase *et al*. 2007). Miombo woodlands in particular are in much higher risk of this threat because of more rapidly increasing population pressure than in regular forests – which usually will be reserves or national parks in East Africa (Campbell *et al.* 1996, Akinnifesi *et al.* 2006). In addition to this, fire frequencies and browsers which kill, not only vegetative regeneration, but also surviving seedlings, and thus reduce all natural regeneration in these woodlands (Piiroinen *et al.* 2008). For efficient and effective regeneration management, better knowledge of the regeneration ecology of most miombo tree species is needed (Kanschik & Becker 2001). Additional knowledge on vegetative propagation of tree species which do not regenerate easily from seed is crucial at this point when climate change and biodiversity loss is alarming the world. Many authors have described different methodologies of propagating recreational-, fruit-, fodder- and timber-value trees (Dewir *et al*. 2006, Dick *et al.* 1998, Danthu *et al*. 2002, Zahawi 2005, Mng'omba *et al.* 2008). Less is known for tropical miombo woodland trees, particularly those which are hardly regenerating from seeds. Vegetative propagation results from tested commercial value tree species have shown good results with high possibility of regeneration through leaf and stem cuttings, air layering and tissue culture (Janos *et al.* 2001, Dick *et al.* 1998, Danthu *et al*. 2002, Zahawi 2005). Results from the present study also indicate the possibility of regenerating three tested tree species by air layering (Figure 6). Air layering has been described in many tests to be efficient for regeneration of trees in their natural environment (Janos *et al.* 2001). Regeneration in the natural environment was also used in the present study. The method is cheap, easily adopted and has been used for many years (Mng'omba *et al*. 2008). Although there are some variations between species in the success of propagation, both in the present study and former studies (Table 4) (Danthu *et al*. 2002), we can still rely on species specific tests for future establishment of new plant materials for aforestation programs in degraded areas in the tropics such as Tanzania (Zahawi 2005). Finding the most appropriate way of doing air layering for any propagated miombo tree species is important for enhancing successful results in future planting (Janos *et al.* 2001). Different requirements of individual tree species are a key for establishing new forests through restoration of degraded areas (Mng'omba *et al.* 2008). In addition to this, availability of new plant material through this means, will be cheaper and easier for farmers, which will stimulate the planting of fruit-bearing-, charcoal-, firewood-, building pole-, and timber tree species for income generation and subsistence purposes (Leaky & Simons 1998, Zahawi 2005). In addition to the technical knowledge, local knowledge on planting trees for restoration is also essential for better management of miombo woodlands (Koku 2002). The acquired propagation experience, once acquired, is easily transferred between farmers with low costs and in an efficient way (Topp-Jørgensen *et al.* 2005). The impact of farmer's having individual woodlots would be a reduced pressure on the natural ecosystem. For trees which do not regenerate easily from seeds, it will create a means for conserving these species genetic material which would rescue endangered strains from disappearing in nature (Mng'omba *et al.* 2008). Biodiversity conservation will thus be achieved in the same token as habitat restoration.

Results from this study, provides some information on vegetative propagation of *B. cathartica*, *L. bussei* and *P. maprouneifolia*, miombo tree species. Measure of success and failure from the air layers are indicated in the results chapter for each category. The five different paired experiments (see material and method chapter) were aiming at providing information on vegetative propagation properties of the three tested tree species. Each of the test results within each category and species are discussed independently in chapters below.

