Working Paper

Agroforestry and Forestry in Sulawesi series:

Modelling tree production based on farmers' knowledge: case for kapok (*Ceiba pentandra*) and candlenut (*Aleurites mollucana*) under agroforestry scenarios

Degi Harja Asmara, Endri Martini, Andi Munawir and Sumarni Lalisa

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Tel: +62 251 8625415
Fax: +62 251 8625416
Email: icraf-indonesia@cgiar.org
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About the authors

Degi Harja Asmara was Tree Interaction Researcher and Computer Modeler at ICRAF Indonesia from 2000 to 2015. He developed tools and databases for supporting research in agroforestry and related fields. He is studying for a doctoral degree in Forest Science at Laval University, Quebec, Canada.

Endri Martini has been ICRAF Indonesia's Agroforestry Extension Specialist since 2011. Previously, she worked at ICRAF on various issues of agroforestry related to biodiversity conservation and community development. She obtained her Master of Science degree in natural resources and environmental management from the University of Hawaii at Manoa, USA. Her bachelor degree was from Institute Pertanian Bogor, Forestry Faculty, majoring in Silviculture.

Andi Munawir obtained his bachelor degree at the Department of Silviculture, Faculty of Forestry, Hasanuddin University, Makassar, South Sulawesi, Indonesia. He was an intern at ICRAF, researching production estimates of kapok trees in Bantaeng District, South Sulawesi based on farmers' perspectives.

Sumarni Lalisa obtained her bachelor degree at the Department of Silviculture, Faculty of Forestry, Hasanuddin University, Makassar, South Sulawesi. She was an intern at ICRAF, researching production estimates of candlenut trees in Bantaeng District, South Sulawesi based on farmers' perspectives.

Abstract

The role and value of species in agroforestry systems are often well known, however, less is known of the actual growth and production of many of these species, particularly, for underutilized species. This limited information hinders the assessment of growth and production of the species. Candlenut (*Aleurites moluccan*a) and kapok (*Ceiba pentandra*) are two underutilized agroforestry species for which limited information is available. Growth and production (yield) predictions can be used to identify the best strategies for managing agroforestry systems and analysing the costs and benefits of various scenarios.

Production and growth estimation of candlenut and kapok in this study combined measurement of growth indicators (diameter, crown width) with farmers' local knowledge. The growth prediction model, Spatially Explicit Individual-based Forest Simulator (SExI-FS), was used to explore the yield dynamics of candlenut and kapok under various agroforestry scenarios.

Farmers' perceptions were shown to be reliable for estimating fruit yields. Perceptions were more reliable from farmers who directly harvested the fruit. The inclusion of Crown Position and Crown Form indexes improved the estimation correlation of yields with tree diameters. The simulation model in a mixed kapok and candlenut scenario showed that candlenut was more competitive than kapok if planted at more than 30% of the total plant density.

Keywords

Candlenut, kapok, yield, agroforestry, modelling, local knowledge

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1. Introduction

Traditionally managed agroforests have complex vegetation structure comprised of many plant species deliberately mixed to produce multiple products and uses. There are obvious ecological and economic advantages for developing complex agroforestry, mixed species' systems (Michon and de Foresta 1996, de Foresta et al 2000). While the role and value of species in agroforestry systems are often well known, little is known of the actual production and growth of those species, particularly, for underutilized species. This limited information has restricted assessment of production and growth of trees that typically require intense investments of time and money. On the other hand, farmers with long experience of mixed systems understand the production and growth of tree species in such systems. Thus, estimating tree production and tree growth based on farmers' knowledge is a viable alternative to long-term field testing.

Local ecological knowledge that is based on real-world observation and farmers' experience is believed to provide reliable biophysical data (Sinclair and Joshi 2000). Laxman et al (2001) found that local knowledge was like scientific knowledge: cumulative and evolutionary. Although local knowledge arises from various approaches, it most often leads to valid conclusions. A method for understanding fruit production based on farmers' knowledge was tested by Salafsky (1995) for durian (*Durio zibethinus*) by employing a geographical information system (GIS) analysis to examine the beliefs of forest tree-garden owners in West Kalimantan, Indonesia. The study concluded that farmers generally had accurate perceptions as to how ecological factors influenced durian production. Moller et al (2004) used a combination of traditional ecological knowledge and science to monitor populations for sustainable wildlife harvests by indigenous peoples. Conventional scientific practices are precise but can be expensive and may require specialized skills or technology whereas most traditional monitoring methods used by indigenous cultures are rapid and low-cost, producing easily comprehensible assessments (Moller et al 2004).

Yield predictions for agroforestry systems can be used for finding the best strategies for managing tree gardens and analysing the costs and benefits of scenarios. While observation of annual crops can be fast and easy, research on perennial plants can take years and sometimes require larger areas to provide sufficient data. The combination of local ecological knowledge and physical observation of yield productivity in agroforestry systems can, thus, be an efficient and effective method of obtaining results.

