



Spatial Modeling of Land Suitability in Agroforestry Block of Gadjah Mada University's Teaching Forest

Pemodelan Spasial Kesesuaian Lahan pada Blok Agroforestri Kawasan Hutan dengan Tujuan Khusus, Universitas Gadjah Mada

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ABSTRACT

The decision on species to rehabilitate and enhance the villagers' prosperity needs information on land characteristics, plants' growth requirements, and financial prospects. This study aimed to model the suitability of forest plants, fruit plants, and agriculture crops that are in-situ, desired by the community, and has prospecting financial return based on the biogeophysical characteristics of the Agroforestry Block of the Gadjah Mada University's Teaching Forest (KHDTK UGM). The land suitability resulted from matching land mapping unit (LMU) characteristics and the plant's growth requirements. The overlay of slope and soil maps generated LMUs. Soil samples were taken and analyzed to identify the characteristics of each LMU. This research suggested that the highest suitability of planting patterns would result in higher land productivity and community prosperity. The Agroforestry Block with the S₂ suitability class covered only 26.64% of the area. The land characteristics that inhibit the suitability were solum depth, slope, texture, pH, N, P₂O₅, and drainage. This research suggested that agroforestry planting patterns in the S₂ suitability class should combine timber species (teak and mahogany), Leguminosae (lamtoro and gamal) to improve land quality and as the source of cattle fodder, fruits (jack fruit and mango), and farm crops such as pineapple, casava, konjac, and red ginger. In addition, the combination of cajuput and corn was recommended for LMU with the S₂ suitability class for those species.

INTISARI

Penentuan jenis-jenis tanaman untuk rehabilitasi dan peningkatan kesejahteraan hidup masyarakat memerlukan informasi karakteristik lahan dan persyaratan pertumbuhan tanaman serta prospek finansial hasilnya. Penelitian ini bertujuan untuk memodelkan spasial ekologis Blok Agroforestri di Kawasan hutan dengan tujuan khusus (KHDTK) UGM dan kesesuaiannya untuk tanaman hutan, buah-buahan, dan tanaman pertanian yang merupakan tanaman in situ, diinginkan masyarakat, dan memiliki nilai finansial perusahaan yang menguntungkan. Analisis kesesuaian lahan memasangkan karakteristik biogeofisik unit lahan (LMU) dengan persyaratan tumbuh tanaman. LMU merupakan hasil tumpang susun peta kelerengan dan jenis tanah. Karakteristik LMU diidentifikasi dengan survei dan hasil analisis laboratorium sampel tanah. Rekomendasi kombinasi tanaman yang paling tinggi kesesuaiannya diharapkan akan meningkatkan produktivitas lahan dan kesejahteraan masyarakat. Lahan dengan kelas kesesuaian S₂ untuk tanaman hutan dan buah hanya 26,64% luas Blok. Karakteristik lahan pembatas pertumbuhan tanaman adalah: kedalaman solum, kelerengan, tekstur tanah, pH, N, P₂O₅, dan drainase. Pola tanam agroforestri diusulkan untuk dapat mengoptimalkan produktivitas lahan diutamakan untuk jenis yang memiliki kelas S₂ berupa tanaman hutan (jati dan mahoni), leguminosae (lamtoro atau gamal) untuk perbaikan kualitas lahan dan pakan ternak, dan tanaman buah (nangka dan mangga) serta tanaman pertanian (nanas, ubi kayu, porang atau jahe merah). Kayu putih direkomendasikan ditanam bersama jagung pada LMU kelas S₂.

Introduction

The management of teak forests in Java has been carried out for hundreds of years and has faced various limitations, such as technical problems and social conflicts (Peluso 1992). Teak forests in Java commonly lie in densely populated areas with high land and financial demands, which often leads to social issues and threatens forest resource sustainability. Santoso (2004) suggested that the main social problems lie in the demands for timber to fulfill subsistence needs and access to the land/forest resources for the community surrounding the forest areas. Furthermore, Widodo (2013) emphasized that the root problem is in the forest planning and regeneration systems which cannot improve forest productivity. The forest growth has been less than the total cut and mortality. In addition, the yield regulation tends to be monoculture for only teak. There is no other type of timber or non-timber forest products included in the current yield regulation, which leads to non-alignment with the diversity of community needs. Hence, the management system urgently needs to be improved.