4.1 Species difference

Results from the present study showed that there was no significant difference of propagating the three tested species (Figure 6). The propagated species belong to families which were reported to have high rooting ability from cuttings (Itoh *et al*. 2002). There is a possibility of getting better results from the three species with proper propagation timing in relation to precipitation (Mng'omba *et al.* 2008). However, slight differences of success were observed between species. *L. bussei* had more success (53% and 37%) than *B. cathartica* (43% and 27%) and *P. maprouneifolia* (33% and 30%) in category A and B respectively (Figure 7). The reasons could be its genotypic abilities for survival during dry seasons (Geldenhuys 2010). At the time of cutting, *L. bussei* had green leaves which were assumed to continue producing high amount of auxins compared to *B. cathartica* which had no leaves, and *P. maprouneifolia* which had few shading leaves only, during the time of experiment. In category C, *B. cathartica* had higher success of producing roots (16.7%) followed by *L. bussei* (5.7%) and *P. maprouneifoli*a (2.1%). The bark of *B. cathartica* was thicker and this made it likely to lose less moisture than the other two species. However, mean root length was found to be longer in *L. bussei* than the other two species (Figure 7), possibly because it had more active branches with green leaves. All three tree species produced roots within four weeks after the start of rain seasons. *L. bussei* produced roots at the same time as the other two species despite that it started to develop callus within four weeks after setting the experiments. The results from the study suggests that, end of dry season or early rain season would be the appropriate time for wounding and setting air layers for the tested tree species. Time of the year in which the experiments were fixed, was a challenge due to very dry climatic conditions for most tree species (Figure 13), particularly in the year of this experiment (July 2009- January 2010). This seemed particularly to be the case for *L. bussei*, where callus development was seen within four weeks after setting of experiments, but there was no root development until the start of rain season. In addition to this, most of the tree species were in the resting state and there was no tree growth which would have been expected to stimulate root development.

Figure 13. *Lonchocarpus bussei* (left), *Pseudolachnostylis maprouneifolia* (centre) and *Bridelia cathartica* (right). Tree species of Kitulanghalo forest reserve between September and November 2009, Morogoro, Tanzania.

4.2 Diameter classes

Tree diameter is one of major factors for success of many propagated tree species. Experiences show that vegetative propagation of tropical trees is more successful in smaller trees (Itoh *et al.* 2002). Present results showed the same trend of higher success in D1 experiments of two species in category A and B. However, *B. cathartica* had more success in D2. The reasons could be its growth characteristics and recovery response to injuries. It is known that, rooting ability of trees with small maximum growth size and ability to recover from damage is high compared to large size maximum growth trees (Itoh *et al*. 2002).

In category A and B, *L. bussei* and *P. maprouneifolia* had more success in D1 than in D2 and (D3) respectively, while *B. cathartica* had more success in D2 than D1. In these categories, it was easy to propagate *L. bussei* and *P. maprouneifolia* in D1 and *B. cathartica* in D2 (Figure 8a and 8b). The reasons could be species vegetative behaviour difference in their natural ecosystem (Danthu *et al.* 2002).

In category C, *B. cathartica* resulted to high percentage of rooting in D2 compared to D1 which indicates that, bigger tree size was most sufficient for propagation of this species (Mangingo & Dick 2001). *P. maprouneifolia* had higher percentage of rooting in D1 than in D2 and D3 respectively (Figure 8c). Smaller trees were better for propagation of *P. maprouneifolia*. This tree grows to a large size when matured, hence doesn't meet the criteria of been propagated using mature branches (Itoh *et al.* 2002). *L. bussei* developed roots in only D2, which could indicate that larger tree size would be suitable for future propagation of this species. This species seemed to fall into the group of trees which their vegetative propagations are better with mature trees (Mangingo & Dick 2001).

4.3 Eco-Cap and plastic sheet

Plastic sheets are the most used material for air layering in Tanzania. Plastic sheets were compared to a newly innovated method (Eco-Cap) for air layering to test its feasibility in tropical areas. Eco-Cap was designed to collect and drain excessive moisture in and from the rooting media (Godøy, 2008). The method can be easily understood and used in the natural tropical ecosystem. However, Eco-Caps were difficult to handle in the field due to problems of fitting the plastic tightly around the branches (I speculate that it was industrial problem which calls for more modification and research). In addition to that, branches fitting in size were hard to find, which increased time of selecting and fixing the caps on branches of the tested trees. Water loss was higher (70%) compared to plastic sheets (50%) in dry season (range 0-100%). Despite of all shortcomings, Eco-Cap was observed to be good for collecting and draining rain water to and from the rooting media during the rainy season (Personal observation). An additional benefit of Eco-Cap is that the same amount of rooting media was applied to each branch. This ensured standardized amount of rooting media around the wounded area. Moreover, Eco-Cap experiments were not disturbed by animals since the outer cover was hard and highly protecting the rooting area compared to plastic sheets which were more easily destroyed by animals and insects. Eco-Cap was very light in weight for field usage and efficient to use compared to plastic sheets which required more preparation in the field. Eco-Cap was observed to be environmental friendly in terms of reuse and they were hard, not easy to lose from the branches in the field compared to plastic sheets which tear apart very easily in dry natural ecosystem. The method can be easily recognized in the field which may add to easy monitoring in the field (Godøy 2008).