Candlenut (*Aleurites moluccan*a) and kapok (*Ceiba pentandra*) are two well-known agroforestry species that are often prioritized for development by smallholders in their agroforestry systems in Indonesia (Gunasena and Roshetko 2000, Roshetko and Evans 1999). Both species contribute to the livelihoods of farmers yet limited information on their growth and production is available. These species are tolerant of drought and provide ecosystem functions as wind breaks (Krisnawati et al 2011a, Brown 2012). However, their domestication is limited compared to other more economically valuable commodities such as rubber, coffee and cacao. For farmers, these two species provide additional income, particularly, during droughts that decrease the production of other more economically valuable species. Information on production and growth helps measure species' potential for greater domestication, which ultimately helps enhance farmers' livelihoods.

Thus, growth and production of candlenut and kapok were estimated in this study by combining measurement of growth indicators (diameter, crown width) with farmers' local knowledge. The growth prediction model, Spatially Explicit Individual-based Forest Simulator (SExI-FS), developed by Harja and Vincent (2008) was used to explore the yield dynamics of candlenut and kapok under various agroforestry scenarios. The results of this study are expected to contribute to the development of more efficient methods for estimating growth and production of underutilized species cultivated in agroforestry systems.

2. Data Collection

Species' descriptions

Ceiba pentandra (kapok) is native to Mexico, the Caribbean and West Africa. The tree is cultivated for the seed fibre, particularly in Southeast Asia. The species is also known as Java cotton, Java kapok, silk-cotton, 'samauma' or 'ceiba'. Kapok fibre is an important commercial fibre for Indonesia and also Thailand, the main producers of kapok, with about 80,000 t and 40,000–45,000 t per year during 2000–2004, respectively. The standard plantation of *Ceiba pentandra* is 7 x 7 m spacing (204 trees/ha). Under optimal conditions the tree yields 330–400 fruit per year (15–18 kg fibre and about 30 kg seed), with average annual fibre yield ranging 450–700 kg/ha. The tree grows to 60–70 m (200–230 ft) and has a very substantial trunk of up to 3 m (10 ft) in diameter, with buttresses. It can be found in various types of moist evergreen and deciduous forests as well as in dry forests and gallery forests. As a pioneer species, it mostly occurs in secondary forests. The wood is variable in colour, from white to light brown, but sap-staining fungi may darken it. The wood is very light, with specific gravity of 0.3032 g/cm^3 (Duval 2009).

Aleurites moluccana (candlenut) is a medium-sized tree, up to 20 m tall, with wide-spreading or pendulous branches. Seedlings are planted at a density of 300/ha. In plantations, nut yields are estimated at 5–20 t/ha/year, with individual trees producing 30–80 kg/year. A report by Elevitch and Manner (2006) on plantations of 200 trees/ha found nut yields at 80 kg/tree or 16 mt/ha/yr. Oil production varies 15–20% of nut weight. Most oil produced in India, Sri Lanka and other tropical regions is used locally and does not feature in international trade (Orwa 2009). The habitat of candlenut is subtropical dry to wet and tropical very dry to wet forest climates. Preferred altitude for candlenut is 0–700 m (0–2300 ft) with rainfall of 640–4290 mm (25–170 in). Candlenut is a light-demanding species but still able to live under shade of up to 25% of canopy openness. The species is quite drought tolerant and can grow on less fertile soil. The wood is straw coloured and very light weight (specific gravity of 0.35 g/cm^3) and can be burned as a low-quality fuel (Elevitch and Manner 2006).

Location

The study was conducted in Bantaeng District, South Sulawesi Province, Indonesia, in a relatively dry climate zone (Faridah et al 2012). Bantaeng is located at 5º21'23"–5º35'26"S and 119º51'42"–120º5'26"E, with a total area of 395.83 km^2.

Agroforestry plays an important role in local livelihoods in Bantaeng, with candlenut and kapok as two of the most important species (Khususiyah et al 2012). Measurement and observation in this study was conducted in sub-districts dominated by candlenut and kapok: Bissapu, Eremerasa, Pa'jukukang, Sinoa and Gantarang Keke.

Method

Data was collected using a combination of biophysical measurements and individual interviews with farmers to obtain their perceptions and local knowledge of candlenut and kapok growth and production. Measurements were conducted during the fruiting season of kapok and candlenut, that is, from August to October 2013 for kapok and from September to November 2014 for candlenut (Munawir 2013, Lanisa 2015).

Tree gardens that contained kapok and candlenut were selected as study sites in each sub-district. Interviews were conducted with the owners of the tree gardens regarding the previous year's production of individual kapok and candlenut trees. The owners were asked to measure the individual trees in their gardens. The tree characteristics measured were tree size (diameter at breast height (DBH)), Crown Position Index (CP) and Crown Form Index (CF). CP is an index of light gap above the canopy while CF is an index of crown condition. CP values 1 through 5 are illustrated in Figure 1 and CF values 1 through 5 are illustrated in Figure 2. CP and CF are good predictors of tree-growth competition (Vincent 2002).

