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Restoration of forest landscapes and contribution of local species to the resilience of ecosystems in reforestation in the Kouibly department in Côte d'Ivoire

Gnagbo Anthelme*[1], Egnankou Wadja Mathieu[2], Koffi Adjoua Bénédicte[3], Adou Yao Constant Yves[2]

[1] *Department of Agroforestry, Jean Lorougnon Guédé University, Daloa, Ivory Coast*

[2] *Department of Biosciences, Félix Houphouet-Boigny University, Abidjan, Ivory Coast*

[3] *Department of Plant Biology, Péléforo University Gbon Coulibaly, Korhogo, Ivory Coast*

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Abstract

The restoration of forest landscapes is a response to forest degradation caused by deforestation, excessive logging, fires and climate change. Ecological restoration then becomes an essential complement to the conservation of ecosystems. In Côte d'Ivoire, land pressures and population migrations in the central-western region have fragmented the last forests. This degradation threatens the integrity of ecosystems, reducing agricultural yields and increasing the vulnerability of farming families. To restore this local biodiversity, this study proposes a reforestation policy aimed at recreating habitats to strengthen the resilience of ecosystems. In the villages studied, plants were distributed to farmers for planting. Plant monitoring includes georeferencing and recording plant vigor and heights quarterly. Over the entire study, 27 farmers made 192.24 hectares available for reforestation. *Terminalia ivorensis* and *Terminalia superba* have the highest survival rates, followed by *Irvingia gabonensis*. Low survival rates of some species, such as *Ricinodendron heudelotii*, are due to unfavorable climatic and phytosanitary conditions. The fastest growth is observed in *Irvingia gabonensis* and *Ricinodendron heudelotii*. Reforestation policies must favor the most resilient, locally adapted species, then include phytosanitary measures for vulnerable species. Permanent monitoring is essential in order to adjust management practices according to observations, health, and climatic conditions.

* **Corresponding Author:** Gnagbo Anthelme ✉ agnagbo@gmail.com

Introduction

Forest landscape restoration is a holistic approach aimed at restoring the health, biodiversity and ecological functions of degraded forests while providing social and economic benefits to local communities (Chazdon *et al.*, 2016). It is a response to forest degradation caused by factors such as deforestation, excessive logging, forest fires and climate change. In a global context of ever-increasing anthropogenic disturbance of natural and semi-natural ecosystems, the sole conservation of these ecosystems is no longer enough. Ecological restoration is therefore an essential complement to conservation (Cristofoli and Mahy, 2010). The restoration of forest landscapes can include forest rehabilitation actions, such as plantations, assisted natural regeneration, or water and soil management. It is a long-term evolutionary process which involves adaptations according to social changes, in the perception of actors, demographic, institutional or relating to environmental conditions (Guizol *et al.*, 2022).

In Côte d'Ivoire, land pressures have led to large-scale population migration movements, mainly in the central-western region of the country. The weakness of Ivorian forest management structures linked to the difficult socio-political situation leads to an extension of cultivated areas as well as a fragmentation of the last remaining forests (Yao-Kouassi *et al.*, 2023). The Kouibly department, once one of the most wooded regions, finds itself seriously affected by a significant loss of its forest cover. Extensive cultivation is exacerbated by the massive arrival of non-native populations due to the post-electoral crisis of 2011 (Kassoum, 2018). Forests are found to be very degraded by the rise of export crops. This loss of tree cover threatens the structural and functional integrity of ecosystems marked by a drying of the water table as well as an impoverishment of agricultural land (Assale *et al.*, 2016). This results in a significant loss of agricultural yields, further weakening farming families who suffer a drastic drop in their income. As a result, communities experience food shortages, fall victim to tropical diseases and bear the effects of climate disruption.

It is therefore appropriate to identify a perspective for restoring local biodiversity. This will make it possible to recreate habitats for local fauna and flora in order to strengthen the resilience of ecosystems. This will ultimately involve contributing to climate regulation, water purification, and prevention of soil erosion, carbon sequestration and improvement of the livelihoods of populations in forest products. The objective of this study is therefore to rehabilitate the different habitats in rural areas through a reforestation policy.

