Adopting tree improvement into agroforestry system: a case study of introducing improved *Acacia mangium* in community-based forest in Pacitan, East Java

A Nirsatmanto*, D Kartikaningtyas, S Sunarti, T Setyaji, B R Handayani, Surip, and F Mangkuwibowo
Centre for Forest Biotechnology and Tree Improvement, Purwobinangun, DI Yogyakarta, Indonesia

*Corresponding author’s e-mail address: arifnirsatmanto@biotifor.or.id

**Abstract.** Tree improvement is a part of breeding development practices for producing genetically improved stock. Beyond the success on realizing the high productivity, products from tree improvement need some prerequisites for adopting in its operational, such as site-matching, fertilizer, spacing, monoculture and other silviculture practices, some of which are difficult to be fulfilled by the small grower under agroforestry system. As a result, the improved stocks are not commonly planted in small grower’s land. However, in supporting the development of productive agroforestry system, adopting tree improvement into agroforestry practices is necessary. This paper presents a case study of introducing the improved *Acacia mangium* in community-based forest in Pacitan, East Java. The site planting for this program was selected by considering the fact of the long history of traditional planting of *Acacias* in community-based forest in Pacitan accompanied with the increasing demand of the *Acacias* wood for home industries. The program was started at 2012 with the slogan of “planting and manage with your own available resources”. There are four main steps for achieving the goal of programs: 1) introducing improved stock through free distributing the seedling, 2) supervising and monitoring the growth and economic value, 3) establishing seed orchard, 4) autonomous on improved seed production for further replanting. After 6 years, this program revealed that while maintaining a high productivity and economic value, improved stock of *A. mangium* from tree improvement program could be successfully planted in small grower’s land under sustainable agroforestry practices with low cost of silviculture practices.

**Keywords:** productivity, small grower, economic value, silviculture

1. **Introduction**

Tree improvement is basically defined as the application of genetic principles through breeding for improving tree productivity on some important traits that subsequently increases the economic value. Forest tree improvement is applied when control of parentage is combined with other forest management activities, such as site preparation or fertilization, to improve the overall yields and quality of products from forestlands [1]. Concerning to the breeding progress on expected genetic gain and the input on forest management practices, there are two scenarios on the expected productivity of the improved stocks resulted from the tree improvement program in operational scale. First, the improved stock will produce high productivity when planting under high input on forest management.
Second, the improved stock will produce moderate productivity when planted under low input on forest management. Whatever the scenarios selected, the improved stock could be expected to produce more benefit than the unimproved stock under the same relevant level on each forest management.

Agroforestry is one of land management system which is commonly adopted by small grower. It comprises land use systems and technologies in which the woody perennials are deliberately integrated on the same land management unit with herbaceous crops and or animals in either some forms of spatial arrangement or temporal sequence [2]. Thus, the productivity measures in agroforestry would be more complex either in ecological, economic and socio-cultural aspect.

The uses of productive tree species are necessary to increase the benefit of land uses under agroforestry practices. Beyond the success on realizing high productivity, improved stocks resulted from tree improvement often need some prerequisites for adopting in its operation, such as site-matching, fertilizer, spacing, monoculture and other silviculture practices, some of which might be difficult to be fulfilled by the small grower under agroforestry system. As a result, the improved stocks are not commonly planted in small grower’s land. However, in supporting the development of productive agroforestry system, adopting tree improvement into agroforestry practices is necessary. [3] stated that highly selected planting stocks without best practice silviculture is waste of money and a significant loss in potential; poor silviculture will dictate returns. Therefore, it is important to find out a compromised way in incorporating the planting requirements of improved stocks resulted from tree improvement program with the resources available belong to small grower under existing agroforestry practices.

In 2012, Centre for Biotechnology and Tree Improvement (CFBTI) has set up a program for deploying genetically improved seed for helping the farmer to be familiar with improved seed of tree species. The slogan of “planting and manage with your own available resources” was created in this program to attract the farmer for planting the improved stocks without any worries in a high-input cost of planting management. The planted species is *Acacia mangium* from second-generation of breeding conducted by CFBTI. The site planting for this program is in Pacitan Regency that was selected due to its long history on traditional planting of *Acacias* in community-based forest in this site accompanied with the increasing demand of the *Acacias* wood for home industries. After six years, the program has provided some results and success indicators in the implementation.

