Research article

INVESTIGATION OF THE ASEXUAL REPRODUCTIVE CHARACTERISTICS OF NATIVE SPECIES FOR SOIL BIOENGINEERING IN THE WEST INDIES

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Abstract- In the Caribbean, erosion and landslides are frequent hazards. To respond to societal needs in terms of erosion prevention, it is necessary to stabilize the banks of watercourses and the slopes of gullies. To achieve this objective, soil bioengineering offers more environmentally respectful solutions than traditional civil-engineering techniques. Soil bioengineering includes vegetation as a building material. These techniques are not very widespread in the Caribbean and therefore basic research is necessary.

Vegetative propagation is a low-cost, fast and effective way to obtain plant material; the development of soil bioengineering techniques thus implies controlling species vegetative propagation.

As a first approach to identify appropriate species, we conducted a literature review on the rooting ability of cuttings from thirty-one Caribbean native herbaceous, shrub and tree species adapted to riparian conditions. We led a first *ex situ* study to evaluate the vegetative propagation potential of cuttings, in the context of soil bioengineering development.

Our results indicate that some native Caribbean species can easily be propagated through cuttings. Among the selected species, three trees, five shrubs and three herbaceous species were found to be adapted to controlled propagation in low-tech conditions, consistent with soil bioengineering techniques in the Caribbean.

Keywords: soil bioengineering, nature-based solutions, erosion, tropical riparian ecosystems, cuttings, Caribbean, Proteger project

INTRODUCTION

To respond to societal needs for erosion prevention and risk protection and to guarantee the safety of human investments, local authorities must carry out stabilization works to protect the banks of watercourses and the slopes of gullies. In most cases, these constructions use civil engineering techniques, mostly involving rock or concrete riprap. Although these widely used civil engineering techniques are mechanically efficient, they have a strong negative impact on riparian ecosystems, affecting ecological structures and functions by degrading riparian and aquatic biodiversity, buffer zones and ecological corridors (Cavaillé et al. 2015, Schmitt et al. 2018, Janssen et al. 2019).

Compared to civil engineering, soil bioengineering represents a softer and more respectful option, from both an environmental and a landscape perspective. Soil bioengineering is a nature-based solution to the societal challenge of disaster risk protection, whose implementation imitates natural plant communities (Cohen-Shacham et al. 2016). Soil bioengineering can be defined as the inclusion of vegetation into engineering designs to improve and protect slopes, embankments and structures from the problems associated with erosion and other types of shallow slope failures (Clark & Hellin 1996). Thus, a characteristic of soil bioengineering is that the plants and plant materials used build living structures that can stand alone or work in combination with inert materials (Schiechtl & Stern 1996, Adam et al. 2008); the vegetation itself provides mechanical functions (stability, anchoring).

Humid tropics are particularly subject to erosion. Precipitation regimes, associated to frequent hurricanes, are characterized by high rainfall events. More than 40% of the precipitation events have an intensity greater than 25 mm per hour versus less than 5% in non-tropical zones, and intensities above 150 mm per hour are very common (Díaz 2001). On the steep slopes, corresponding to geologically young volcanic edifices, even minor disturbances can induce erosion and landslides. The costs associated with these hazards are considerable and soil bioengineering is therefore a feasible economical, and ecologically friendly, alternative for erosion control (Clark & Hellin 1996) even if pure civil engineering may sometimes be unavoidable.

The Greater and Lesser Antilles constitute the "Caribbean Island hotspot", i.e. one of the 34 world hotspots of biodiversity. The local flora and fauna there are both rich and threatened, with a high level of endemism (Myers et al. 2000). The Guadeloupe archipelago shows a remarkable biodiversity among its islands: the terrestrial vegetation counts 1706 native species (UICN 2019) harbored in 34 types of ecosystems (Rousteau et al. 1996). In the context of global change and the run-away erosion of this exceptional biodiversity, conserving and restoring degraded ecosystems, particularly those under anthropogenic pressure such as riparian areas, must become a priority. Soil bioengineering techniques can be efficient tools to overcome biotic (e.g. invasive species) or abiotic (severe erosion) damage and to reestablish successional trajectories (Polster 2016). The breadth of indigenous species richness carries the promise of finding suitable species for the development of such techniques.