Material and methods

Study site

Kouibly is a department located in the Guémon region, in the west of Côte d'Ivoire. Kouibly's economy is mainly based on agriculture. The plantations are dominated by crops of *Theobroma cacao* L., *Hevea brasiliensis* (A. Juss.) Müll.Arg., *Coffea canephora* Pierre ex A.Froehner, as well as various food crops such as *Oryza sativa* L. and *Musa* × *paradisiaca* L., *Manihot esculenta* Crantz. The Kouibly department is largely covered by dense and humid forests, typical of tropical regions. These forests are home to a rich and varied flora with precious species like *Khaya ivorensis* A. Chev., *Tectona grandis* Lf., Useful *Entandrophragma utile* (Dawe & Sprague) Sprague, *Terminalia superb* Engl. & Diels, *Terminalia ivorensis* A.Chev., *Milicia excelsa* (Welw.) CC Berg. The villages of Makaïbly, Pombly, Ouyably-Gnondrou, Koulayéré, Taobly were visited as part of this study.

Preparation and establishment of plantations

Four villages have been identified for the establishment of nurseries. They are Makaïbly, Pombly, Ouyably-Gnondrou, Koulayéré and Taobly. The different species put in the nursery are *Ricinodendron heudelotii*, *Irvingia gabonensis*, *Terminalia ivorensis*, *Terminalia superba*, *Mansonia altissima*, *Tieghemella heckelii*, *Khaya ivorensis*, *Picralima nitida*. These plants were distributed to farmers for planting in previously identified plots.