A management plan should consider the biogeophysical characteristics of the land, the socio-economic conditions, and the local context dynamics to accommodate the needs of the community surrounding the forests (Senawi et al. 2018). The yield regulation should also consider other types of timber besides teakwood as the main product, including firewood and intermediate income sources for the communities. In this context, production and social management are inseparable.

Agroforestry land use is typical in private forests by combining forest trees, fruit trees, and seasonal crops. The aim is to deal with the high land demand, limited land availability, and other social problems (Suryanto & Putra 2012). Agroforestry is a sustainable management system to increase land productivity,

diversity, and sustainability by integrating trees/forest plants and livestock simultaneously or sequentially according to local customs (Leakey et al. 2006). Studies suggest that agroforestry provides environmental, sociocultural, and economic benefits (Rachmawati 2011; Diniyati et al. 2013; Elonard 2015; & Efendi 2016). However, the unavailability of spatial data with sufficient quality and comprehensive information on land characteristics and suitability for various planting patterns hinders its implementation for large-scale forest management (Ahmad et al. 2017; Ahmad et al. 2019; Rahmawaty et al. 2020). Spatial data is inevitable in land use planning, including terrestrial spatial data for small-size areas and remote sensing data for larger-size areas.

The implementation of agroforestry in the Agroforestry Block (AF Block) of Gadjah Mada University's Teaching Forest (KHDTK UGM) needs to select species suitable for the biophysical characteristics, accepted by the community and have high economic value. Species selection requires information on the biophysical characteristics of the land and its capabilities resulting from land evaluation. Land evaluation is a land resource characteristics assessment to estimate the ability, carrying capacity, or potential for various uses (Senawi 2012). The land evaluation processes involve identifying and interpreting land conditions by comparing various possible uses and effects (Rayes 2007) to show the relative uses (Carr & Zwick 2007). The results provide alternative uses, the limits of the possible use, and the management actions needed for sustainable use under the constraints (Senawi 2007).

Ahmad et al. (2017), Ahmad et al. (2019), and Nath et al. (2021) conducted studies on more general spatial analysis in India and Chuma et al. (2021) in Congo. The analyses exclude species suitability and detailed ecological factors. In the case of KHDTK UGM, detailed information for species suitability analysis is

also unavailable. Therefore, the land unit becomes the approach in this preliminary species suitability analysis. There was no available comprehensive land characteristics inventory and land suitability analysis of KHDTK UGM up to this research. However, this information is a fundamental requirement for land use planning (Hardjowigeno & Widiatmaka 2015). Species suitability resulted from comparing available ecological factors and species growth requirements. This study aims to develop a spatial model of land suitability for forest trees, fruit trees, and seasonal crops in the AF Block of KHDTK UGM. The model considers biogeophysical characteristics and socio-economic conditions of the community surrounding the forest areas.

Materials and Methods

Study Site and Time

This research used the AF Block of KHDTK (Figure 1), which covered 5,191 ha or around 47.6% of the total area. By design, the AF Block dealt with social problems by improving the welfare of the community surrounding the forest areas and rehabilitating land and forest resources. The annual rainfall in this area

was 900 – 1,600 mm/yr, with an annual average air temperature of 27-30°C. The study was conducted from May to October 2020.

Land Mapping Units

This research employed the land evaluation method per land unit to collect and analyze the data. Following Carr & Zwick (2007), the slope and soil-type maps were overlaid using ArcGIS software, resulted the land mapping units (LMUs) and used as the basis for field survey sample selection, species suitability analysis, and planting pattern recommendation in the AF Block. The research area was relatively small and had a relatively similar average annual rainfall, thus rainfall was excluded in LMUs. The field survey aimed at ground-truthing the LMUs in the AF Block and collecting soil sample of each LMU. The LMU inventory and soil survey followed the method proposed by Rayes (2007), using randomly selected samples for each LMU. The soil samples' chemical properties were analyzed by The Soil Laboratory of the Agricultural Technology Research Center, Yogyakarta.



