Growth performance of *Falcataria moluccana* in the mixed cropping pattern and its severity from Gall-rust disease: A case study in Ciamis, West Java

B Dendang and A Sudomo
Research and Development Institute for Agroforestry Technology.
Jl. Ciamis-Banjar Km 4 Po Box 5. Ciamis, West Java, Indonesia

E-mail: arispck@yahoo.com

**Abstract.** Monoculture *Falcataria moluccana* plantation managed by local communities in Ciamis – West Java, is facing a gall-rust disease caused by fungal pathogen *Uromycladium tepperianum*. A mixed planting crops system is considered less vulnerable to pests and disease problems. In addition, it is possible to increase the productivity of community forest plantations. This study was aimed to evaluate the effects of mixed-crops plantation on the productivity of *F. moluccana* and the incidence and severity of gall-rust in the plantation. Then it will be compared to the existed monoculture *F. moluccana* plantation in the area, that was established two years before. The mixed-crop consisted of *F. moluccana*, *Acacia mangium*, and *Gmelina arborea*. These were alternately planted in three different rows with three replications. The observations of growth increments as well as incidence and severity of gall-rust were carried out in 1.5 years after planting. The results showed that the annual height- and diameter- increments of *F. moluccana* in the mixed-crop plot were 331.2 cm and 2.77 cm, respectively. Meanwhile, the results in the monoculture plot were 325.62 cm and 2.64 cm. The survival rates of *F. moluccana* in both planting patterns were slightly different (85.3% and 88%). Gall-rust incidence and severity were only observed in the *F. moluccana* monoculture plot, i.e., 0.15% and 0.48%, respectively. The mixed-planting crops system seems possible to be applied for controlling the gall-rust disease that attacked the *F. moluccana* stands. Further research on comparing the similar ages of mono- and mixed- cultures of *F. moluccana* in different locations were suggested.

1. **Introduction**
Natural forest areas continue to decrease in the world including in Indonesia due to land-use conversion for other purposes such as agricultural croplands, oil palm plantations, mining exploitation, etc. This phenomenon has lead to unsufficient supply for the demand of woody raw materials. The development of community forest plantation is one of the Indonesian government programs to address the need for woody raw materials, apart from the industrial forest plantation. The plantation forests have a significant contribution of supply for about 70% for Java Island's timber demand, the most populated island in Indonesia [1]. However, as the plantations are managed traditionally by the local
communities, until now, the productivity of community forest plantations are not optimum yet. It still cannot significantly improve the local communities’ welfare and prosperity.

The less productivity of the community forest plantations could be caused by less consideration to site-species matching in the plantation establishment [2]. Local people mostly planted their lands with the most preferred plant species, without considering site-species match. The lack of information about other potential species which could be similar, even more economical- and ecological- benefits rather than the existed plant-species, has made the local people tend to stick on their preferred choice.

Falcataria moluccana is the dominant plant species in community forest plantations in Java, followed by other fast-growing species, viz. Acacia mangium and Gmelina arborea. The attractiveness of F. moluccana is associated with its shorter rotation compare to two other species. F. moluccana stands can be harvested in 5 - 7 years old [3], while A. mangium and G. arborea in 8 years old [4, 5]. Another reason is the various utilization of F. moluccana, which can be used for containers, wallboard, household furniture, plywood, pulp, paper, and handicrafts. This difficulty is related to the seed source, which is mostly uncertified, without distinct informations about its genetic- and physiological- qualities [3].

The F. moluccana plantations are threatened by the gall-rust disease, which was firstly reported in 2009. Until now, it still challenging to be controlled. The disease is caused by Uromycladium tepperianum (Sacc.) Mc. Alpin) [6 - 8]. The infected plants can be recognized through the appeared symptoms, viz. various forms of swelled-structures (galls), which developed on the infected parts of the plants. At the initial development, the surface of the galls is coated with billions of active reddish-brown spores, which spreading quickly by wind blow [6]. U. tepperianum infection on leaves and shoots causes leave rolled and shoot bent [9].

