



Summary and images of the result of the study “Enrichment planting of teak (*Tectona grandis* L.f.) in degraded deciduous dipterocarp forests” after 10 years and predicted for up to 15 years in tropical highlands of Viet Nam

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1) Introduction

The Deciduous Dipterocarp Forest (DDF) is a unique forest ecosystem in the tropical highlands, Viet Nam. DDFs grow in extreme ecological environmental conditions such as high temperature, drought, and forest fire in the dry season, with low rainfall, and waterlogging in the rainy season. Soil is variable, with a lot of sand or clay or a lot of gravel that makes it difficult to cultivate. Under such conditions, only tree species belonging to the Dipterocarpaceae family can grow, develop, and form DDF, helping to balance the ecological environment, such as water retention, soil improvement, and biodiversity conservation. In particular, species belonging to Dipterocarpaceae have a high carbon sequestration capacity, which has the potential to provide carbon-accumulating forest environmental services to mitigate climate change.

However, in the last few decades, the dipterocarp forest has been degraded by over-logging, and the forest has been no longer capable of creating an economy from wood. Next, in favor of the economy, hundreds of thousands of hectares of dipterocarp forests were converted to industrial crops such as cashew, rubber, and acacia hybrids with the expectation of high income. Consequently, these industrial plants have been not suitable for the extreme ecological environment of the dipterocarp forest and are being cut down.

Teak is a valuable wood species in the domestic and international markets for many uses. The teak tree has been introduced into experimental planting in Viet Nam for more than 70 years, but this study is the first time the teak is introduced to enrich degraded deciduous dipterocarp forests. The research idea was based on ecological simulation, as natural teak is observed living in dipterocarp forests, bamboo forests, and semi-deciduous arid forests in Thailand and Myanmar.

The objectives of this study are to rehabilitate the remaining degraded dipterocarp forest areas, restore specific forest ecosystems, rehabilitate environmental ecological functions, and biodiversity,

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increase carbon sequestration, and at the same time provide additional economic value from teak trees planted when the degraded DDFs are depleted of wood.

The study "Enrichment planting of teak in degraded deciduous dipterocarp forests" started in 2011 and ended in 2014 (after 3-4 years of trial planting), and was a research project managed and funded by Dak Lak province government. The end was to comply with the regulations on the implementation of the provincial research project.

The methods of enriching degraded deciduous dipterocarp forests by teak that have been studied are summarized below:

- The degraded DDFs were studied and enriched with the following characteristics: The stand volume (M) ranged from 5 to 110 m³ha⁻¹, the stand density (N) of DDFs greater than 10 cm in diameter at breast height (DBH) ranged from 50 to 600 trees ha⁻¹, concentrated trees at small diameter (<25 cm). The forests were sparse with many gaps in the forest canopy. The remaining natural trees were of poor quality. The dominant species includes one or two species as follows *Dipterocarpus tuberculatus* Roxb., *Terminalia chebula* Retz., *Pentacme siamensis* (Miq.) Kurz, *Shorea obtusa* Wall. ex Blume, *Dipterocarpus obtusifolius* Teijsm. ex Miq., *Xylia xylocarpa* (Roxb.) Taub. and *Lagerstroemia calyculata* Kurz.
- Plant teak in the gaps of the forest canopy, the diameter of the gap for one planted teak tree was approximately 6 m. In large gaps, many teak trees were planted, with teak trees planted 3 m apart and natural dipterocarp trees 3 m apart. The density of teak planting ranges from 100 to 600 trees ha⁻¹ depending on the density of the DDFs (Figure 1)