Figure 1. Study Site: Gadjah Mada University's Teaching Forest (KHDTK UGM)

Species Suitability Analysis

This research used interviews and in-situ observation to collect information on the forest and fruit trees analyzed for their suitability in the AF Block. The species were selected based on criteria of local familiarity, social capability, financial feasibility of its cultivation, potential added values for small-medium enterprises (SMEs) development, and community aspiration. The selection resulted in 23 species for the species suitability analysis, consisting of five forest trees, ten fruit trees or *multipurpose tree species* (MPTS), and eight seasonal crops (see Table 1).

This research used the Benefit-Cost Ratio (BCR) as the financial feasibility indicator for agroforestry farming. BCR is the ratio between present value benefits and costs. Agroforestry farming would become profitable if it resulted in a BCR value of more than one or $BCR > 1$ (Gray et al. 1987). However, the BCR value of agroforestry farming for several species

was unavailable. In this case, the Revenue-Cost Ratio (RCR) became the indicator for the financial feasibility. Moreover, there was little research on the financial feasibility of agroforestry farming, combining forest trees, MPTS, and crops. Therefore, this research also included references to monoculture farming. The references on the financial feasibility of *Gliricidia sepium* and *Leucaena leucocephala* were unavailable. However, the species suitability analysis still included these two species considering their benefits for improving soil nutrients. The complete financial feasibility analysis, such as the Net Present Value (NPV), was beyond the scope of this research.

Land suitability analysis used the matching method of the biogeophysical characteristics of each LMU with each plant's growing/ecological requirements (Rachmawati et al. 2020). This research used 11 land characteristics for the analysis (Table 2). This research used suitability classes and growing

Table 1. List of species for suitability analysis in the Agroforestry Block of Gadjah Mada University's Teaching Forest

No	Local Name	Scientific name	Financial analysis information			
			B/C or R/C	Planting distance (m ²)	Source	AF/Mono
Forest Trees						
1	Teak	<i>Tectona grandis</i>	1.49	10x10	Setiawan & Lahjie 2011	AF
2	Mahogany	<i>Swietenia sp.</i>	8.08	3x3	Gusra 2013	AF
3	Sengon	<i>Paraserianthes falcataria</i>	8.40	n.a.	Saputro et al. 2020	AF
4	Eucalyptus	<i>Eucalyptus sp.</i>	2.33	4x4	Wakka & Hayati 2011	AF
5	Kayu putih	<i>Malaleuca cajuputi</i>	1.18	3x1	Kartikawati et al. 2014	Mono
Fruit/Fodder/MPTS						
1	Rambutan	<i>Nephelium lappaceum</i>	4.50	10x10	Sitanggang & Norhalimah 2014	Mono
2	Cacao	<i>Theobroma cacao</i>	8.10	4x4	Sofyan et al. 2015	AF
3	Cashew	<i>Anacardium occidentale</i>	2.87	n.a.	Solehuddin et al. 2008	Mono
4	Jackfruit	<i>Artocarpus heterophyllus</i>	1.60	n.a.	Ristek.go.id 2000	Mono
5	Sapodilla	<i>Manilkara zapota</i>	6.21	n.a.	Midiandyah et al. 2022	Mono
6	Petai	<i>Parkia speciosa</i>	1.77	n.a.	Febryano 2008	AF
7	Avocado	<i>Persea americana</i>	7.07	n.a.	Tamalia et al. 2019	Mono
8	Mango	<i>Mangifera indica</i>	3.60	n.a.	Muhlis et al. 2017	Mono
9	Lamtoro	<i>Leucaena leucocephala</i>	*	-	-	-
10	Gamal	<i>Gliricidia sepium</i>	*	-	-	-
Annual/Seasonal Crops						
1	Banana	<i>Musa paradisiaca</i>	1.28	n.a.	Rinojati et al. 2016	AF
2	Corn	<i>Zea mays</i>	1.90	n.a.	Suryana & Agustian 2014	Mono
3	Cassava	<i>Manihot esculenta</i>	2.56	n.a.	Zaini & Bustomi 2017	Mono
4	Sweet potato	<i>Ipomoea batatas</i>	1.80	n.a.	Andana et al. (2021)	Mono
5	Soybean	<i>Glycine max</i>	1.27	n.a.	Zakaria et al. 2010	Mono
6	Pineapple	<i>Ananas comosus</i>	2.14	n.a.	Pratiwi et al. 2016	Mono
7	Konjac	<i>Amorphophallus muelleri</i>	3.72	n.a.	Rahayuningsih & Isminingsih 2021	Mono
8	Red ginger	<i>Zingiber officinale</i>	1.30	n.a.	Juwitaningtyas 2018	Mono