This paper presents detailed information of the program and a review of the progress in adopting the tree improvement into agroforestry system as a case study of introducing the improved *A. mangium* in community-based forest in Pacitan, East Java. The paper covers a conceptual framework of the program, the implementation, and growth performance of main tree species after six years, including the potential benefit and economic value. The results of study can be useful as an example in supporting the increases benefit of land uses under sustainable agroforestry and tree improvement practices.

2. Methodology

2.1. Description of the study area

Pacitan is a regency located in southwest East Java Province between 7°55’ to 8°17’ longitude and 110°55’ to 111°25’ latitude, with total area at around 1,389 Km² covering 12 districts (Figure 1).
Generally, the lands in Pacitan are dominated by calcium rich soil, particularly in the southern regions, and fertile soil in the northern region. More than 62% of the land topography are laid out in the hilly and rocky mountainous as a part of the Thousand Mountains (>31% slope). The soil types consist of Red Mediterranean Soil with Lithosols Association, Volcanic Tuff compounds Lithosols, Reddish complexes Lithosols and Grey Alluvial, contain many potential minerals (https://en.wikipedia.org/wiki/Pacitan_Regency). The climate of Pacitan is humid tropical with average annual rainfall around 2300 mm/year and temperature of 27°C [4].

The sites of planting for this study are allocated in three separate villages: Wonogondo, Katepung and Pringkuku. The first two sites are adjacent at Kebonagung district with average monthly rainfall of 337 mm. While the last site is distant at Pringkuku district, about 30 km away from Kebonagung, with average monthly rainfall of 236 mm.

2.2. The conceptual framework
The conceptual framework of this study is developed under some considerations of adopting tree improvement concepts into agroforestry practices and wood-based home industries (Figure 2). The focus of framework is for helping the farmer become more familiar with the genetically improved stock for planting material in their land without any worries in a high-input cost and resources needed.
Figure 2. Conceptual framework for the adopting tree improvement into agroforestry practices based on the existing farmer's own resources and wood-based industrial need

Under the framework scheme, the program is then set in a slogan of "plant and manage with your own available resources". This program would imply that the cultivation for the tree planting adopts the commonly technique practiced by the respective farmers, except for the improved stocks. The improved stock as main tree species for planting is genetically improved *A. mangium* resulted from second-generation of breeding cycles. There are four main steps for achieving the goal of program: 1) introducing improved stock through free distributing the seedling, 2) supervising and monitoring of the growth and economic value, 3) establishing seed orchard, 4) autonomous on improved seed production for further replanting.

2.3. Research design
The focus of this study is to observe the growth performance of improved stocks *A. mangium* resulted from tree improvement in existing agroforestry system that was being practiced by small growers. According to the farmers’ preferences and their own available resources, there are three types of planting design used in this study: 1) monoculture, without any other vegetation, 2) mixed with crops, 3) mixed with 3-5 other woody-tree species. Some permanent plots are then set up within each planting area design for data collection.

2.4. Field assessment and seed orchard establishment
Ensuring field planting practiced by the farmers and growth of the trees, monitoring and observation are then taken place by CFBTI staff together with the local staff of forestry agency. Data on growth performance of improved *A. mangium* trees and the mixed tree species and crops were collected, and another potential risks and disturbance were also identified.

Anticipating the increases demand of *Acacias* seed and to support the autonomous on improved seed production in Pacitan for further replanting, seed orchard was then established using the high productive genetic material selected from second-generation breeding of *A. mangium* in CFBTI. The orchard was established in a representative site closer to site planting in community-based forest with good accessibility. The seed orchard is targeted to produce improved seed of *A. mangium* at capacity around 50 kg per year.
3. Results and Discussion

3.1. Orientation and preparation of the project

Preparation of the project was conducted through some discussions with relevant authorized agencies in Pacitan Regency (The Head of Pacitan Regency, The Head of Forestry Regional Office) and collecting secondary data. Several field surveys to observe the existing agroforestry model in Acacias planting and to select representative sites for the plot project were also taken place (Figure 3).