Although the flora of the Lesser Antilles is well known, their riparian assemblages remain poorly identified. The main species used in the few existing soil bioengineering projects are mostly exotic, even though some native species have been identified as suitable (Clark & Hellin 1996, Díaz 2001, Corail 2008). In Guadeloupe, the first study characterizing these plant communities has only recently been conducted (Gayot et al. 2017). It proposes an operational typology composed of twelve distinct riparian plant community types, influenced by four main covariables: rainfall, altitude, salinity and river slope. One of the main findings of this study is that plant cover is largely influenced by the surrounding flora and is heavily impacted by alien plant species. Among the species observed, 80 species of trees, shrubs, and herbaceous plants in different riparian ecosystems have been identified as potentially useful in soil bioengineering.

To be suitable for soil bioengineering, species must present a compatible set of biotechnical traits. They must be ruderal pioneer species with a higher ratio of below-ground biomass than above-ground biomass (roots strongly developed with respect to the aerial parts), both aerial and root components must have a high growth rate, and the plants must be able to regenerate quickly after a disturbance. Other characteristics may also be required such as immersion tolerance, tolerance to burial, drought resistance (for dry sites) and nitrogen fixation to improve soils. They must produce enough seeds, plants or vegetative material to be planted on construction sites; it must be easy to multiply them in large numbers, and they must be socially acceptable to the local population (Clark & Hellin 1996, Díaz 2001, Norris et al. 2008).

A challenging first step toward using indigenous species in soil bioengineering in the Caribbean is to control asexual propagation, particularly with cuttings. Indeed, vegetative reproduction through cuttings is a low-cost, fast and effective ways to obtain woody plant material, and as such, is a prerequisite for the basic soil bioengineering techniques of live fascines, brush mattresses, brush layers or live stakings (Díaz 2010, Clark & Hellin 1996, Zeh 2007).

Even though little information is available in the literature on the rooting ability of cuttings from Caribbean native species, the natural ability to some cuttings to resprout has been described for tropical species (Hallé 2005, Bellefontaine 2018), including those of riverine ecosystems (Rood et al. 2003, Kontoh 2016). Asexual propagation may be a strategy that tropical riparian trees and shrubs widely use in response to the high level of flood disturbance in their environments (Nakamura & Inahara 2007). We can therefore hypothesize that a large number of Guadeloupian riparian species are able to resprout through cuttings and will therefore potentially be useful in soil bioengineering. Among the 80 Caribbean riverine species proposed by Gayot et al. (2018), we selected a large number of species (31) of the most promising native species in order to make (i) an extensive bibliographical review and (ii) a first evaluation with few replicates per species, of their cutting propagation potential in the cost-constrained conditions common for soil bioengineering projects.

MATERIALS AND METHODS

Bibliographic review

A literature review was conducted on the Google Scholar (2019) search engine (latest update: 2 October 2019) and included studies published in peer reviewed journals, books, papers in conference proceedings and technical reports. The keywords used were ‘propagation’ OR ‘cuttings’ OR ‘vegetative multiplication’ associated with each species name and their taxonomic synonym, following the Tropicos database. Works in French, Spanish, English and Portuguese were retrieved and screened for relevance. We then summarized the information extracted from these publications according to the plant part considered in the cutting experiment, the experimental conditions and the final result of the vegetative propagation tests.

Species selection and sampling

The 31 native riparian species (5 herbaceous plants, 6 shrubs, 20 trees) were selected according a multi-criteria analysis including traits useful for bioengineering: ecological status (pioneer), resistance to disturbance, propagation potential, ability to fix nitrogen, and growth form.