Remarks: n.a. = not available; *no secondary information was found in the financial analysis of the *Gliricidia sepium* and *Leucaena leucocephala*; AF: the reference is in agroforestry planting pattern; Mono: the reference is in monoculture planting pattern

Table 2. Land characteristics compared to plant growth requirements

No	Characteristics	Unit	Source of information/description
1	Type of soil	Category	A soil type map (KHDTK UGM Manager) and field observations
2	Solum depth	cm	Soil survey/field observation
3	Soil texture	Category	Soil survey/field observation
4	Soil pH	n.a.	Soil survey/field observation
5	N total	%	Lab analysis results on soil samples
6	P ₂ O ₅	mg/100g	Lab analysis results on soil samples
7	K available	mg/100g	Lab analysis results on soil samples
8	Drainage	n.a.	Field observation
9	Inundation/flood	Category	Field observation
10	Slope	%	Slope map (KHDTK UGM Manager) and field observations
11	Rainfall	mm/yr	Secondary data (KHDTK UGM Manager)

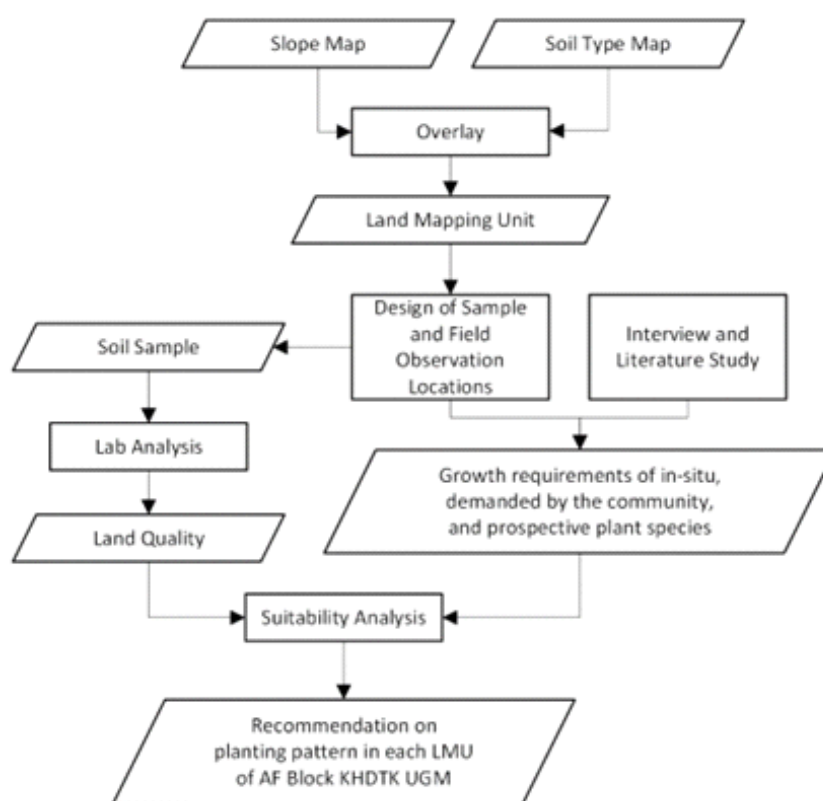
requirements for each species from Ritung et al. (2011). Each LMU was matched with the growing requirements of each species to obtain the suitability class and sub-class for each species (Ritung et al. 2011; Senawi 2012). The suitability analysis resulted in land characteristics that inhibit for each species to grow optimally in each LMU. The lack of detailed LMU data did not allow this research to conduct the spatial model accuracy test.