Pacitan is covered by around 77,318 hectares forest land in which around 97% of the forest land are managed by the farmer as community-based forest distributed in 12 districts. The largest community-based forest area is in two districts of Tulakan and Kebonagung. The tree species planted are dominated by sengon, jati, mahoni, pinus and Acacias because of the high economic value of the wood for industry. However, due to vary of lands and climate conditions, the distribution of the planted tree species is also different among the districts.

Acacias species has been well known by the farmers in Pacitan and its planting is a part of long history in the forest land rehabilitation program started in 1970’s year. Therefore, the people have a good familiarity with the Acacias species, such as A. mangium, A. crassicarpa and A. auriculiformis, both in cultivation and harvesting technique, and wood-market product as well. These Acacias are the third largest tree species planted for community-based forest in Pacitan covering 11,500 hectares with around 55,300 m$^3$ of annual wood production. In case of existing seedling material for planting, there are two types of sources commonly practiced by the farmer: from natural regeneration and from seedling seller.
Figure 4. Survey on sawing and Acacias wood-based home industry harvested from community-based forest in Pacitan Regency, East Java, and Klaten, Central Java

The wood of Acacias is mostly transferred as raw materials for home wood-industries in Klaten of Central Java Province, while only small portions are used for the local industries in Pacitan (Figure 4). Among the Acacias species, A. auriculiformis is more preferred by the farmers due to the high price of logs. However, the trees from this species are commonly harvested at longer time of ages (>15 years), although the younger ages with small diameter of logs are also marketable in lower price.

Figure 5. Audience of CFBTI Team with The Head of Regency of Pacitan reporting the results of survey and detailed of the project (A). Signing of Memorandum of Understanding (B)

Three selected sites for project were distributed in two districts involving Kebonagung and Pringkuku. The two selected villages in Kebonagung were Katepung and Wonogondo, while one village in Pringkuku was Pringkuku. Most of farmers in all the sites have been familiar in planting of Acacias due to a high demand of Acacias wood production harvested from the community-based
forest in these sites. Memorandum of Understanding (MOU) of the project was then signed by the Head of Pacitan regency and Director of CFBTI (Figure 5).

3.2. Seedling preparation and distribution to the farmer
The genetically improved stocks distributed to the farmer were prepared in nursery of CFBTI in Yogyakarta (Figure 6). Seed for raising of the seedling were collected from second-generation seed orchard established in Wonogiri, Central Java which is managed under tree improvement program for *A. mangium* generated by CFBTI and then certified by the National Forest Tree Seed Agency. Genetic material for breeding in seed orchard were originated from provenances of Papua New Guinea [5].

![Figure 6](image)

*Figure 6. Seedling preparation in nursery of CFBTI and distributing the seedling to the representative of farmers*

After four months age, the 12,000 of 40 cm height of seedling were packed and transferred to around ± 110 km at the three sites planting in Pacitan Regency. Thereafter the seedling were distributed free in charge to the farmer in three selected sites: two in Kebonagung districts and one in Pringkuku districts. Number of farmers who received the genetically improved seedling varied among the districts. Depending on preferences and available land area, average number of seedlings also varied among the farmers from dozens to thousands of seedlings. Short-briefing in advance about the genetically improved seedling was also provided by CFBTI during the distribution.

3.3. Adopted agroforestry system
In this project, there are three types of agroforestry system practiced in the planting arrangement of improved *A. mangium* in community-based forest in Pacitan (Figure 7 and Figure 8). The types of planting varied among the farmers from three different sites. The two sites in Kebonagung districts: Wonogondo and Katepung, adopted the monoculture of single tree species and mixed with other tree species. While for one site in Pringkuku adopted mixed with crops.
Figure 7. Three types of planting system under the project. Monoculture at two years age (A), mixed with other trees species at two years age (B), and mixed with crops at planting age (C) and at three years later (D).

Figure 8. Pattern of the three existing planting design in community-based forest in Pacitan: monoculture or pure species (A), mixed with other tree species (B), mixed with crops.