Cuttings were collected during the rainy season in July 2019. The plants sampled were located in a riparian area on the Basse-Terre Island (Figure 1) between 0 and 300 m above sea level. For trees, one branch (minimum diameter of 2.5 cm) was taken off with a telescopic saw from four different individuals per species. Cuttings 60 cm in length were prepared and leaves were immediately removed. For shrubs and herbaceous plants, segments with at least four nodes were collected from four different individuals per species (making 4 cuttings per species, with a total of 31 species and 124 cuttings). For two of these, *Thelypteris reticulata* and *Ischnosiphon arouma,* we ensured that specific organs dedicated to asexual propagation were present, respectively vegetative bulbils and innovation shoots carried by long internodes (Proctor 1977, Cremers 1992). The cuttings were stocked at ambient temperature in the shade and planted within 24 hours after sampling.

Experimental conditions

The experimental conditions were as representative as possible of those occurring in bioengineering works. Complex and costly laboratory techniques used to produce plant material would be unaffordable and technically unfeasible in soil bioengineering projects. We therefore followed the low-cost procedures commonly used in soil bioengineering (Figure 2). As cutting rooting rates can be negatively affected by light intensity (Loach & Gay 1979, Grange & Loach 1985), the plants were protected from light stress under a shadehouse (60% light reduction) as it can be used on soil bioengineering sites in tropical environments (Mafian 2009). Irrigation, corresponding to daily precipitation, maintained a favorable hydric balance in the replanted area. The cuttings were planted in 70 L containers filled with a mix of river sand and natural soil (3/4:1/4) within 24 hours of sampling. Two thirds of the length of each cutting were buried and polarity was respected. The cuttings were left in the containers three months for woody species, and three weeks for the faster developing non-woody species.

RESULTS

Only 13 (10 trees, 2 shrubs, 1 herbaceous plant, Table 1) among the 31 species we selected received attention in the literature (21 publications) related to cutting rooting ability. Various experimental settings were considered in these previous studies, and less than 10%

were conducted in natural conditions. Indeed, most of the studies applied highly controlled *in vitro* propagation, under bell propagation or used hormones to enhance the rooting potential of the plant material. Furthermore, different plant parts were considerered in these experiments, mostly stems (more than 90% of the studies) but also leaves owing to distinct ontogenic stages (juvenile, mature). Of the 13 species previously tested and reported in the literature, stem cuttings from eleven species were able to resprout.

In our experiment, cuttings from 25 species started to emit leaves a few days after planting (Figure 3). However, few were able to root and among the 31 species tested, only eleven showed the ability to root from cuttings. Three trees, five shrubs and three herbaceous species emitted roots, 25% to 100% of the individuals depending on species (Table 2, Figure 4). The resprouting species showed a diversity of ecological features and belonged to all forest ecosystem types. The number of successfully rooting species was quite unbalanced depending on ecosystem type; ten of the eleven successful species belong to the seasonal evergreen forest type whereas only one is found in the coastal forest. Among the successful species, three were helophytes: two herbaceous plants - *Dieffenbachia seguine* and *Hymenachne amplexicaulis,* and one shrub - Ludwigia *hyssopifolia*. Some of the other successful species cover a large ecological range, like *Homalium racemosum* and *Piper dilatatum,* which are common from dry forest to rainforest, whereas others, like *Citharexylum spinosum*, belong to a single ecosystem type, in this case the dry forest.

DISCUSSION

Our review of the available literature highlighted the need to acquire further results concerning the asexual propagation potential of native Caribbean riparian species to use in bioengineering projects. The bibliographic data concerning the selected species were sometimes very old (Noisette 1826, Jacques et al. 1847) and the methods employed to obtain plants from cuttings (i.e. leaf cutting propagation, *in-vitro* propagation) are often incompatible with the conditions required for bioengineering techniques (Thirunavoukkarasu et al. 2004, Deccetti et al. 2005).