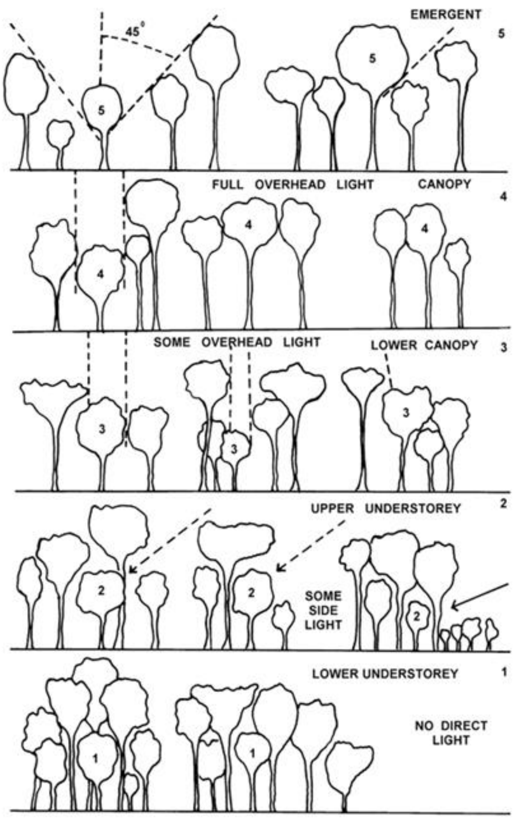

Figure 1. Crown position index

Source: Alder and Synnott (1992)

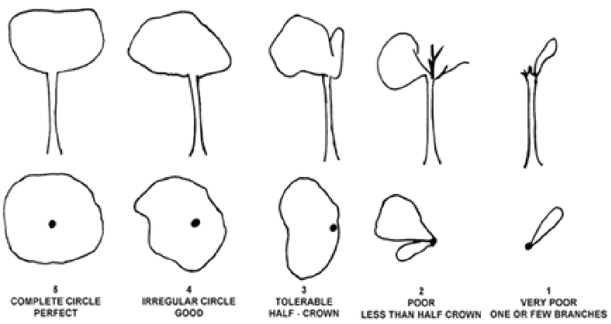

Figure 2. Crown form index

Source: Alder and Synnott (1992)

In this study, 510 trees of kapok and 473 trees of candlenut, with diameters ranging 10–150 cm, were measured (Munawir 2013, Lanisa 2015). Fifteen farmers were interviewed to obtain information on candlenut and 27 farmers were interviewed for kapok.

Data analysis

The kapok and candlenut yields' model used a general linear model with key variables: DBH, CP and CF. All analyses used R software version 3.2.1 (R Core Team 2015) and R Studio version 0.99.467 (R Studio Team 2015).

3. Results and Discussion

Correlation between yields based on farmers' perceptions of tree characteristics

Correlation between yields based on farmers' perceptions with measured tree characteristics can be different between species because each species has its own unique characteristics. Different tree characteristics (DBH, CP and CF) were plotted against yield. Linear regression was applied to obtain the correlation coefficient and general linear model with interaction between yields and DBH, CP and CF.

Kapok

Correlation between yield and diameter in kapok trees showed that only 59% of yield was explained by diameter (Figure 3.). The other 41% was explained by other factors, including tree conditions, ecological factors, respondent subjectivities and other unknown factors.

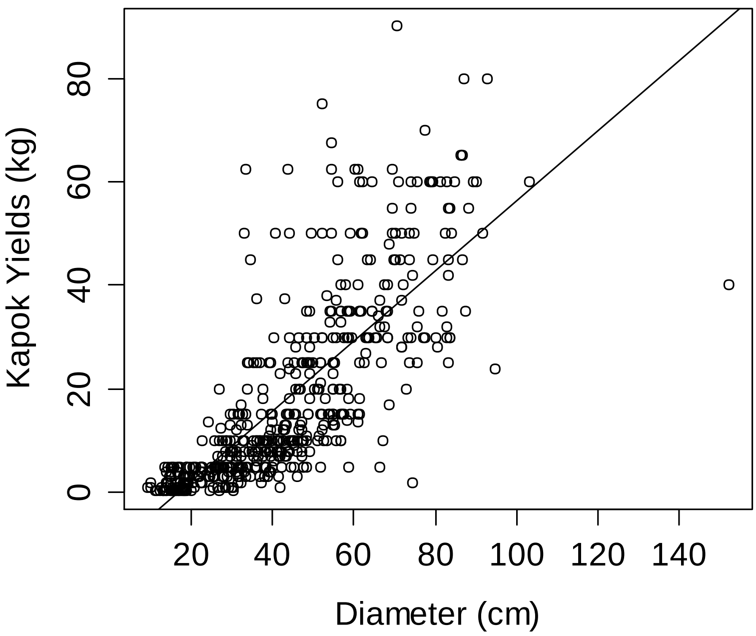

Figure 3. Correlation between yields based on farmers' perspectives

Note: Diameter (cm) measured from 510 individual kapok trees (r=0.585)

If CP and CF as indicators of ecological factors and tree conditions were included in the correlation model estimation, the correlation between yields with DBH, CP and CF increased to 75% from 59%. The model prediction used to calculate the correlation between kapok yields, diameter, CP and CF index was:

$$Yields = -3.55 + (-0.31+0.11CP+0.15CF) * Diameter$$

Where: Yields is kapok yields in kg; CP and CF index in 1–5 scale; Diameter is DBH in cm.