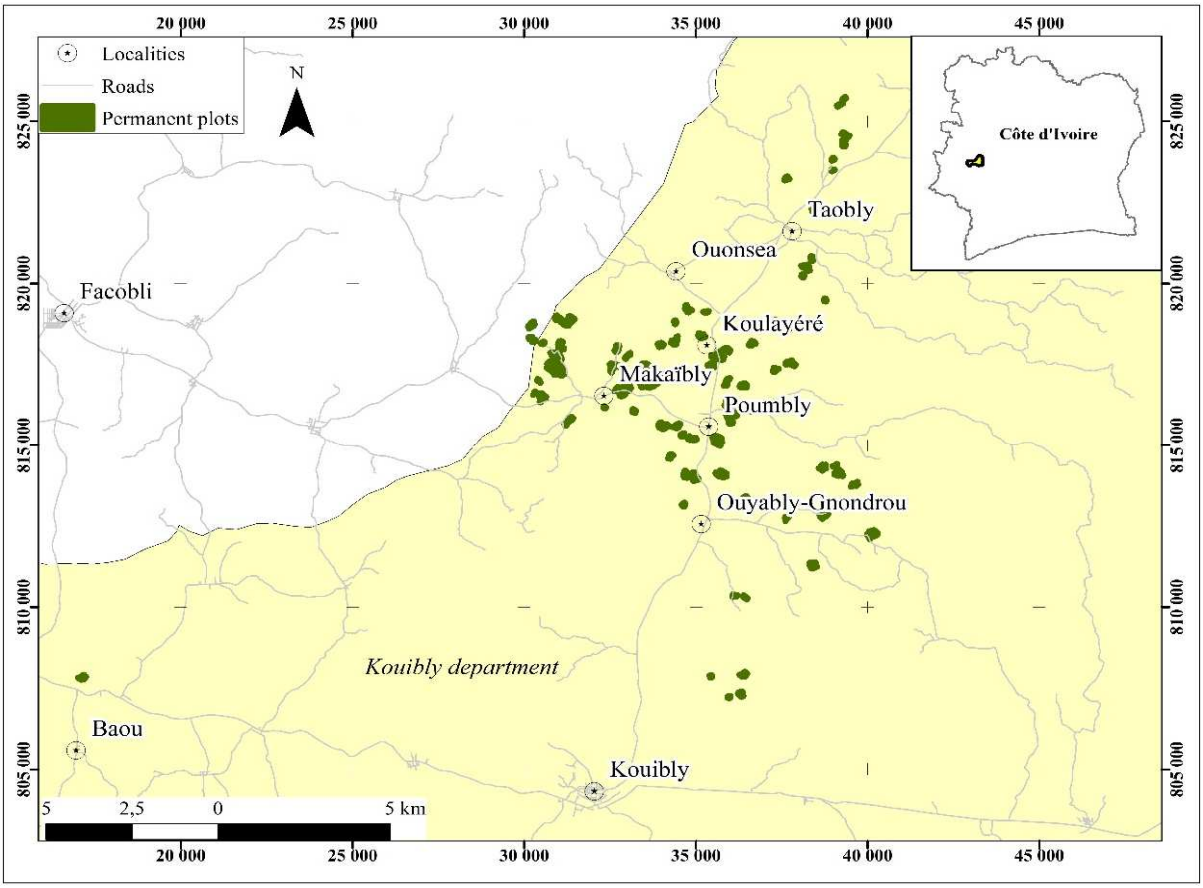

Fig. 1. System of permanent reforestation plots.

These are plantations of food crops, industrial crops and fallows. For the planting of nurseries, 7 localities were selected for the establishment of permanent reforestation and reforestation plots. They are Ouyably-Gnondrou, Makaïbly, Pombly, Koulayéré, Taobly, Ouonséa and Baou. In these different villages, farmers were invited to propose plots for reforestation or fallow reforestation. A team was also formed to monitor these plots.

Monitoring of plants and reforestation plots

A permanent plot monitoring team was formed to monitor the planted plants. These are agents designated within local committees in charge of environmental conservation. The plots are georeferenced and the contours digitized before planting the nurseries. For each plant planted, the species is identified, georeferenced and the date is recorded. Once a quarter, the plant's vigor is checked and its height recorded. Dead feet are reported and georeferenced. The survival rate of plants in reforestation is then calculated and interpreted as follows (Evans, 2009).

Survival rate = {(Number of surviving plants)/(Initial number of plants)}×100

A high survival rate (80-100%) indicates good planting success, with little plant mortality. When the survival rate is average (50-79%), this indicates moderate success, but may require analysis of factors affecting survival to improve outcomes. A low survival rate (<50%) indicates a significant problem with planting conditions or post-planting care, requiring intervention to identify and correct problems.

Comparison tests were carried out after checking the normality of the data was verified using the Kolmogorov Smirnov test (Ferignac, 1962).

Analyzes of variance (ANOVA) and Tukey HSD tests with 95% confidence interval (Cuevas *et al.*, 2004) were carried out to compare survival rates and then plant heights between the different biotopes.

Result

In the study area, 27 farmers spread across all 7 project localities made their plots available. The cartographic data shows a total area of 192.24 hectares distributed between 67 permanent plots. The areas recorded for these permanent plots vary between 0.03 and 6.48 hectares (Fig. 1). Out of all planting activities, 82,384 plants were planted between July 2022 and March 2024. These are *Ricinodendron heudelotii*, *Irvingia gabonensis*, *Terminalia ivorensis*, *Terminalia superba*, *Mansonia altissima*, *Tieghemella heckelii*, *Khaya ivorensis*, *Picralima nitida*. The following Table 1 presents the data collected for these different tree species planted in the Kouibly department.

Terminalia ivorensis and *Terminalia superba* present the highest values of individuals placed in the ground. These are the most common species in the different biotopes of the study area and which were the easiest to maintain in the nursery. However, *Terminalia ivorensis* with 85.10 pc, *Irvingia gabonensis* with 83.38 pc and *Terminalia superba* with 82.25 pc have the highest survival rates. These plants are adapted to the microenvironments of the study area. These are plots of food crops, industrial crops and fallow land. *Mansonia altissima*, *Tieghemella heckelii*, *Khaya ivorensis* and *Picralima nitida* show intermediate survival rates. Field investigations revealed that the planting of these species coincided with an absence of rain. The plants already produced were planted from September 2022. This period was marked by poor or even absence of precipitation in the localities concerned. As for *Ricinodendron heudelotii*, the low survival value observed is linked to a phytopathology observed on the plants planted. On all permanent plots, *Ricinodendron heudelotii* plants were affected by a fungal disease which withers the leaves until the affected plant dies.