In the cost-constrained conditions applied in our experiment, 60% of the selected herbaceous plants (non-woody, short species with one non-woody stem) and 83% of the selected shrubs (woody species reaching up to 5m with numerous ramifications) resprouted from cuttings, whereas only 15% of the selected tree species rooted. Asexual propagation potential is a functional trait that has been linked to plant size. Indeed, ground plants may compensate for their vulnerability to frequent disturbance by a high resprouting ability whereas trees can avoid many disturbances by being larger and taller. In their case, resprouting may be less necessary (Vesk 2006). The selected herbaceous and shrub species easily colonize highly degraded or frequently disturbed areas (Fournet 2002). Their natural vegetative propagation ability may be the expression of a strategy contributing to the success of their establishment and fast development in areas where unavoidable disturbances often cause the loss of most above-ground biomass. Our results are thus consistent with the hypothesis of a high vegetative multiplication ability in Caribbean riparian plant communities, at least for herbaceous plants and shrubs. We show that native species can be integrated into soil bioengineering structures such as helophyte fascines. However, though the resprouting ability of native herbaceous and shrub species is interesting for soil bioengineering, it is quite surprising how few tree species were able to resprout from cuttings.

Indeed, even if some genera from the present study like *Ficus* or *Inga* are known for their limited ability to root from cuttings (daSilva 1998, Danthu et al. 2002), many tests involving tropical forest tree species cuttings have been successfully conducted (Amri 2010, Bellefontaine 2018), including for Caribbean trees (Lilin & Koohafkan 1987). Propagating woody species from cuttings or plantings is particularly challenging for soil bioengineering in

Guadeloupe, as the preserved riverine ecosystems mostly support riparian forests. In the natural succession of riparian ecosystems, the first stage often involves fast-growing pioneer trees closing the canopy. Tree species drive the entire structure and evolution of riparian forests and further investigation is needed to provide more options for multiplying these crucial components of the ecosystem. Indeed, in current soil bioengineering practices, cuttings from shrub and tree species are key elements (Clark & Hellin 1996, Díaz 2001), and being able to grow more varied species from cuttings would be relevant, considering the large diversity of biotic and abiotic conditions occurring in Guadeloupe.

The poor resprouting rate of trees cuttings in our study could possibly be explained by our experimental conditions. After unpotting, the base of some of the cuttings showed signs of rot, suggesting a water excess that may have impeded gaseous exchange at the site of root initiation. However, our experimental design allowed us to identify the species able to root easily in moist soils like along riverbanks. Independently of the experimental conditions, various parameters influence the rooting success of cuttings of tropical woody species: the species considered, the abiotic conditions (substrate, watering, temperature, air humidity), the position from which the cutting is taken, the age of the individual from which the cutting is taken, the sampling season of the cuttings, the use of hormones, the application of incisions, the time elapsing between harvesting and planting and the related conditions, and the maintenance (partial or total) of leaves (Bellefontaine 2018). Testing all these parameters would be very time-consuming, and using horticultural techniques, such as growing micro-cuttings in a controlled atmosphere, would not be operationally compatible with soil bioengineering practices. However, the use of hormones could be relevant. A hormonal induction could increase the rooting success in the cuttings of the selected species. Indeed, the role auxins, in particular indole-3-butyric acid (IBA), play in the promotion of root emission has been established in tropical trees cuttings (Teklehaimanot et al. 2004, Amri 2009). IBA influences polysaccharide hydrolysis, inducing an increase in the content of physiologically active sugar. These sugars feed meristematic tissues and contribute to root primordia and root formation (Husen & Pal 2007, Amri et al. 2010). Even though an IBA treatment on cuttings before the installation procedure would undoubtedly impact the cost of the bioengineering project, it may remain feasible and would be applicable in field conditions. The present study concerns the first results of a broader four-year project composed of various interconnected experiments. Applying indole-3-butyric acid, an efficient rooting hormone on tree species (Hartmann et al. 1997) to the species that showed poor resprouting is the next step to determine the practicality of using cuttings. Beyond the challenge of propagating species with cuttings, other aspects, such as sexual propagation will be considered to develop soil bioengineering techniques through planting Caribbean native species. In a further study, of the 31 species we selected, the 20 that were unable to resprout from cuttings will be tested for seed germination potential.