The risk of F. moluccana plantations to gall-rust infections is enhanced because of monoculture planting applied by the local communities. Monoculture plantation is generally more vulnerable to pests and disease outbreak compared to mixed silvicultural planting technique plantation. In gall-rust case, monoculture F. moluccana plantation provides an abundant host for the spores of U. tepperianum to be spread easily. The spores spreading can be reduced by planting it mixed with the less susceptible or more resistant plant species.

This study established experimental plots which aimed to determine (1) the growth of F. moluccana, and (2) gall-rust incidence and severity in the F. moluccana stands planted in mixed cropping pattern with A. mangium and G. arborea. It was conducted to encourage local people to plant F. moluccana in the mixed pattern, as well as to reduce the dispersal rate of gall-rust disease.

2. Methodology
2.1. Location
Both the F. moluccana monoculture- and the mixed- plots were established in private forest land in Sedekan Subvillage, Mekarjadi Village, Sadananya Sub-District, Ciamis District of West Java Province (GPS coordinate S 7° 19'10.5", E 108° 19'55.4"). It is located at an altitude of 203 m asl. The daily temperature ranged from 18° - 27°C, and rainfall (based on data in 2015) 2,243 mm year⁻¹ [10]. The mixed plot was established in December 2017, while the monoculture plot was established two years before. The plots observation was conducted for 1.5 years since the establishment of mixed-plot.

2.2. Research procedure
The plot of the mixed-cropping plot of F. moluccana, A. mangium, and G. arborea was alternately planted in three different rows, which consisted of 25 plants, spacing 2 x 2 m, with three replications (Figure 1.A). Each plant was fertilized by spreading 100 gr NPK within 50 cm around the plant to support its initial growth. Two border lines around the plot were also established. The F. moluccana monoculture plot has been established two years before the mixed-cropping plot established (Figure 1.B).
After 1.5 years planted, 25 trees of each species in the mixed-cropping plot and 25 *F. moluccana* trees in the monoculture plot resulted in 300 trees in total. These were subject to be assessed for determining plant-growth increment and gall-rust incidence and severity. The gall-rust severity was classified refers to the criteria described in Table 1 [11].

| Score | Symptoms |
|-------|----------|
| 0     | Healthy plants, no symptoms. |
| 1     | The disease symptoms were observed; the infection appears only at the tip. |
| 2     | The disease symptoms were observed; the infection is in the shoots and branches. |
| 3     | The galls were observed in the branches. |
| 4     | The galls were observed at the top and/or stems. |
| 5     | Died plants. |

2.3. Data analysis

The averages of tree height and diameter were calculated to determine tree-growth increment. The percentage of survived trees was determined by the ratio of the number of living trees to the total
planted trees of each species in each plot. While gall-rust disease incidence (DI) and severity (DS) were quantified using the following formulas [12].

\[
DI = \frac{n}{N} \times 100\%
\]

\[
DS = \frac{(n_0 \times z_0) + (n_1 \times z_1) + \ldots + (n_5 \times z_5)}{N \times Z} \times 100\%.
\]

Remarks:

- DI = Disease Incidence
- DS = Disease Severity
- n = Number of infected plants
- N = Total number of observed plants
- n0 – n5 = Number of plants with z-score
- z0 – z5 = Score value
- Z = maximum score

3. Results And Discussion

After 18 months observation, A. mangium stands showed the highest survival rates of 88% in the mixed-cropping plot, followed by F. moluccana and G. arborea with survival rates of 85.33% and 34.67%, respectively. In comparison to A. mangium and G. arborea stands, the best tree increment was showed by F. moluccana in the mixed-planting crops. There were no apparent differences in the tree survival rate (88% and 85.3%), and the increment of tree height (331.2 cm/year and 325.62 cm/year) and diameter (2.64 cm/year and 2.77 cm/year) of F. moluccana those planted in mono-and mixed-cultures patterns, respectively (Table 2).