Statistical test results showed no difference of success between Eco-Cap and plastic sheets in all the three categories of results (Figure 9). Despite of bad weather and high loss of water, Eco-Caps had almost the same performance as plastic sheets. I assume that, results of Eco-Cap would have been better if propagation tests were performed in the wet season to ensure continuous moisture around the cut branch. Also, Eco-Cap is likely to have performed better if industrial problems-with this particular batch used in the experiment were eliminated. Based on present results and environmental conditions on which the experiments were performed, I speculate that more tests on improved models of Eco-Cap could give better results in the future.

4.4 Rooting hormone

Some of miombo tree species has produced roots in experiments without rooting hormone in earlier studies (Akinnifesi *et al.* 2005). However, little is known about the effect of hormone in most miombo tree species. Rooting hormone is used to speed up the process of roots development (Abdullah *et al.* 2006), but it might not be necessary to use it in some tree species when they produce a high natural amount of auxin, such as e. g. of *Inga feuillei* (Brennan & Mudge 1998). The results from the three tested tree species in this study showed that rooting hormone was not necessary for roots development. However, *B. cathartica* seemed to have more success in experiments with hormone. I therefore assume that rooting hormone was important for the speeding up the process of root development in this species (Figure 10). This result could, however, indicate either of two things, (1) rooting hormone was not necessary if the tree was propagated for a long time or (2) rooting hormone was necessary for faster results. In one of the species, (*B. cathartica*), hormone application had a positive effect on root development at the end of the experiment. Those without hormone might still have developed roots (they had living callus), but at a slower rate than those with hormone. However, hormone did not influence callus formation (see results chapter).

In category A and B, *L. bussei* and *P. maprouneifolia* had same success regardless of whether rooting hormone was applied or not (Figure 10a, 10b). These two species are thus assumed to recover from wound by developing roots for survival without any need of hormones (Hoffmann *et al*. 2004). As mentioned above, *B. cathartica* had slightly less success in experiments without rooting hormone, but generally all three propagated tree species responded well without rooting hormone. This is the advantage to local people because they can have very cheap way of propagating these tree species for reforestation on degraded areas around the villages without using rooting hormone.

4.5 Rooting media

Rooting media is another important factor when it comes to propagation of different tree species because of its effect to root development. In this manor, it is important to find appropriate rooting media for best propagation results of each tree species. In most parts of the world, sphagnum moss is used as a rooting media and there are many recommendations for its use (e. g. Morton 1987, Chia *et al*. 1997). However, in the tropical countries like Tanzania, sphagnum moss is only found in protected areas where people cannot collect it. The only alternative would be to buy imported sphagnum moss which is very expensive for a local farmer in a poor country like Tanzania. To avoid these expenses, many farmers have adopted *Cyprus* saw dust for propagation of fruit trees in Tanzania. In this study, the success from saw dust was very low in all experimented species. The effect of chemicals contained in the saw dust, which might interfere with root development, could be the main reason for failure of saw dust (Jackson *et al.* 2007). Results of saw dust were compared to industrial made coconut fibre which had very low amount of chemicals. There was a clear difference in success of the two used rooting media as shown in results chapter.

In category A, species performances were different when saw dust was used in comparison to coconut fibre. *B. cathartica* showed a clear negative response to saw dust, *L. bussei* had little success with sawdust being used, while in *P. maprouneifolia*, there was no difference of success between sawdust and coconut fibre. Success using sawdust as a rooting media thus seemed to depend on tree species. Sawdust could then be expected to perform well in those miombo tree species which are able to resist the chemicals contained in it (Figure 11a).