Distribution of measured trees were not equally distributed per group of CP and CF. Most of the measured kapok trees had CP=3 and CF=3 because most of the kapok trees occurred in monocultural systems or simple mixed agroforestry containing a few other species, such as teak or candlenut. Correlation between diameter and kapok yields varied between CP and CF categories (Figure 4). CP 1 and CF 1 both have significantly different linear regression trends if compared to CP and CF of other categories. This is because in CP 1 and CF 1, the trees have lower production.

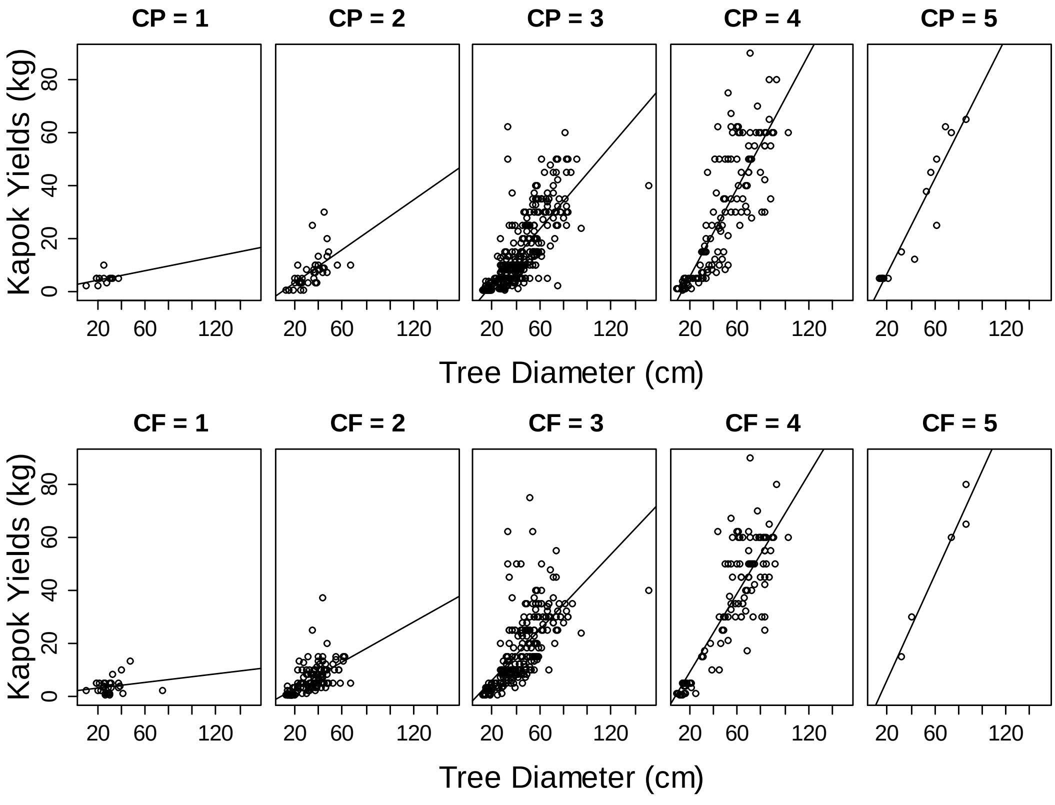

Figure 4. Correlation between kapok yields with diameter, CP and CF

Ceiba pentandra is a fast-growing species with annual increases in height and diameter during its first 10 years of about 1.2 m and 3–4 cm, respectively. In forest gaps, tree height growth is 2 m/year (Duval 2009). The crown transparency is 88%, with allometric relation for DBH-Height and DBH-

Crown Width as shown in Figure 5, which was calculated using secondary allometric data from Meilby and Puri (2013), Gawali (2014), Leopold et al (2001) and Majid et al (1998).

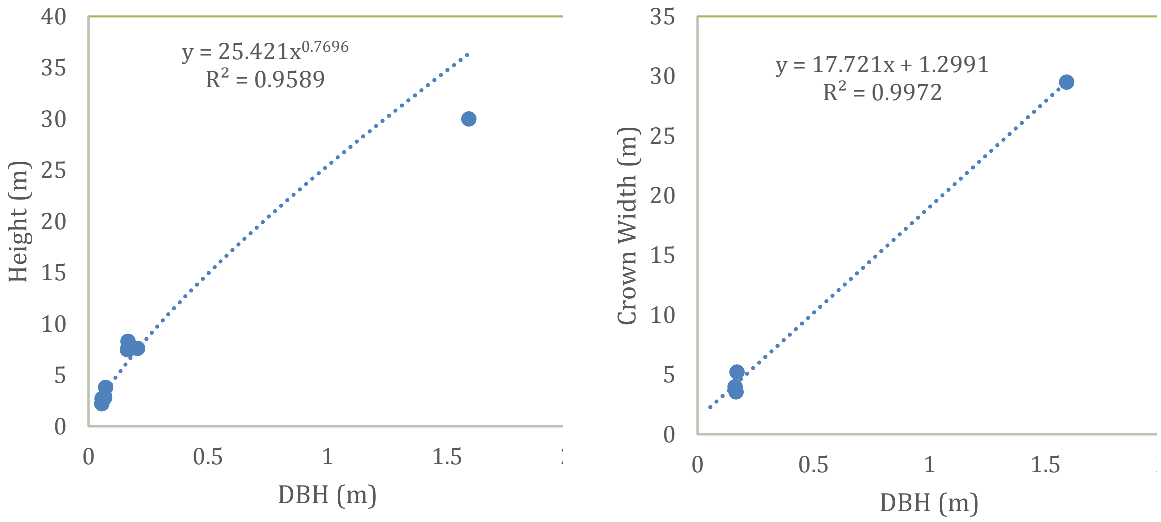

Figure 5. Allometric relation of Ceiba pentandra for DBH-Height and DBH-Crown Width