Table 2. The tree’s survival, height, and diameter of the plants in a 1.5-year mixed cropping pattern and a 3.5-year F. moluccana monoculture.

| Species                  | Age (year) | Survival (%) | Height (cm) | Increment Height/year (cm year-1) | Diameter (cm) | Increment Diameter/year (cm year-1) |
|--------------------------|------------|--------------|-------------|----------------------------------|---------------|-------------------------------------|
| F. moluccana (Mixed-planting) | 1.5        | 85.33        | 496.8       | 331.20                           | 4.16          | 2.77                                |
| A. mangium (Mixed-planting) | 1.5        | 88           | 401.33      | 267.55                           | 3.35          | 2.23                                |
| G. arborea (Mixed-planting) | 1.5        | 34.67        | 187.33      | 124.89                           | 2.13          | 1.42                                |
| F. moluccana (Monoculture)  | 3.5        | 88           | 1139.67     | 325.62                           | 9.25          | 2.64                                |

The mixed-planting pattern seems useful to reduce gall-rust incidence and severity in F. moluccana. The monoculture F. moluccana showed 0.15% gall-rust disease incidence and 0.48% disease severity. While in the mixed-planting plots, there was no gall-rust signs and symptoms observed on the F. moluccana trees (Table 3).

Table 3. Disease incidence and severity of gall-rust on F. moluccana.

| Parameter            | Monoculture of F. moluccana | Mix of F. moluccana |
|----------------------|-----------------------------|---------------------|
| Disease Severity (%) | 0.48                        | 0.00                |
| Disease Incidence (%)| 0.15                        | 0.00                |
3.1. Plants growth in two different planting patterns

In the mixed-culture plot, the numbers of survived A. mangium stands against the infection of the gall-rust fungal pathogen was higher than the other two species. The percentage of survived stands of A. mangium was 88%, F. moluccana was 85.33% and G. arborea was 34.67%. The superiority of A. mangium is likely to be associated with its characteristic as an exotic species that has a wide range of adaptability in various conditions of plantation forests in Indonesia. Even the spread of seeds carried by the wind can produce natural regeneration that grow well on marginal lands; nevertheless, as a pioneer plant – A. mangium is proved to have better survivability than F. moluccana and G. arborea.

The highest growth increment of 1.5 years stand showed by F. moluccana (496.80 cm height and 4.16 cm diameter), followed by A. mangium (401.33 cm height and 3.35 cm diameter) and G. arborea (187.33 cm height and 2.13 cm diameter). Research in Sumbawa showed that after 21 months of growth, the height and diameter of F. moluccana in monoculture pattern was 489 cm/6 cm, while the height and diameter of G. arborea in monoculture pattern was 425 cm/8.5 cm [13]. It shows that the high growth of monoculture pattern was found in F. moluccana compared to monoculture in A. mangium, except for the diameter. This study showed that in the mixed pattern, the initial growth of F moluccana was in height, followed by diameter growth due to competing at close spacing (2 m x 2 m). The growth of F. moluccana is faster than A. mangium and G. arborea because biological rotation of F. moluccana is 5 – 7 years and biological rotation of A. mangium and G. arborea are eight years [5, 3, 4]. Height and diameter growth of 2-years-old A. mangium monocultures in Hawaii were 6.8 m and 6 cm, respectively. While in Costa Rica were 8 m and 9 cm, respectively [14]. This showed that in its favorable habitats, A. mangium can grow almost two times higher than the results of this study. In mixed cropping pattern, A. mangium has the best survival but lower height increment compared to F. moluccana. It might be caused the growth of A. mangium inhibited due to obstructed canopy. The biological rotation of A. mangium are slower than F. moluccana [4, 3].

In this study, G. arborea has the lowest survivability (34.67%). This condition might be caused by species competition for sunlight and soil nutrition. In the mixed cropping with tight-spacing between tree stands (2 m x 2 m), F. moluccana and A. mangium, which have better growth-rate, would have suppressing effects on the G. arborea stands. Those species will use space very quickly at wide spacing. However, the broader tree-spacing (2 m x 4 m) of monoculture plantation tended to produce higher growth rather than the dense spacing [15]. High growth in Eucalyptus plants will be higher at wide spacing. Meanwhile, Eucalyptus grandis has decreased in height growth with reduced spacing [16, 17].