Recommendations for planting patterns

Plant species suitability and land unit

characteristics, especially growth-inhibiting factors, became the considerations in formulating recommendations on species combination and planting patterns. The suitability analysis included only species with profitable BCR or RCR (Table 1) and potential contributions to increase income for the community surrounding the forest areas. Moreover, the species composition in the recommended planting patterns for each LMU was the best option resulting from simulation based on the considered aspects.

Figure 2 summarizes the research stages.

**Figure 2.** Research flow chart

Results and Discussion

Mapping of Land Units

The overlay of slope and soil types spatial data and regrouping slivers of areas less than 1.25 ha resulted in seven LMUs in AF Block (Figure 3 and Table 3). These LMUs became the basis for determining the field survey samples, soil sample collections, and the formulation of recommendations. The LMU modeled the land characteristics by analyzing its suitability for a particular use/ species planting (Mendoza, 2000). The characteristics of each LMU reflected land suitability for certain species planting based on the evaluated aspects. The LMUs became the basis for recommendations on the best planting patterns to achieve the forest rehabilitation goals and increase community income from the scheduled yields harvested from each species. Actual land cover data could add detailed information on LMUs and consideration for species planting implementation. LMUs with land cover dominated by shrubs or bare

lands, such as LMU-5 and LMU-6, should become the priority for rehabilitation with an agroforestry system.

The class-IV land capability dominates the AF Block, covering around 2,675 ha and accounting for 52% of the total area. The class-IV land capability indicates that the AF Block required urgent rehabilitation to allow optimum utilization and to increase community income. Land degradation might occur due to its natural infertile conditions and low rainfall. The area hosted a monoculture teak plantation for more than a century without species rotation, resulting in selective nutrient depletion. Between the end of the 1990s and early 2000s, this area experienced a massive teakwood plundering following the succession of the New Order regime, resulting in quite large-size bare lands. Many of these bare lands remained unrehabilitated up to this research observation. Bare lands were relatively easy to degrade by the runoffs that transported the solum debris.