Table 1. Monitoring of species planted in rural areas in Kouibly.

Species	Area (ha)	Number of plants	Density (individual /ha)	Surviving plants	Survival rate (%)
Ricinodendron heudelotii	46	12,090	262.83	4,188	34.64
Irvingia gabonensis	39	12,330	316.15	10,281	83.38
Terminalia ivorensis	46	20,080	436.52	17,089	85.10
Terminalia superba	54	20,300	375.93	16,697	82.25
Mansonia altissima	23	10,684	464.52	6,585	61.63
Tieghemella heckelii	12	5,300	441.67	3,000	56.60
Khaya ivorensis	10	1,100	110.00	780	70.91
Picralima nitida	8	500	62.50	289	57.80

Across all the biotopes observed, the survival rates between permanent plots of industrial crops, crops and fallows present significant differences ($F = 268.699$; $p < 0.0001$). The industrial crop plots are mainly fields of *Theobroma cacao* with 22 permanent plots, *Coffea canephora* and *Anacardium occidentale* are each observed on one plot. An average survival rate of 85.08±5.99 pc observed is the highest on these permanent plots of industrial crops. This is the biotope with the highest survival rate value across all permanent plots. These plots are followed by permanent plots placed in food crop fields. These are plots of monocultures or mixed cultures of *Manihot esculenta*, *Musa* x *paradisiaca*, *Phaseolus vulgaris*, *Dioscorea esculenta*, *Colocasia esculenta*, *Xanthosoma maffafa*, *Capsicum annuum*. This type of biotope has an average survival rate of 65.35±8.69 pc for the species placed in the ground. The biotopes which have the lowest average survival rates are fallows made up of old plantations and relics of highly degraded forests. The average survival rate observed is 37.50±7.07 pc for all species placed in the ground.

On all the permanent plots, 5 height measurement sessions were carried out during the study for the different plants (Fig. 2). Growth trends vary depending on the species planted. The different average heights of the plants at the time of planting were not taken into account. From 6 months,

Ricinodendron heudelotii shows a regular average increase in size from 82 cm to 213 cm at 18 months. A notable acceleration is observed between 12 and 15 months during the rainy season. *Irvingia gabonensis* shows a consistent growth trend similar to *Ricinodendron heudelotii*, starting at 88 cm and reaching 268 cm at 18 months, with significant growth observed after 12 months also in the rainy season. The other species have moderate growth.

The highest growth rates are therefore observed in *Irvingia gabonensis* and *Ricinodendron heudelotii*. These two species reach more than 2 meters in height in 18 months. On several permanent plots of land in the villages of Makaïbly, Ouyably-Gnondrou, Pombly, and Koulayéré, individuals over 5 meters high are observed. Next, *Terminalia ivorensis*, *Terminalia superba* and *Tieghemella heckelii* exhibit moderate growth rates, reaching approximately 100-130 cm at 18 months. Finally, *Mansonia altissima*, *Khaya ivorensis* and *Picralima nitida* exhibit slower growth rates, with heights between 82 cm and 98 cm at 18 months.

Discussion

This study carried out in the Kouibly region provides essential information on the growth and survival of different tree species over a period of 18 months. Distinct growth trends and survival rates are observed. This suggests differences in the levels of adaptation and resilience of species in different reforested biotopes. The data analysis method was preceded by extraction of outliers. These are values that are significantly lower or higher than the data usually reported. The work of Van Eslande (2016) on the characterization of the ecosystem services of grasslands in France also carried out an extraction of aberrant data.