Our study was conducted over a short three-month period whereas the ultimate survival of cuttings can only be assessed after approximately three years in temperate environments (Rey & Burylo 2014). Even though a longer monitoring period could confirm the satisfactory development of the cuttings, our results remain relevant since quick resprouting is essential in soil bioengineering to stabilize the soil soon as possible. Indeed, cuttings that have not resprouted after three months would not be suitable.

As we choose to test a large number of species (31) we only had four replicates per species, that is low and does not allow any statistical analysis. But still, the four individuals per species came from different genotypes. Added to the large number of species tested, this experiment gives important and robust information about their potential resprouting capability from cuttings and about their potential use in soil bioengineering. These first results are very important for practitioners that have been facing an almost total lack of information about the resprouting ability of Guadeloupian indigenous species from cuttings. Until now practitioners were mostly using exotic species such as *Gliricidia sepium* or *Chrysopogon zizanioides*, contributing to the homogenization and to the threat of the Caribbean riche and endangered flora. Soil bioengineering is not very widespread in the Caribbean and needs basic research. Our experimental results and the associated bibliographical review open new avenue for the use of local species and are therefore innovative and important for soil bioengineering in the Caribbean, both for practitioners and researchers. This first approach could be completed by the characterization of other plant traits, relevant in the context of soil bioengineering: e.g. the flexural behavior, pull out resistance, tolerance to submersion (Schiechtl & Stern 1996 Saifuddin & Normaniza 2016, Leung et al. 2018), in further studies.

CONCLUSIONS

Some native Caribbean riparian species can be used in the development of soil bioengineering. Among the 31 selected species, the asexual propagation of three herbaceous plants, five shrubs and three tree species was compatible with the cost constraints typical of soil bioengineering projects. This first study conducted over a short period on few repetitions permitted the acquisition of valuable result for follow-up scientific and applied works. Further investigation concerning both asexual and sexual propagation of riparian species is planned to enhance the development of soil bioengineering with native species in Guadeloupe and in the Caribbean at large.

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Figure legends

Figure 1- Geographical location of the Guadeloupe archipelago, (Geoportail 2017)

Figure 2- Shadehouse installation of the cutting experiment

Figure 3- Leaf emission on cuttings of selected species.

Figure 4- Root system of resprouting cuttings. Photographs were taken 3 months after plantation for *D. seguine, P. mimosoides, P. dilatatum*, *P. dussii, T. reticulata, C.spinosum* and *C. cymosa* and 3 weeks after plantation for *C. hirta, L. hyssopifolia* and *H. amplexicaulis*. Bars represent a 1 cm scale.

Figure 1

Figure 2

Figure 3


A. inermis
A. glabra
C. pentadra
C. cymosa
C. icaco
C. argenteum
C. spinosum
C. hirta
C. coloccoca
C. sulcata
D. seguine
H. courbaril
H. racemosum
I. ingoides
I. laurina
L. heptaphyllus
L. roseus
L. hyssopifolia
M. nobilis
P. mimosoides
P. dilatatum
P. dussii
P.officinalis
S. dentata
T. heterophylla