Candlenut

Correlation between yield and diameter in candlenut trees showed that only 30% of yield was explained by diameter (Figure 6) while the other 70% was caused by other factors, including tree conditions, ecology, respondent subjectivities and other unknown issues.

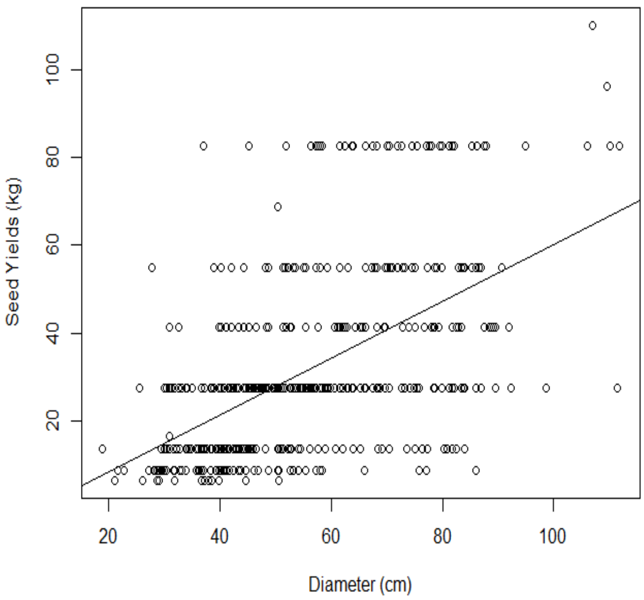

Figure 6. Correlation between yields based on farmers' perspectives

Note: Diameter (cm) was direct measured from 473 individual candlenut trees (r=0.295)

When CP and CF as indicators of ecological factors and tree condition were included in the correlation model estimation, the correlation between yields with diameter, CP and CF increased to 36% from 30%. The correlation was too low, with a possible cause being the fruit collection technique, which is very different compared to kapok. For candlenut, farmers usually collect the fruit that have fallen to the ground, so they are not sure which tree produced the fruit. The model prediction used to calculate the correlation between candlenut yields, diameter, CP and CF was:

$$Yields = 4.16 + (-0.19+0.33CP+0.16CF) * Diameter$$

Where: Yields is candlenut yields in kg. CP and CF index in 1–5 scale. Diameter is DBH in cm.

Distribution of measured trees was not equal per group of CP and CF. Most of the measured candlenut trees had CP=3 and 4, and CF=3 and 4, because most of the trees were in monocultural or simple agroforestry systems with other species, such as teak or kapok. Correlation between diameter and kapok yields varied between CP and CF categories (Figure 7). During measurement, there were no trees that had CP 1 and CF 1 because there were no new plantings in the previous 5 years; candlenut was no longer considered a priority species compared to other more economically valuable species, such as clove and cacao. Correlation between yields with tree diameter for CF 5 had a different trend of linear regression when compared with other correlations.