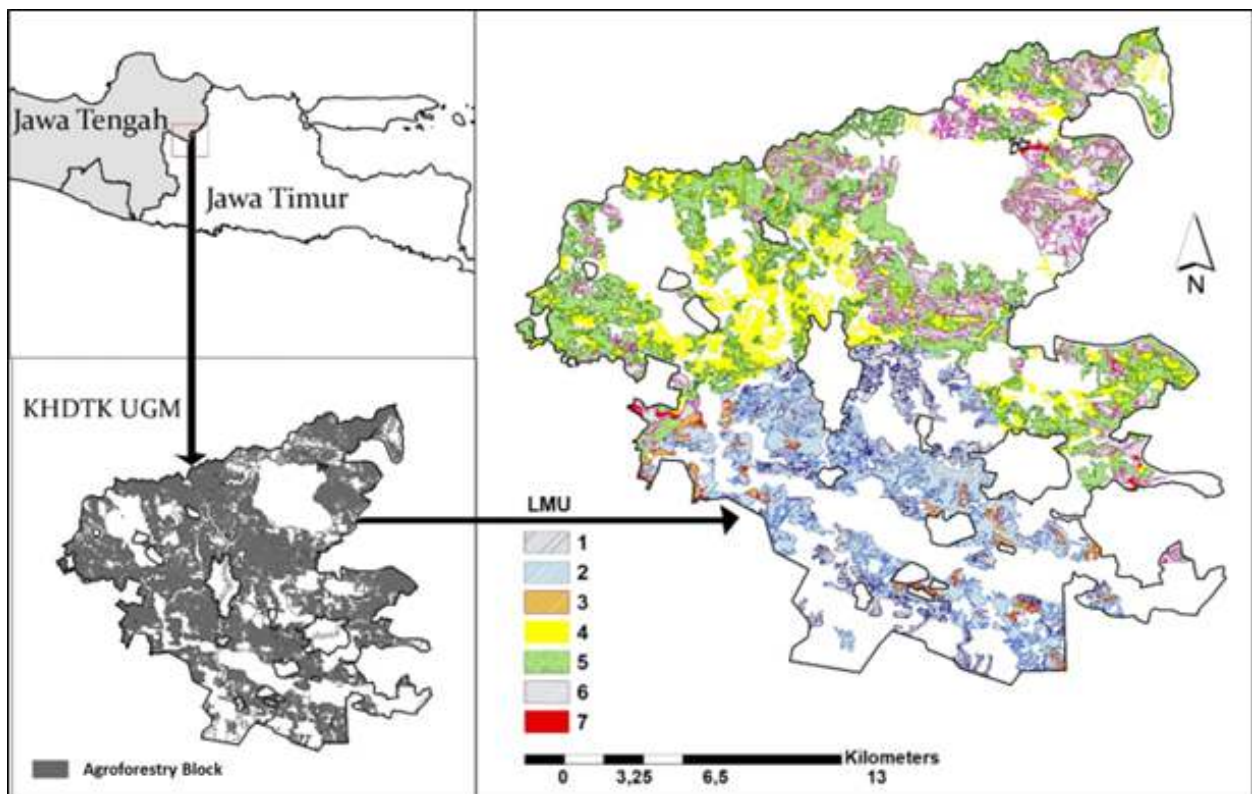


Figure 3. Land Mapping Unit (LMU) Maps of Agroforestry Block for land suitability evaluation

Table 3. Description of land mapping unit of agroforestry block in KHDTK for land-use allocation

LMU	1	2	3	4	5	6	7
Area (Ha)	928,24	570.44	886.71	108.07	1,970.77	704.26	22.33
% total area	17.88	10.99	17.08	2.08	37.97	13.57	0.43
Land Capability Class	II	II	III	III	IV	IV	VI
Slope (%)	0 - <8	0 - <8	8 - <15	8 - <15	15 - <25	25 - <45	>=45
Soil types	Litosol	Vertisol	Vertisol	Vertisol	Litosol	Litosol	Litosol
Soil texture	Medium	Slightly fine, medium	Medium, rough	Rather rough	Rough	Medium, slightly rough	Rough
Effective depth (cm)	>50cm	<30cm	>100cm	>75cm	>60cm	>60cm	<40cm
Rock outcrop (5%)	0	0	< 15	<5	<15	15 - 25	>25
Soil drainage	good	good, moderate	good	good	rather fast	rather fast	very fast
Flood hazard	No	No	Low	Low	Medium	Medium	High

Remark: LMU = land mapping unit; Land Capability Class follows Ogunkunle, et al. (2006)

Species Suitability for Each LMU

Table 4 compiled the result of the sub-class land suitability analysis in the AF Block for each species. LMU-1 was suitable for all species except *Melaleuca cajuputi*, while LMU-2 and -3 were suitable for all species. LMU-4 was suitable for *Melaleuca cajuputi*, rambutan, mango, and jackfruit. LMU-5 was suitable for rambutan, petai, mango, lamtoro, pineapple, and soursop, while LMU-6 was suitable for all crops except

eucalyptus, corn, cassava, and sweet potato. LMU-7 was a marginal land unsuitable for cultivation, especially for seasonal crops.