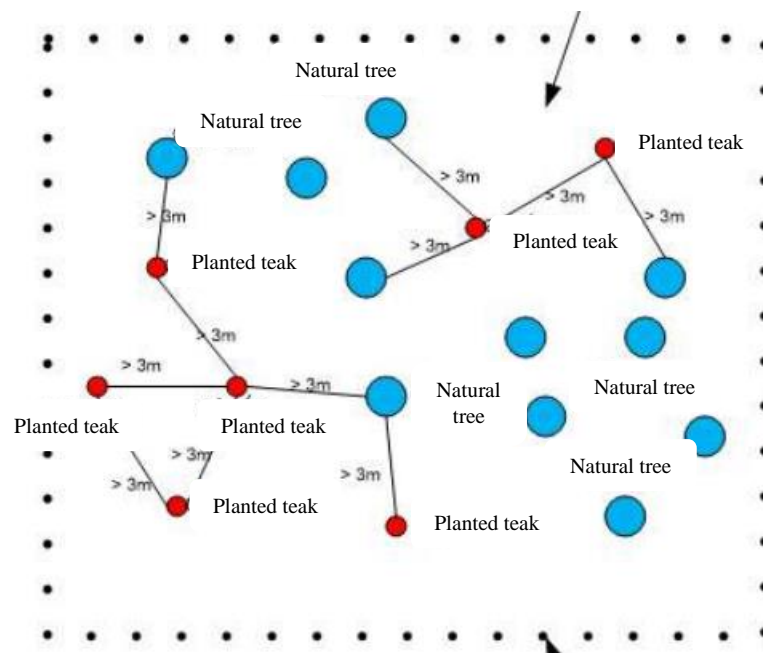


Figure 1: Diagram of planting teak in the gaps of the forest canopy to enrich degraded deciduous dipterocarp forest

42 experimental plots were established for the enrichment of degraded DDFs with teak. Each plot had an area of 4,900 m² (70 × 70 m). The experimental plots were arranged along with the gradients of ecological environmental factors in degraded DDFs. Mainly according to the change in soil characteristics and forest status. Climate and topographical factors are quite uniform. The trial plots were located in the districts of Buon Don, Ea Soup and Ea HLeo, Dak Lak province, Viet Nam.

At the end of the study in 2014, teak planted in the initial growth stage, 3-4 years old, could not fully assess the adaptability of planted teak such as growth ability, as well as the recovery potential of the degraded DDF ecosystem. Therefore, after the end of the project, the project leader continued to monitor and measure the experimental plots until 10 years of age. Below is the information on research results up to age 10 and projections up to a rotation cycle of 15 years for a small-diameter teak purpose.

2) Results after 10 years of experimental planting of teak to enrich degraded deciduous dipterocarp forest

By 2022, the experimental plots of enrichment planting of teak in degraded DDFs were 10 years old, measured on the experimental plots in areas that were suitable to teak, and summarized as follows:

- Measurement location: Experimental plots (6 plots) in Anh Duong Company, Buon Don District, Dak Lak Province, Viet Nam.
- Time of measurement: November 2022
- The ecological environmental conditions of the degraded DDFs were suitable for teak planting: Teak has different levels of suitability or is not suitable in the ecological gradients of the degraded DDFs; especially changes in soil characteristics. After 10 years of follow-up, it shows that teak suits the ecological environmental conditions of degraded DDFs as follows:
 - Forest soils are suitable for teak:
 - ✓ Soil color: Using Munsell's (1994) soil color chart, it is shown that teak adapted to soil color notation: 7.5YR 7/6, reddish yellow soil (Figure 2)
 - ✓ Soil physics: The soil has a gravel ratio of 55 - 70%, a sand ratio of 20 - 40%
 - ✓ Soil chemistry: P₂O₅ = 5 – 11 mg/100 g of soil, K₂O = 8 - 11 mg/100 g of soil, Ca = 6 - 10 meq/100 g of soil.
 - ✓ Drainage soil and soil are not waterlogged in the rainy season.
 - Degraded DDFs status is suitable for teak: The stand volume (M) ranges from 5 - 100 m³ ha⁻¹, the density of DDF with DBH greater than 10 cm ranges from 50 - 350 trees ha⁻¹, the forest trees are mainly with diameter < 25 cm, a sparse forest with many gaps

in the forest canopy. The remaining natural wood trees are of poor quality. The dominant dipterocarp species indicative of teak adaptability include one or two species such as *Dipterocarpus tuberculatus*, *Terminalia chebula*, *Pentacme siamensis*, *Shorea obtusa*, *Xylia xylocarpa* and *Lagerstroemia calyculata* Kurz.

- Climatic factors in the distribution of DDFs are suitable for teak: Annual average temperature $T = 25^{\circ}\text{C}$, and the average annual rainfall $P = 1600 \text{ mm year}^{-1}$.
- Topography in the distribution of DDFs is suitable for teak: Flat, slightly sloping areas are very good for drainage in the rainy season; 100-400 m altitude above sea level