Figure 4

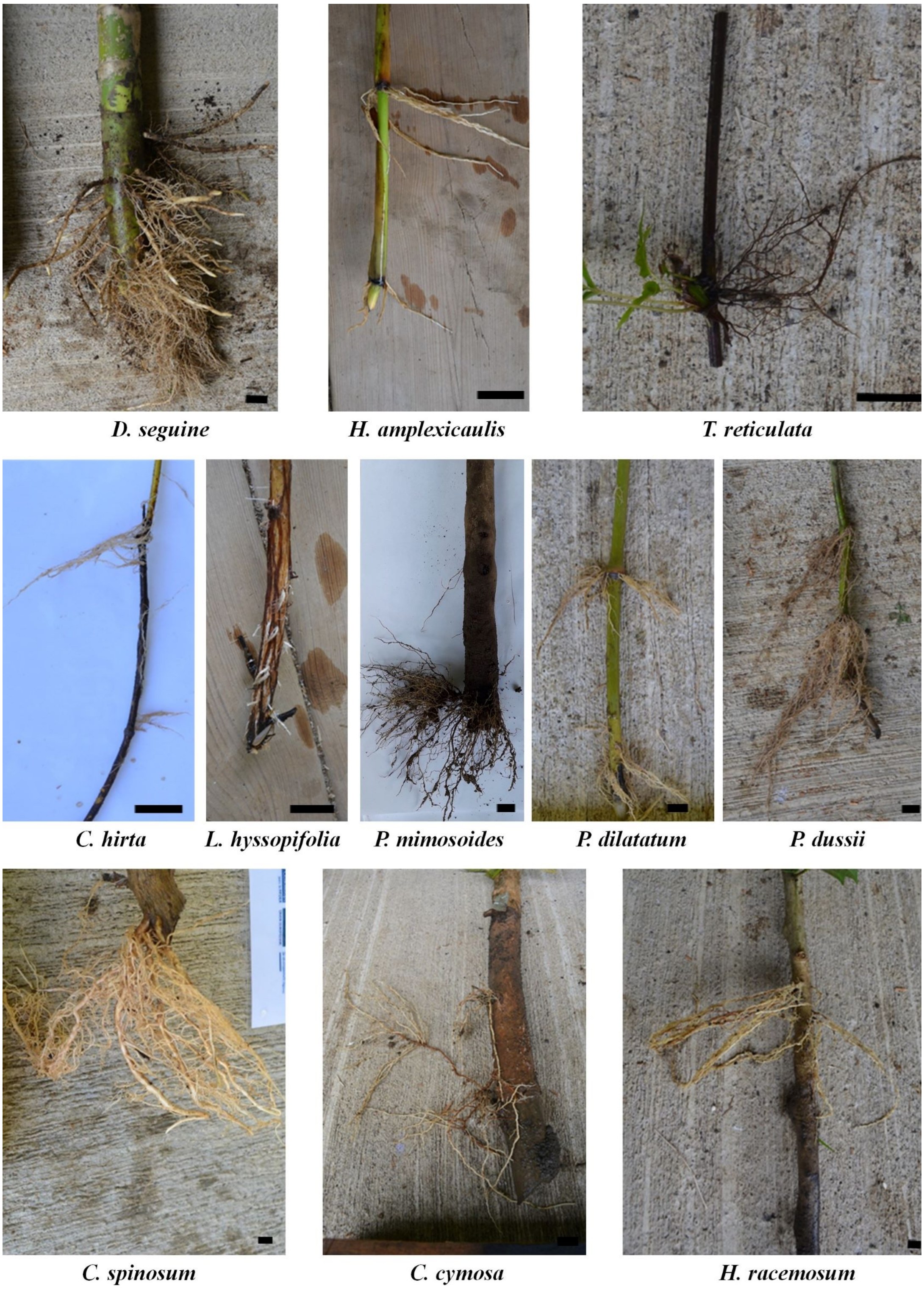
D. seguine
H. amplexicaulis
T. reticulata
C. hirta
L. hyssopifolia
P. mimosoides
P. dilatatum
P. dussii
C. spinosum
C. cymosa
H. racemosum

Table1 Selected species with bibliographic references on their vegetative propagation.

Species	Type	Part considered	Method	Result	Reference
Andira inermis (W. Wright) Kunth ex DC.	Tree	Not mentioned	Under bell	Positive	Jacques et al. 1847
Annona glabra L.	Tree	Stems from juvenile	In vitro	Positive	Deccetti et al. 2005
Ceiba pentandra (L.) Gaertn.	Tree	Orthotropic stems	Not mentioned	Positive	Louppe & Oteng-Amoako 2008
Chimarrhis cymosa Jacq.	Tree	-	-	-	-
Chrysobalanus icaco L.	Shrub	Stems	Hormonal induction	Positive	Hernández et al. 1999
Chrysophyllum argenteum Jacq.	Tree	Not mentioned	Not mentioned	Positive	Noisette 1826
	Tree	Stems	Under bell	Positive	Planchon 1888
Citharexylum spinosum L.	Tree	Stems	Cuttings	Positive	Díaz 2001
Clidemia hirta (L.) D. Don	Shrub	-	-	-	-