Basically, the monoculture of single tree species system as used this study was not truly adopted as only planting of *A. mangium* in a larger area. This is just likely a mosaic of single species in the small plot which was surrounded with other existing species (Figure 8-A). Around 80 - 100 trees of *A. mangium* were purely planted within the plot of 3 × 2 meters spacing with no other trees or crops. The surrounded vegetation was mostly a mixed tree species including of teak, mahogany, *sengon*, natural regeneration of *A. auriculiformis* in varies of ages, growth and irregular spacings. This type of planting was adopted mostly due to the availability of open space area after very long-time cultivation of crops planting. This type of open space area indicated the poor nutrients in the soils that is not available for further planting with crops. Farmers used these areas for planting by considering the
ability of *A. mangium* as wide adaptability species, and under natural condition, it tolerates more adverse condition especially on dried and degraded soils, and also can grow on soils with pH as low as 4.2 [6].

In the plot where the *A. mangium* was mixed planting together with other tree species, the spacing was larger than the monoculture plot at around 3 × 3 meters. The composition of other tree species was mostly dominated by *sengon* which was planted earlier than the *A. mangium*. Although irregularly distributed and dominant in growth and crown development, *sengon* seemed not to be the greatest competitor for *A. mangium*. Another species was teak, *A. auriculiformis* and mahogany which were naturally regenerated and tend to show poor growth compared to *sengon*. Under these composition and canopy structure, *sengon* would be as a good mixed tree species to be planted together with *A. mangium*. This is because the typical of small leaves and crown size of *sengon* is less blocking out sunlight to under story of *A. mangium*.

In the mixed-plot where *A. mangium* was planted together with crops, the spacing were 4 × 2 meters: 4 meters between the rows, 2 meters within the row. The larger spaces of 4 meters will be allocated for planting of crops, while the trees planted at narrower space of 2 meters will simultaneously thinned following the increasing of inter-tree competition. There is no other tree species planted together in this type of plot. The two crops planted in this plot are padi and corn in which the corn was planted during the first year, while padi was at the second and three years.

### 3.4. Cultivation practiced

Fertilizer applied in planting of *A. mangium* varied among the farmers, depending on the resource availability in both types of organic and an-organic fertilizer, and doses per seedling as well. Fertilizer was not applied in the monoculture of single tree species by the farmers, but in the other two plots most of farmers used organic fertilizer such as compost and dung, and a few of farmers used an-organic such as NPK. These indicated that fertilizer use is a likely management alternative in community-based forest in Pacitan, except fertilizer for the crops that were planted together with the *A. mangium*.

Weeding was not specifically practiced by the farmers in the plot, because it was just practiced and imposed to maintain the crops rather the trees of *A. mangium*. Weeding was practiced by manual, and there is no application of chemical. Agroforestry system applied in community-based forest of *A. mangium* seemed likely control in lower abundances of the growing and spreading of weeds, particularly when the *A. mangium* planted in mixed with other tree species.

Artificial pruning and singling were not much practiced in the plot because of the planted *A. mangium* has been improved in both growth traits and stem form. Almost all the trees grown in single and straight stem. This such ideotype of improved *A. mangium* would be beneficial for agroforestry system in supporting the growth of crops. However, some light pruning is still necessary to be practiced, particularly in the plot of mixed with crops due a slower of self-pruning since it will stimulate the growth of crops in more longer periods of replanting.

### 3.5. Supervision and monitoring

Following the seedling distribution, field visit for supervision and monitoring were periodically conducted by staff of CFBTI at the three sites of plots (Figure 9). Basically, there is no serious problem in the planting of improved *A. mangium* under the scheme of the project. This is because the farmers have flexibility in the planting system and maintaining of the tree based on their available resources. However, data from growth measurements showed that there is a significant difference of the growth among the three types of agroforestry system. Plot with mixed crops planting showed the best one for stand volume productivity, followed by the plot mixed with other tree species [7]. This seemed to be due to the differences of tree density between the two plots: tree density in mixed crops planting plot was higher than that in mixed another tree species plot. While in monoculture plot without mixed any other crops or tree species the trees of *A. mangium* showed consistently the poorest growth. The difference could be observed from the mean annual increment of height growth in the
three types of system which were 4.03 m, 2.92 m and 2.46 m for mixed-crops, mixed-tree and monoculture plot, respectively [7].