The annual growth factor rate of F. moluccana in mixed and monoculture patterns is slightly different. Environmental factors can cause un-noticeable differences as locations of those two plots are close to each other. The conditions of rainfall, altitude, soil type and nutrient content, the ambient temperature, and humidity are relatively similar. Thus, the effects on the growth of F. moluccana in both plots were not significantly different. The survival rate of F. moluccana in mixed cropping pattern is lower than those in the monoculture plot. This phenomenon possibly due to competition with other species (A. mangium and G. arborea) in the mixed plot, which is dominated by A. mangium. As a pioneer species (with dominant of 88% plants survived), A. mangium is likely to suppress F. moluccana survivability. In the mixed-crops plot, competition among species for sunlight and nutrients have occurred. Moreover, the narrow spacing between trees (2 m x 2 m) may enhance the space-competition both in the canopy and substance levels. The other factor that can explain the A. mangium dominancy is specific biochemical substances released by A. mangium canopy that inhibit the growth of other plants species in the mixed-crops plantation [18].

Higher diversity of tree species increases the number of ecological niches, which can further increase the number of associated species [19]. The actions needed in managing mixed plantation are pruning and thinning so that the remaining stand growth is optimal. F. moluccana has been reported showing a better growth rate compare to Khaya anthoteca and Peronema canescens in mixed cropping pattern [20]. The canopy growth of the fast-growing species (F. moluccana) can limit the growth of
K. antotheca, which grown slower [20]. The mixed-species plantation with two or four species can be more productive and provide more advantages in biodiversity, economy and forest health over the monoculture one [21].

As the mixed-species plantations can have negative or positive effects on tree growth [22], species selection is crucial to obtain an optimum combination of plant species. That combinations have complementary traits that will maximize the positive- and minimize the negative- impacts of their interactions [23]. By applying a proper silvicultural management system, the mixed-species plantation can be more productive than monoculture plantation [21].

3.2. Gall-rust disease in F. moluccana stands

Gall-rust disease was only observed in F. moluccana monoculture plantation. This indicates that a monoculture planting pattern provides abundant host-plant for the disease. Monoculture cropping pattern does not provide boundary-plants to protect F. moluccana from the gall-rust attack [11]. The gall-rust fungi only requires F. moluccana as a host to complete their entire life cycle (autoecious). The development of gall-rust disease in F. moluccana can be influenced by cultivating factors, such as the plant age, fertilizers and gall-rust controlling agents [24]. As in this plot was no chemical control applied and similar fertilizing practices were applied to both plots, the development of the disease was more influenced by plant age. Older F. moluccana stands were reported had lower gall-rust incidence and severity compared to the younger ones [25]. However, this study found the opposite fact, where the disease incidence and severity of the 3,5-years-old F. mollucana planted in monoculture plot were higher than the 1,5-years-old F. moluccana planted in the mixed-crops plot. This indicates that mixed cropping pattern had a positive impact on reducing gall-rust spread.

Gall-rust infection is not found in the mixed cropping patterns. This planting pattern does not provide favorable conditions for the development of the disease [26]. The most crucial consideration of cultivation techniques is how to create an environment that provides beneficial factors for the plants and inhibiting factors for the pathogens. The availability of favorable hosts continuously enhances the survivability of the disease, which will allow it to spread massively. This situation mostly occurs in community forest plantations that harvest the trees based on their needs. The new F. moluccana plants which were planted in the over-logged-land will provide a new host for the existing gall-rust disease. This phenomenon was in line with the study on coniferous plants that showed monoculture plantations were more susceptible to biotic- and abiotic- disturbances, and currently, the susceptibility can be aggravated by climate change effects [27].

The absence of gall-rust fungi in F. moluccana stands in mixed-cropping patterns may associate with the dispersal mechanism of the fungal pathogen. As the gall-rust fungi are specific-host pathogen and the spores spreading is facilitated by wind blowing. Then the presence of other barrier-plants can inhibit pathogens’s spread, such as A mangium and G. arborea in mixed-cropping pattern. The U. tepperianum spores from the outside did not directly attack F. moluccana due to the blocking effect of the barrier-plants. However, if an F. moluccana tree in the mixed system was attacked by the gall-rust, it will spread very quickly to other F. moluccana stands. Thus, the mixed-species plantation is more resilient to damage caused by insects or diseases [28 - 30].