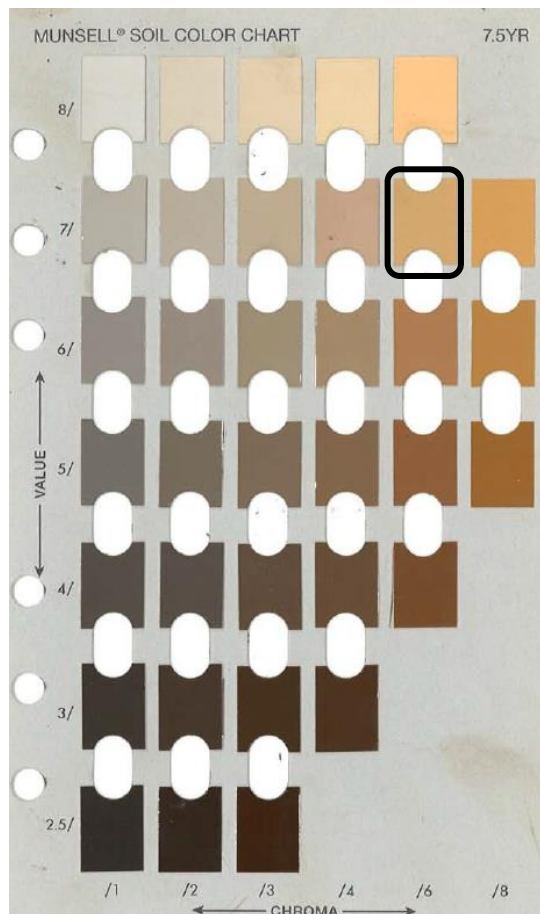


Figure 2: Munsell's (1994) soil color chart. The black frame shows the soil color of degraded deciduous dipterocarp forests adapted to teak

- Growth and increment of planted teak enriching degraded DDFs at the age of 10, in teak-adapted areas:
 - ✓ The average DBH ranged from 15 – 20 cm, the increment in DBH was 1.5 – 2.0 cm year⁻¹.
 - ✓ The average height (H) ranged from 12.0 – 14.0 m, and the increments in H was 1.2 – 1.4 m year⁻¹.

- ✓ The teak density planted was from 300 – 500 cây ha⁻¹.
- Ten-year-old planted teak has closed its canopy with natural species of the Dipterocarpaceae family, starting to restore the DDF ecosystem and creating the potential to increase economic value thanks to the high selling price of teak.

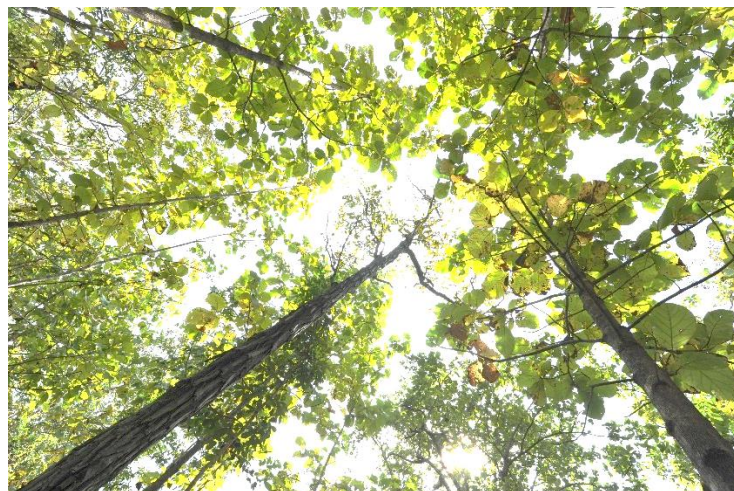
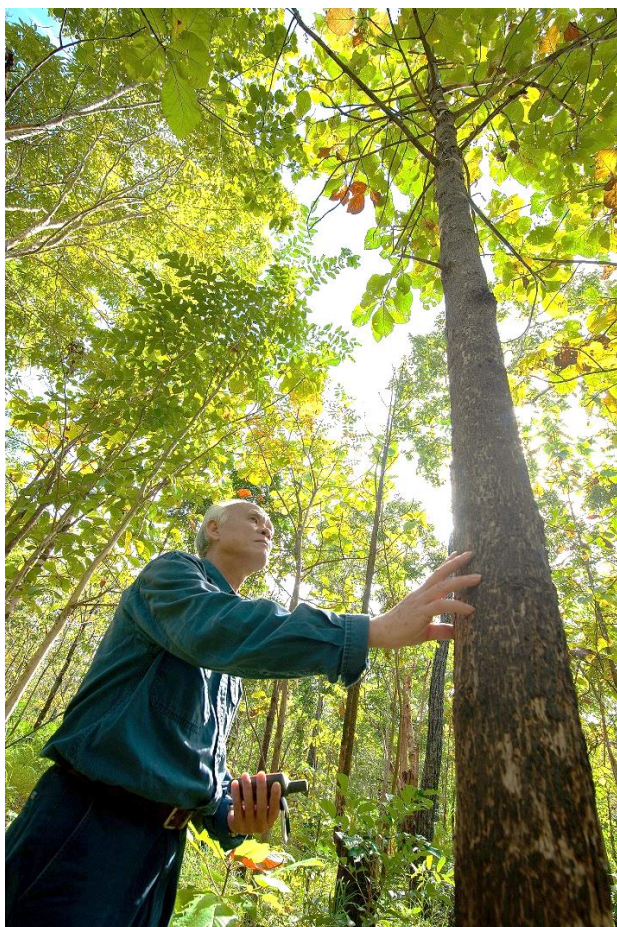
3) Predicting the eco-environmental efficiency, growth, yield and economic efficiency of teak in enrichment planting in degraded deciduous dipterocarp forests with a 15-year rotation cycle for small timber purposes in the suitable areas