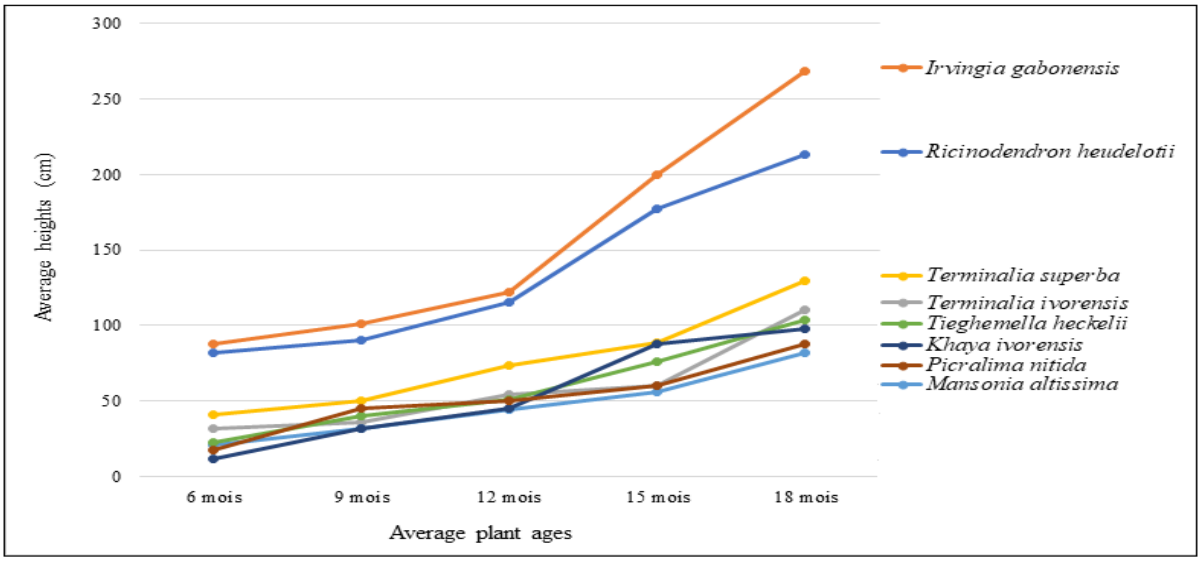

Fig. 2. Monitoring plant growth in permanent plots.

The appearance of reforested areas varies widely. These include fallow land, perennial crops, annual food crops, crop mosaics as well as a community forest. Two reforestation techniques are observed on these different plots. A type of reforestation on perpendicular lines is observed with spacings between plants varying from 3 to 5 meters. The second type of reforestation is carried out without alignments with gaps varying between 3 and 10 meters. In cocoa plots, the plants are either introduced only in the thinned areas, or reforested within the cocoa plantation. These spaces have a high level of maintenance. However, this type of reforestation poses the problem of the sustainability of the replanted plants. For megaphanerophytes approximately 3 meters apart, thinning is necessary in the population of plants planted in the ground. According to the work of Calvet *et al.* (1997) discount rates, namely thinning periods and levels, directly impact silvicultural production. It is illusory to want at all costs to cover

the soil as quickly as possible with dense planting, even if it means thinning out afterwards (Ferlin, 1981). For this author, the competition between trees for the water available in the soil is then too intense, and their development is strongly affected. From the start, it is therefore desirable to provide a large volume of soil to the plants through large spacings. This will result in a smaller number of vigorous plants per hectare which will grow much more quickly. Farmers will be forced to remove reforested trees by having a good agroforestry type plantation. Reforestation with reduced spacing is inappropriate in agroforestry plantations.