The attack intensity of gall-rust can be influenced by environmental factors such as temperature and rainfall in the site. The temperature and rainfall in the study locations were 18ºC - 27ºC and 2,243 mm year-1 [24]. The monthly variations of temperature and rainfall correlate significantly with the attack of gall-rust. The temperature has more dominant effects on disease progression compared to the humidity [31]. High relative humidity and low-speed wind blow promoted gall-rust disease development [25]. The location of this study was flat topography, 203 asl (lower attitude) and the absence of fog. These were significant local site conditions that reduced gall-rust disease incidence and severity [25].

Even though the attack of the gall-rust disease on F. moluccana can occur in shoots, branches, and stems, the results of this study showed that shoot infection was the most commonly found [32]. The previous study showed that the intensity of gall-rust on the shoots of F. moluccana was higher
(49.31%) than the branches (25.74%) and stemmed (11.57%) [32]. Gall-rust attacks on the stem caused more severe damages, which mostly ended with tree-death, compare to those infested in the shoots and branches.

4. Conclusion
The growth increment of *F. moluccana* planted in mixed-cropping pattern with *A. mangium* and *G. arborea* is better than those planted in the monoculture plot. The mixed-cropping pattern also showed its effectiveness in controlling gall-rust disease incidence and severity. This study highlighted the possibility of a mixed-cropping pattern for *F. moluccana* plantation managed by local communities in order to improve plantation productivity and reduce gall-rust risk. However, as the mixed-crops and monoculture plots did not establish at the same time, data bias due to different plant-age which may be associated with physiological responses of the plants may occur. Thus, further testing of which comparing the similar age of mono- and mixed- cultures of *F. moluccana* in different locations were suggested.

Acknowledgment
The authors thank Mr. Amok as the Leader of the farmer group (for helping the establishment of the plot), Srita Farida (Data Entering), Mr. Agus (owner of the land of the experiment) and some technician (doing measurement of this trial). The research was established by the collaboration with farmer group on private forest

References
[1] Awang S A 2001 Gurat Hutan Rakyat di Kapur Selatan Jogjakarta: Debut Press
[2] Hardiyanto 2005 Beberapa Isu Silvikultur Dalam Pengembangan Hutan Tanaman
[3] Indrajaya Y 2013 Penentuan Daup Optimal Hutan Tanaman Sengon (Paraserianthes falcatoria (L.) Nielsen) Dengan Metode Faustmann (Determining Optimal Rotation of Sengon (Paraserianthes falcatoria (L.) Nielsen) Plantation Forest Using Faustmann Method) p. 31–40
[4] Nina M and Pratiwi 2008 Kajian penetapan daur optimal hutan tanaman Acacia mangium ditinjau Dari Kesuburan Tanah J PHT 5 (2) 109–118
[5] Indrajaya Y and Siarudin M 2015 Daup tebang optimal hutan rakyat gmelina (Gmelina arborea Roxb.) Di Tasikmalaya Dan Banjar, Jawa Barat, Indonesia (Optimal Harvesting Rotation of Gmelina (Gmelina arborea Roxb.) Private Forest in Tasikmalaya and Banjar, West Java, Indonesia)
[6] Rahayu S 2008 Penyakit Karat Gall pada F. moluccana (F. moluccana (Miq.) Barneby & J.W. Grimes). in Makalah Workshop Penanggulangan Serangan Karat Puru pada Tanaman F. moluccana 19 Nov 2008
[7] Anggraени I, Dendang B and Lelana N 2010 Pengendalian penyakit karat gall (Uromycladium tepperianum (sacc.) MC, Alpin pada F. moluccana (F. moluccana Miq.). Barneby & J.W. Grimes) di Panjalu Kabupaten Ciamis Jawa Barat J. PHT 7 (5) 273-278
[8] Widyastuti, S M, Harjono and Surya Z 2013 Initial infection of *F. moluccana* leaves and *A. mangium* Phyllodes by *Uromycladium tepperianum* fungi in a laboratory trial *J.MHT* (Journal Manajemen Hutan Tropika) 19 (3) 187-193
[9] Anggraeni I and Santoso E 2003 Penyakit karat puru pada F. moluccana (Paraserianthes F.) di Pulau Seram. Puslitbang Hutan dan Konserwasi Alam, Bogor 636/20
[10] Anonim 2018 Kabupaten Ciamis Dalam Angka 2018. Ciamis Regency In Figures Ciamis: BPS Kabupaten Ciamis
[11] Rahayu S, Lee S and Shukor 2010 Uromycladium tepperianum, the gall-rust fungus from *F. moluccana* in Malaysia and Indonesia Mycoscience 149-153
[12] Lestari P, Rahayu S and Widyatno 2013 Dynamics of gall-rust disease on *F. moluccana* (*F. moluccana*) in various agroforestry patterns *Procedia Environ. Sci.* 17 167-171
[13] Roshetko J M and Purnomosidhi P 2004 *Gmelina arborea* – a viable species for smallholder tree farming in Indonesia? 207–215