In category B, *B. cathartica* failed completely with sawdust. *L. bussei* had lower success in sawdust compared to coconut fibre. Still there is a chance of propagating this species in chemically reduced sawdust and expect some reasonable results (Personal speculation). *P.*

maprouneifolia didn't show big difference of success when coconut fibre was compared to sawdust. I assume that this tree species might have had better results if chemically drained sawdust had been used (Figure 11b).

In category C, roots were a measure of success. Most of the experiments with saw dust did not produce roots. There was a complete failure with sawdust as a media in *B. cathartica* and *P. maprouneifolia,* while *L. bussei* had some roots. This measure of success is not reliable because, number of branches (with saw dust) which developed roots in *L. bussei* were very few compared to experiments with coconut fibre.

Therefore, in conclusion, saw dust was, in at least two out of three species, not a good rooting media compared to coconut fibre. However, research is required to see any possibility of using other rooting media such as a mixture of charcoal dust and forest top soil (Jackson *et al.* 2007). Finding of a cheap and efficient method of regenerating miombo trees for planting in degraded area around Kitulanghalo forest reserve is very crucial (Mndolwa *et al*. 2008).

4.6 Height of branches used for experiments

There are some recommendations of different heights on particular tree species for which air layering should be fitted (Itoh *et al.* 2002). For example, in a closed canopy of tropical rain forests, 2-6 meter branch height gave good results of rooting by cutting method in an experiment which was performed in Malaysia (Itoh *et al.* 2002). The effect of height of air layers on miombo trees was tested to see if there was any need of taking branch height in to consideration in future. *B. cathartica* and *P. maprouneifolia* were put into branches height tests, while *L. bussei* was eliminated from this test because it had a straight single stem with branches at the top of the tree. Interesting results were found to dominate in the two tested species.

In category A, there was more success on 1 meter higher branches than the lower branches for both *B. cathartica* and *P. maprouneifolia*. Success of 1 meter higher branch (63%) was significant higher compared to success of lower branch (43%) in *B. cathartica* (Figure 12a). This suggests that, propagation regeneration of this species is more successful when mature and higher branches are used (Abdullah *et al.* 2006). In *P. maprouneifolia,* success for 1 meter higher branch (40%) was slightly higher compared to the lower branch (33%). Generally, 1 meter higher branches had better success to both species than the first branch, only in this category.

In category B, propagation of *B. cathartica* was better for air layers which were placed on higher branches than the lower branches (Figure 12b). In *P. maprouneifolia*, there was no big difference of success between lower branch and 1 meter above it. In category C, successes were the same to both lower and 1 meter above branch in *B.cathartica*. *P. maprouneifolia* had success only in lower branch (Figure 12c). In this case, height of the branch above ground may be a factor that differs between species. It is assumed that, there would be more success in this category if time of root development was increase before taking the measurements. However, roots development is speculated to have a relationship with sprouting behaviour of these tree species (Itoh *et al.* 2002.)

In conclusion it could be said that vegetative propagation of most miombo trees species, which are otherwise difficult to propagate, would be possible if specific requirements for propagation for each species is investigated through tests. Results from the present study provide some evidence of regeneration possibilities of three tested tree species by air layering in their natural ecosystem (Figure 6). I would assume that, end of dry season or early start of rains would be appropriate time for laying out air layers for the tested tree species. However, more research is required for proving this assumption. Propagation of smaller trees had good results in *L. bussei* and *P. maprouneifolia*, while larger trees had better results for *B. cathartica*. The study suggests that air layers using Eco-Caps could be successful if the method is improved. Saw dust is not useful in some species, but could be used in two tested species (*P. maprouneifolia* and *L. bussei*). However, the amount of chemical compounds in saw dust may be the reason for rather poor results using this media and ways to reduce the chemical content could be investigated. Hormone appeared to be not necessary for root development of all three tested species. Heights on which the air layers are placed are variable for each tree species. *B. cathartica* had best results with 1 meter higher experiments in D2. *P. maprouneifolia* showed good success in both heights indicating that, it is possible to propagate it between lower branch and 1 meter higher branches. Generally, it is assumed that lack of moisture – even if water was applied regularly – was the main cause of failure in root development. It is assumed that doing vegetative regeneration could be more successful if cutting is done at the end of dry season or start of the rain season around November.

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