Concerning the growth dynamics of the species, *Ricinodendron heudelotii* and *Irvingia gabonensis* have the highest growth rates. *Terminalia ivorensis* and *Terminalia superba* also showed significant growth, reaching approximately 130 cm in height at 18 months. Their adaptability and ease of maintenance in nurseries have contributed to their widespread use in the reforestation project. *Mansonia altissima*, *Tieghemella heckelii*, *Khaya ivorensis* and *Picralima nitida* exhibit the slowest growth rates, reaching heights between 82 cm and 98 cm tall at 18 months. The poor growth of these plants could be linked to a lack of adaptation to the local environment. For Cheptou (2020) local biodiversity is a moving balance in which the most resilient species integrate into the biotope. In the context of this study, slow-growing species could encounter difficulties adapting to the local ecosystem. The rapid growth of *Irvingia gabonensis* and *Ricinodendron heudelotii* is consistent with the conclusions of the work of Leakey *et al.* (2017), who noted the potential of these species for agroforestry due to their rapid growth and economic value. Previous studies (Hall and Swaine, 1976; Bosu *et al.*, 2006) have also highlighted the moderate growth rates of *Terminalia* spp. in the tropical forests of West Africa.

Terminalia ivorensis, *Irvingia gabonensis* and *Terminalia superba* also exhibited the highest survival rates, indicating their strong adaptation to the microenvironments of the study area. *Mansonia altissima*, *Tieghemella heckelii*, *Khaya ivorensis* and *Picralima nitida* had intermediate survival rates due to dry conditions during the initial planting phase. *Ricinodendron heudelotii* showed the lowest survival rate due to a fungal disease affecting the plants. This highlights the importance of phytopathological monitoring in reforestation projects.

The high survival rates in *Terminalia ivorensis* and *Terminalia superba* are confirmed by studies such as those of Kainer *et al.* (2006), which highlight the resilience and adaptability of these species to tropical climates. Disease stresses on *Ricinodendron heudelotii* imply the need for health management of reforestation in accordance with the work of Tchoundjeu *et al.* (2006) on the implementation of participatory domestication in West Africa. These significant differences also observed in the survival rates between the different biotopes underline the importance of the choice of site and environmental conditions, as reported by Lamb *et al.* (2005) in their study on reforestation practices in degraded lands.

Conclusion

The study on the agroecological characteristics and performance of species planted in permanent reforestation plots in the Kouibly department highlights significant results on the survival and growth of different tree species. The 27 farmers involved in the 7 localities of the project contributed to the planting of 82,384 plants spread over 192.24 hectares, demonstrating active community participation in reforestation efforts.

Terminalia species *ivorensis* and *Terminalia superba* stand out for their high survival rates of 85.10% and 82.25%, respectively, reflecting their optimal adaptation to the microenvironments of the study area. Likewise, *Irvingia gabonensis* displays a notable survival rate of 83.38%. These results indicate that these species are particularly well adapted to local agroecological conditions, including food crop, industrial and fallow plots. Species like *Mansonia altissima*, *Tieghemella heckelii*, *Khaya ivorensis* and *Picralima nitida* exhibit intermediate survival rates,

influenced by factors such as unfavorable climatic conditions at the time of planting. *Ricinodendron heudelotii*, despite its rapid growth, was affected by a fungal disease, which significantly reduced its survival rate to 34.64%. *Irvingia gabonensis* and *Ricinodendron heudelotii* are distinguished by their rapid growth rates, reaching more than 2 meters in height in 18 months, with individuals even exceeding 5 meters in some plots. *Terminalia ivorensis*, *Terminalia superba* and *Tieghemella heckelii* show moderate growth, while *Mansonia altissima*, *Khaya ivorensis* and *Picralima nitida* grow more slowly, not exceeding 1 meter in 18 months.

Recommendation(S)

This study suggests different recommendations to optimize reforestation efforts in similar areas. In the selection of species, priority must be given to planting *Terminalia ivorensis*, *Terminalia superba* and *Irvingia gabonensis* in future reforestation initiatives due to their high survival rates and rapid growth. Reforestation policies should consider phytosanitary measures for vulnerable species such as *Ricinodendron heudelotii* to improve survival rates. It is also important to have permanent monitoring of the growth and survival of plants while adapting management practices according to climatic conditions and field observations.

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