[14] National Research Council 1983, Mangium and Other Fast-Growing for the Humid

[15] Widiyanto A, Siaurudin M and Rachman E 2013 Pertumbuhan tujuh provenan *F. moluccana (F. Mollucana)* pada tiga jarak tanam (Growth of seven provenances of *F. Mollucana* in three spacing) *Jurnal Agroforestry* I

[16] Adlard P G 1992 Research strategy for Monitoring Tree Growth and Site Change, in *In I.R. Clader, R.L. Hall and P.G. Adlard (ed) Growth and Water Use of Forest Plantations.*, In I.R. Cl, p. 48-62

[17] Schonau A P G and Coetze J 1989 Initial spacing, stand density and thinning in Eucalypt Plantations *For. Ecol. Manag.* 29 245–266

[18] Baltodano J 2000 Monoculture forestry: a critique from an ecological perspective. In: Tree Trouble: a Compilation of Testimonies on the Negative Impact of Large-scale Monoculture Tree in *Plantations Prepared for the 6th COP of the FCCC. Friends of the Earth* International p. pp. 2-10.

[19] Larjavaara M 2008 A review on benefits and disadvantages of tree diversity *Open For. Sci. J.* 1 24–26

[20] Hani A 2013 Pertumbuhan *Khaya anthotheca* Welw C.D.C. Pada pola tanam monokultur dan campuran *Jurnal Penelitian Agroforestry* I (2) 101–112

[21] Lok C, Liu C, Kuchma O and Krutovsky K V 2018 Mixed-species versus monocultures in plantation forestry: Development, benefits, ecosystem services and perspectives for the future *Global Ecology and Conservation* p. e00419

[22] Piotto D 2008 A meta-analysis comparing tree growth in monocultures and mixed plantations. *For. Ecol. Manag.* 255 (3–4) 781–786

[23] Brooker R W 2015 Improving intercropping: a synthesis of research in agronomy, plant physiology and ecology *New Phytol.* 206 (1) 107e117

[24] Lelana N 2017 Epidemologi dan keragaman patogen karat puru *F. moluccana* di Indonesia.

[25] Rahayu S, See L, Shukor N A and Saleh G 2018 Environmental factors related to gall-rust disease development on *Falcatoria moluccana* (Miq.) 16 (6) 7485–7499

[26] Katan J 2010 Cultural approaches for disease management: Present status and future prospects cultural practices for disease *J. Plant. Pathol.* 97 754.9

[27] Felton A M, Lindbladh, Brunet J and Fritz O 2010 Replacing coniferous monocultures with mixed-species production stands: an assessment of the potential benefits for forest biodiversity in northern Europe *For. Ecol. Manag.* 260 (6) 939–947

[28] Hartley M J 2002 Rationale and methods for conserving biodiversity in plantation forests *For. Ecol. Manag.* 155 (1–3) 81-95

[29] Nichols J D, Bristow M and Vanclay J 2006 Mixed-species plantations: prospects and challenges *For. Ecol. Manag.* 233 (2–3) 383-390

[30] Griess V C and Knoke T 2011 Growth performance, windthrow, and insects: meta-analyses of parameters influencing performance of mixed-species stands in boreal and northern temperate biomes *Can. J. For. Res.* 41 (6) 1141-1159

[31] Dimock A W 1967 Controlled environment in relation to plant disease research *Ann. Rev. Phytopathol.* 5 265-284

[32] Dendang B, Hani A and Racman E 2015 Sebaran penyakit karat gall di berbagai lokasi ketinggian di Kabupaten Ciamis *Jurnal Agroforestry* 165–171