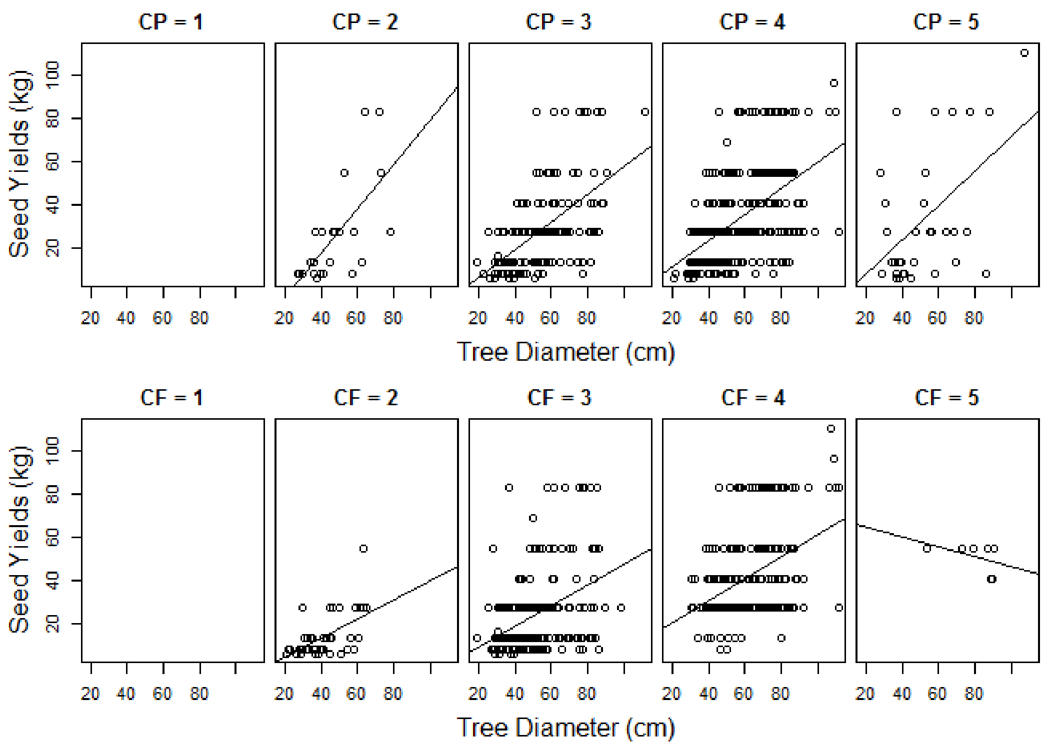

Figure 7. Correlation between candlenut yields with diameter, CP and CF

A study conducted by Rosman and Djauhariya (2006) showed that candlenut production increases up to the age of 20 years and starts decreasing at 70 years. The growth rate of young candlenut trees (3–5

years-old) is about 1.1–4.5 cm/year in diameter and 1.0–2.5 m/year in height (Krisnawati et al 2011). This height growth is greater than the growth rate reported by Elevitch and Manner (2006) in Hawaii: 0.5–1.5 m growth in height per year under favourable conditions. The diameter–height allometry correlation for candlenut was based on observations by Krisnawati et al (2011), as follows: *Height = 1.3 + 34.316 exp(-3.121 exp(-0.044D))*.

Modelling production of kapok and candlenut under various agroforestry systems

Scenarios

For modelling the kapok and candlenut under various agroforestry systems, scenarios were developed based on common practices in the field, with estimated total tree density of kapok and candlenut of 300 trees/ha. Five scenarios were designed based on the composition of kapok and candlenut: 1) Monocultural kapok (100% kapok); 2) Monocultural candlenut (100% candlenut); 3) Agroforestry 1 (AF1) with proportion of kapok and candlenut of 50:50; 4) Agroforestry 2 (AF2) with proportion of kapok and candlenut of 70:30; 5) Agroforestry 3 (AF3) with proportion of kapok and candlenut of 30:70.

The scenarios were vertically projected on 50 x 50 m sampling plot in the SExI-FS model with simulation age of 30 years (Figure 8). The trees were shown as planted at randomized spacings.

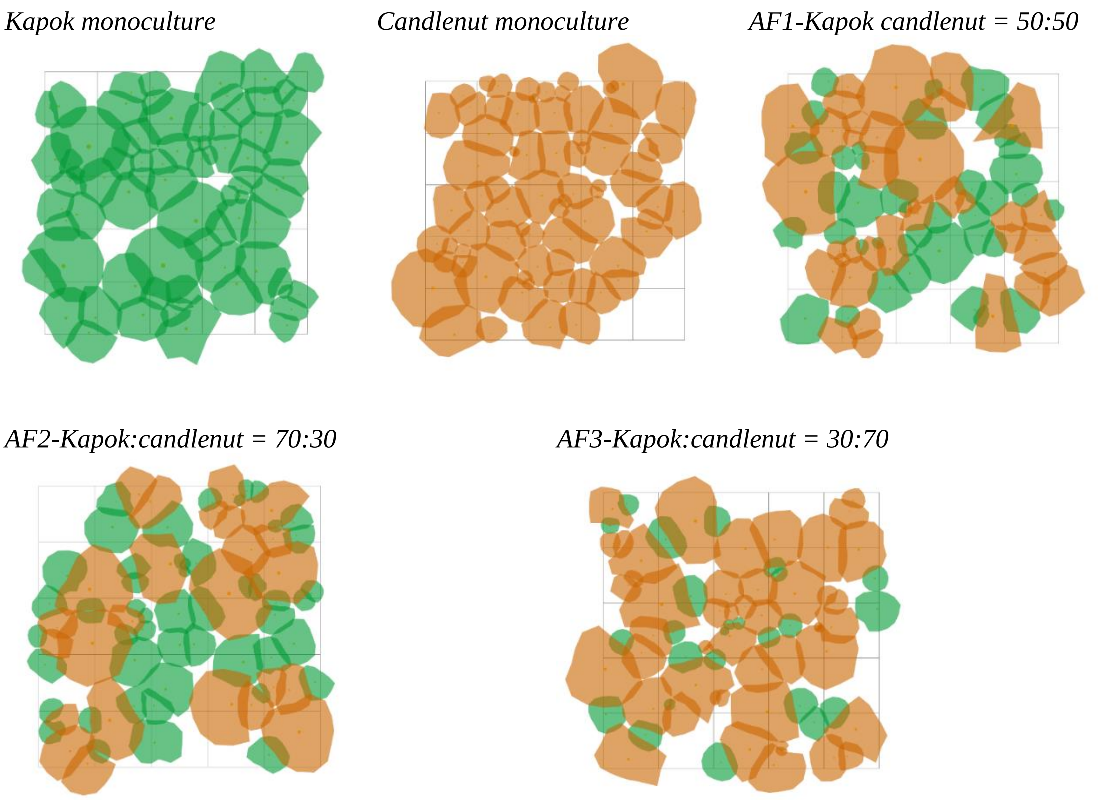

Figure 8. Vertical projection of tree crown by SExI model after 30 years plantation from five simulated scenarios of kapok and candlenut

Modelling

Yield data for modelling the production of kapok and candlenut were based on yield information from farmers and direct measurement in the field on diameter, CP and CF. The models for different scenarios were run for 30 years of simulation age, with the results split based by species, that is, kapok (Figure 9) and candlenut (Figure 10).