Cordia collococa Aubl.	Tree	-	-	-	-
Cordia sulcata DC.	Tree	-	-	-	-
Dieffenbachia seguine (Jacq.) Schott	Herb	-	-	-	-
Ficus citrifolia Mill.	Tree	Stems	Not mentioned	Positive	Bastien 1804
	Tree	Stems	Not mentioned	Positive	Martin 2010
	Tree	Stems	Hormonal induction	Negative	dos Santos et al. 2011
Homalium racemosum Jacq.	Tree	-	-	-	-
Hymenachne amplexicaulis (Rudge) Nees	Herb	Stems	Natural conditions	Positive	Sellers et al. 2008
Hymenaea courbaril L.	Tree	Stem cuttings from juvenile	Hormonal induction	Negative	Pereira et al. 2017
	Tree	Leaf	Hormonal induction	Positive	Thirunavoukkarasu et al. 2004

Inga ingoides (Rich.) Willd.	Tree	Stems	Natural conditions	Negative	Solicaz 2015
Inga laurina (Sw.) Willd.	Tree	Stems	Hormonal induction	Positive	Rios et al. 2001
	Tree	Stems	Hormonal induction	Negative	daSilva 1998
Ischnosiphon arouma (Aubl.) Körn.	Herb	-	-	-	-
Lonchocarpus heptaphyllus (Poir.) DC.	Tree	-	-	-	-
Lonchocarpus roseus (Mill.) DC.	Tree	-	-	-	-
Ludwigia hyssopifolia (G. Don) Exell	Shrub	-	-	-	-
Margaritaria nobilis L. f.	Tree	-	-	-	-
Montrichardia arborescens (L.) Schott	Herb	-	-	-	-

Phyllanthus mimosoides Sw.	Shrub	Stems	Under bell	Positive	Audot 1867
Piper dilatatum Rich.	Shrub	-	-	-	-
Piper dussii C. DC.	Shrub	-	-	-	-
Pterocarpus officinalis Jacq.	Tree	-	-	-	-
Rhizophora mangle L.	Tree	-	-	-	-
Sloanea dentata L.	Tree	-	-	-	-
Tabebuia heterophylla (DC.) Britton	Tree	Stems	Hormonal induction	Positive	Huc & Bariteau 1987
	Tree	Stems	Propagation chamber	Positive	Awang 2012
Thelypteris reticulata (L.) Proctor	Herb	-	-	-	-

Table 2- Percentage of rooted cuttings for the 10 successful selected species; for each species, mean height and ecological type following Fournet 2002 and Rollet et al. 2010 are indicated (S: Swamp forest, C: Coastal forest, D: Dry forest, SE: Seasonal evergreen forest, R: Rainforest).

Species	% of rooted cuttings	Mean height (m)	Helophyte	S	C	D	SE	R
Chimarrhis cymosa Jacq.	50	15	-	-	-	-	x	x
Citharexylum spinosum L.	50	8	-	-	-	x	-	-
Clidemia hirta (L.) D. Don	100	1	-	-	-	-	x	x
Dieffenbachia seguine (Jacq.) Schott	100	1.5	x	x	x	-	x	-
Homalium racemosum Jacq.	50	15	-	-	-	x	x	x
Hymenachne amplexicaulis (Rudge) Nees	100	1.5	x	x	-	-	x	-
Ludwigia hyssopifolia (G. Don) Exell	100	1.5	x	x	-	-	x	-
Piper dilatatum Rich.	25	2	-	-	-	x	x	x
Piper dussii C. DC.	50	2	-	-	-	x	x	-
Phyllanthus mimosoides Sw.	25	1.5	-	x	-	-	x	x
Thelypteris reticulata (L.) Proctor	75	1	-	-	-	-	x	x