From data of trial results to 10 years of enrichment planting of teak in degraded DDFs, based on peer-review publication of Huy et al. (2022)², predicting up to 15-year teak rotation cycle in the suitable areas as follows:

- Rehabilitation of the DDF ecosystem: The dipterocarp forests will restore species diversity, with the predominance of tree species belonging to the Dipterocarpaceae family along with teak trees, increase carbon accumulation by Dipterocarpaceae species and teak trees, and at the same time rehabilitate the ecological environmental functions, provide habitat for animals, especially wild elephants.
- Prediction of growth and yield of teak in the adaptive areas: It is possible to produce teak timber with a small diameter purpose (25 cm) based on enrichment planting in degraded dipterocarp forests on a 15-year rotation cycle. The expected teak growth and yield indicators are as follows: At age A = 15 years of planted teak, with a teak density that can be exploited is approximately 300 trees ha⁻¹, averaged DBH = 25.5 cm, averaged H = 17.0 m, standing teak volume M = 117 m³ ha⁻¹, annually averaged increment of DBH = 1.7 cm year⁻¹, annually averaged increment of H = 1.1 m year⁻¹, and teak annual averaged increment of M = 7.8 m³ ha⁻¹ year⁻¹; teak wood yield: 82 m³ ha⁻¹.
- Projected income from small diameter teak in a rotation cycle of 15 years after deducting all costs: 820 million VND ha⁻¹ (35,000 USD), equivalent to 55 million VND ha⁻¹ year⁻¹ (2,300 USD).
- Estimated area of degraded DDFs suitable for enrichment planting of teak: Based on GIS analysis, about 20-25% of degraded DDFs in production forests in Dak Lak province, Viet Nam are suitable for applying this study, with an area of about 15,000 - 20,000 ha.

² Huy, B., Truong, N.Q., Khiem, N.Q., Poudel, K.P., and Temesgen, H. 2022. Stand growth modeling system for planted teak (*Tectona grandis* L.f.) in tropical highlands. *Trees, Forests and People*, 9 (2022) 100308. <https://doi.org/10.1016/j.tfp.2022.100308>

4) Images of enrichment planting of teak in degraded deciduous dipterocarp forests, planted teak at the age of 10 in the suitability areas (Photos: Bao Hung, 2022)



Natural *Terminalia chebula* tree on the left – Planted teak tree on the right.

The 10-year-old teak enrichment planting has closed its canopy with natural forest species from the Dipterocarpaceae family.



After 10 years of enrichment planting of teak in degraded deciduous dipterocarp forests, the dipterocarp forest ecosystem has begun to recover its ecological environmental functions and is expected to be economically viable from high-value teak trees.



Teak planted to enrich degraded deciduous dipterocarp forest, 10 years old reaching a DBH of 15 - 20 cm



Teak planted to enrich degraded deciduous dipterocarp forest, 10 years old reaching an H of 12 - 14 m



Teak has been well adapted to the marginal gravel soil of degraded deciduous dipterocarp forest



Teak withstands annual wildfires (tree trunks leave burn marks every year).

The teak tree was suitable for the extreme environment of degraded deciduous dipterocarp forests. Teak grows well on gravel soil, withstands high temperatures, drought, and annual wildfires, tolerates low rainfall, and lives on marginal land. Currently, in the country and worldwide, no research result determines a species of native forest tree with high economic value such as teak and can withstand extreme ecological environmental conditions to enrich degraded deciduous dipterocarp forests.

With meaningful results of this study, we are calling for funding to widely apply the results in the Central Highlands, Viet Nam.

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