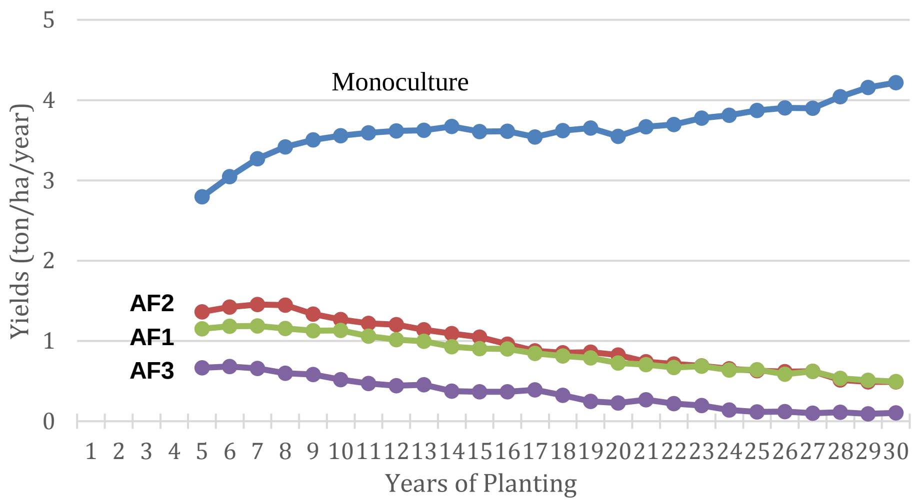

Figure 9. Prediction of kapok yields in 30 years under different scenarios (monoculture, AF1, AF2 and AF3)

Both species have better production in monocultural systems. However, the trend was different between kapok and candlenut after 20 years of simulation: candlenut yields started to decrease while yields increased for kapok. In kapok, there was also a decreasing trend when planted with candlenut under an agroforestry system while candlenut shows an increase in production when grown with kapok under agroforestry systems. Thus, candlenut has higher potential to be grown with other species (including kapok) under agroforestry systems in which at least 70% of the tree component is candlenut.

The results of the modelling were concurrent with empirical observation in another study that showed the average production of candlenut was 10 kg/tree in the first year of fruiting, 25 kg/tree by the sixth year, and 35–50 kg/tree at 10 to 20 years (Tanaka 2002). The tree can reach yields of 50 kg/tree for large trees. Moreover, when candlenut was planted at a density of 200 trees/ha (nearly monoculture), the expected yield of candlenut was about 80 kg of seeds per tree per year (Krisnawati et al 2011). The average yield for candlenut plantations in Indonesia is about 0.35 ton/ha, which is very low, but can reach 2–3 ton/ha under intensive cultivation. In Aceh and North Sumatra, the average yield is up to 1 ton/ha while in South Sulawesi and East Nusa Tenggara yields were only 0.3 and 0.15 ton/ha, respectively (Tanaka 2002).

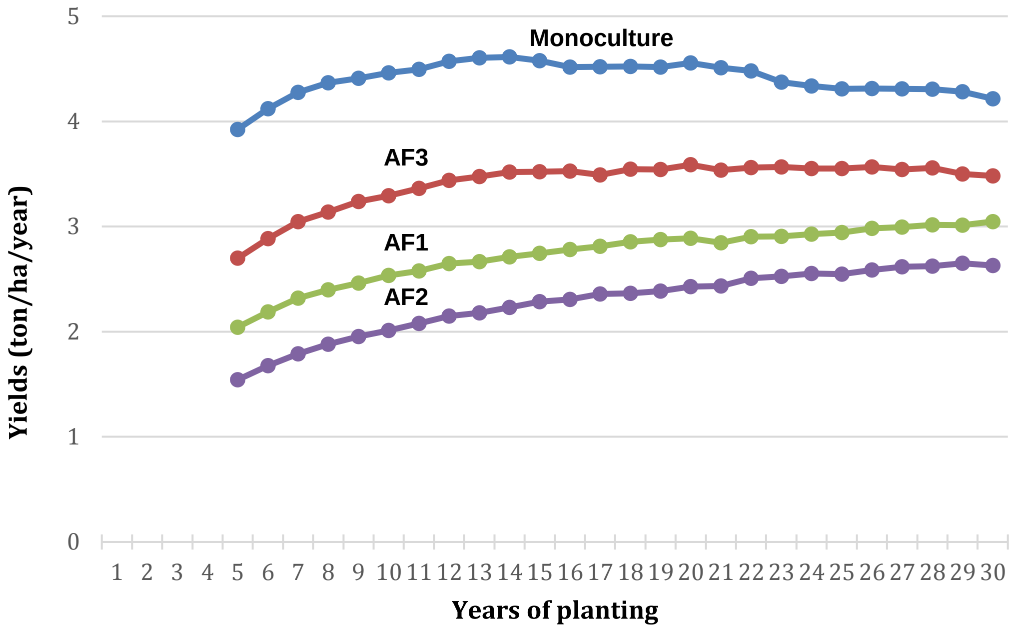

Figure 10. Prediction of candlenut yields in 30 years under different types of scenario (monoculture, AF1, AF2 and AF3)