![Figure 9](image_url)

**Figure 9.** Supervision from CFBTI Teams to farmer and growth measurement

One of the interesting results found in this study that although the stand volume productivity was lower, individual performance of *A. mangium* trees in mixed other tree species plot was better than that in mixed crops planting plot. As mentioned in the previous paragraph that *sengon* trees showed dominance of growth in mixed other tree species plot, but the *A. mangium* trees that was planted together in this plot also performed good growth. Less blocking out sunlight due the light typical of crown development of *sengon* and higher humidity in the above grounds seemed stimulate the growth of *A. mangium* to be higher and bigger, and good stem form as well. However, the different soil condition among the plots has also influenced the growth.

### 3.6. Economic impact

In term of total economic impact, the benefits could be basically analyzed from all available potential products resulted from the adopted agroforestry system. However, the primary objective in this study is to impose the impact of improved *A. mangium*. This is because the added values of the existing system will be from the introduced *A. mangium*, while other potential products from crops and other tree species were assumed to be the same as previously. It should be noted here that the project is aimed for adopting tree improvement results through planting improved stock into the existing agroforestry system practiced by the farmers in community-based forest. Therefore, the benefit received by the farmers will be potentially different depending on the available resources used. In term of respective farmers, the benefit will be considered as comparison of the condition before and after introducing the improved stocks in their land area.
Considering the growth performances of *A. mangium*, logs pricing of *A. mangium* would be higher in the mixed other tree species plot due to the bigger diameter and good stem forms: high bole length and cylindrical stem. Such logs performances would be more suitable for the end-product of sawn timber. In addition, four years of standing trees of *A. mangium* in this plot has been used as collateral of credits to get additional financial from BLU (Figure 10). It revealed that introducing improved *A. mangium* into suited agroforestry system in community-based forest in Pacitan regency could increase benefit and income for the farmers, although it was managed in low cost of existing available resources. Under age rotation for sawn-timber at 10 years age, the stand volume at the harvested age could be expected to reach around 210 m³/ha in mixed-crops plot which correspond to the other plots were ranging from 140 -190 m³/ha.

### 3.7. Seed orchard and seed production

The seed orchard was established to ensure the sustainability in supplying of improved of seedling of *A. mangium* for further replanting in next rotation or other new land area (Figure 11). This is because the seedling of *A. magnum* for planting was previously supplied from other regency in Central Java with unidentified seed quality. Moreover, price of the seedling was high due the long distance of transportation. Therefore, the seed orchard established during the project here would be essential toward supporting the autonomous high-quality seed of *A. mangium* in Pacitan regency.

![Figure 10. Preliminary observation to estimate the potential of economic value of the planted Acacia mangium trees](image)

![Figure 11. Establishment of seed orchard of Acacia mangium for genetically improved seed production for next rotation replanting](image)
Seed orchard of *A. mangium* was established using genetic material resulted from third-generation breeding cycles conducted by CFBTI. The orchard was established in Pringkuku district at around 1.5 hectares area with final density of mother tree for seed collection at around 300 trees [8]. Seed production could be obtained from the seed orchard after five years age with production capacity at around 75 kg per year. This amount of high-quality seed production could be used for new planting for more than 2000 hectares. The overstocked seed production could be sold to another site that is representative for *A. mangium* planting, such as forest industrial plantation in outside Java.

4. Conclusions

The results of study revealed that through the project of adopting tree improvement into agroforestry system in community-based forest in Pacitan, genetically improved stocks of *A. mangium* could provide various additional benefit impacts to the farmers of small grower land. The amount of benefit depends on the existing available resources used with low cost and low input of silviculture. Under agroforestry system, the growth of trees derived from genetically improved seed of *A. mangium* could be optimal if planted together in mixed with other tree species, which is particularly dominated with *sengon*.

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