Based on the simulation models for 30 years, the correlation between kapok and candlenut diameter and yields showed different trends (Figure 11). The plot shows the relationship between tree diameter and yield for 30 years-old trees of varied spacing and growth rates. The average yield of kapok was 16.4 kg/tree, and candlenut was 10.9 kg/tree.

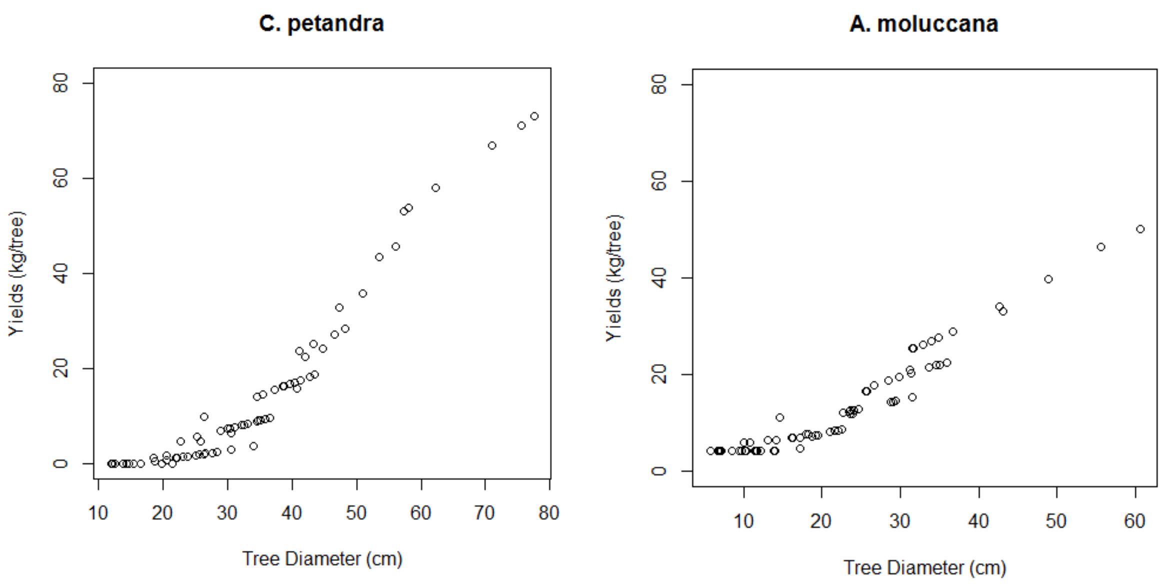

Figure 11. Correlation between yields of kapok *(C. pentandra)* and candlenut (*A. moluccana)* relative to tree size at 30 years-old

4. Conclusion

Data of farmers' perspectives and field measurements demonstrated that there were different levels of correlation between yields and tree diameter of the two species. Farmers' perceptions were more reliable for estimating yields when farmers directly harvested fruit from the trees, as was the case for kapok, compared to candlenut where fruit was collected from the ground. The low correlation index between yields (based on farmers' perspectives) with diameter led to the need to include not only tree diameter in the model but also the CP and CF as variables for better estimation of the yield.

The method introduced in this study is considered a rapid assessment of yield predictions, which is efficient in resources and time allocation. The minimum amount of data to develop a model simulating reliable CP and CF effects is suggested to be 500. This method is valid for species that are grown under natural conditions, without application of fertilizer and pruning. The accuracy of the model for modified genetic (clonal or otherwise improved) material or in more intensively managed tree gardens is not known.

Modelling the yields under various agroforestry systems is useful to predict the species compatibility with other species as shown in this study, that is, the competition between kapok and candlenut. Based on the simulation model, in a mixed kapok–candlenut scenario, candlenut is more competitive than kapok. When kapok is planted with candlenut, it is recommended that candlenut compose a maximum of 30% of the total tree population.

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United Nations Avenue, Gigiri • PO Box 30677 • Nairobi, 00100 • Kenya
Telephone: +254 20 7224000 or via USA +1 650 833 6645
Fax: +254 20 7224001 or via USA +1 650 833 6646
Email: worldagroforestry@cgiar.org • www.worldagroforestry.org

Southeast Asia Regional Program • Sindang Barang • Bogor 16680
PO Box 161 • Bogor 16001 • Indonesia
Telephone: +62 251 8625415 • Fax: +62 251 8625416
• Email: icraf-indonesia@cgiar.org
www.worldagroforestry.org/region/southeast-asia
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