Eight of 11 land characteristics were growth inhibitors for the species in AF Block (Table 5). These eight characteristics included solum depth, slope, soil texture, pH, total N, P₂O₅, drainage, and puddles or water locks. These inhibitors were conditions in each LMU that needed rehabilitation for improvements to

Table 4. Summary of Suitability Analysis for Agroforestry Block in KHDTK UGM

No	Species	LAND SUITABILITY SUB-CLASS OF AGROFORESTRY BLOCKS							Wide (ha)	
		LMU-1	LMU-2	LMU-3	LMU-4	LMU-5	LMU-6	LMU-7	S ₂	S ₃
1.	Teak	S ₃ -fh	S ₂ -bcfgh	S ₃ -bfh	N ₁ -b,f	N ₁ -f	S ₃ b,c,f	N ₁ -bc	570.4	2,519.2
2.	Mahogany	S ₃ -fh	S ₃ -bef	S ₃ -bfh	N ₁ -b,f	N ₁ -e,f	S ₃ -b,c,f,j	N ₁ -bcej	-	3,089.7
3.	<i>Paraserianthes falcataria</i>	S ₂ -cfgh	S ₃ -f	S ₃ -fh	N ₁ -b,f	N ₁ -f	S ₃ -f	N ₁ -cj	28.2	2,161.4
4.	Eucalyptus	S ₃ -fh	S ₃ -ef	S ₂ -bdfh	N ₁ -b,f	N ₁ -e,f	N ₁ -e,f	N ₁ -bcej	86.7	1,498.7
5.	<i>Melaleuca cajuputi</i>	N ₁ -e	S ₃ -e	S ₂ -befhj	S ₂ -befgj	N ₁ -e	S ₃ -c,j	N ₁ -ej	994.8	1,274.7
6.	<i>Manilkara zapota</i>	S ₂ -cfgh	S ₂ -bcfgh	S ₃ -b	S ₃ -b,h	S ₃ -b,c,j	S ₃ -b,c,j	N ₁ -bcj	1,498.7	3,669.8
7.	Rambutan	S ₂ -cfghk	S ₂ -bcfgh	S ₃ -h	S ₃ -b,f	S ₃ -c,e,f	S ₃ -c	N ₁ -cj	1,498.7	3,669.8
8.	Jackfruit	S ₂ -cefgh	S ₂ -bcfgh	S ₃ -bh	S ₃ -b,f	N ₁ -e	S ₃ -bcj	N ₁ -bcej	1,498.7	1,699.0
9.	Petai	S ₂ -cfghk	S ₂ -bcfgh	S ₂ -bfh	N ₁ -b	S ₃ -c,e,f	S ₃ -c	N ₁ -cj	2,385.4	2,675.0
10.	Avocado	S ₃ -fh	S ₂ -bcfgh	S ₃ -f	N ₁ -b	N ₁ -e	S ₃ -bcfj	N ₁ -bcej	570.4	2,519.2
11.	Mango	S ₂ -cfghk	S ₂ -bcfgh	S ₃ -bh	S ₃ -b,f	S ₃ -bcfj	S ₃ -bcj	N ₁ -bcj	1,498.7	3,669.8
12.	Cashew	S ₂ -cfghk	S ₂ -bcfgh	S ₃ -bh	N ₁ -b	N ₁ -e	S ₃ -bc	N ₁ -bcej	1,498.7	1,591.0
13.	Cocoa	S ₃ -f	S ₃ -f	S ₃ -bf	N ₁ -b	S ₃ -c,f,j	S ₃ -cfj	N ₁ -b,c,j	-	5,060.4
14.	Lamtoro	S ₂ -cghk	S ₂ -bcegh	S ₂ -bh	N ₁ -b	S ₃ -c,e	S ₃ -c	N ₁ -bce	2,385.4	2,675.0
15.	<i>Gliricidia sepium</i>	S ₃ -f,k	S ₃ -e,f	S ₂ -bfh	N ₁ -b,f	N ₁ -e,f	S ₃ -c,f	N ₁ -bcej	886.7	2,202.9
16.	Pineapple	S ₂ -cfghk	S ₃ -b,e	S ₂ -bfh	N ₁ -b	S ₃ -bcef	S ₃ -b,c,j	N ₁ -e	1,815.0	3,245.5
17.	Banana	S ₂ -cfghk	S ₂ -bcfgh	S ₃ -b	S ₃ -b	S ₃ -b,c,j	S ₃ -b,c,j	N ₁ -bcj	1,498.7	3,669.8
18.	Corn	S ₃ -c,h	S ₃ -c,e	S ₃ -h	S ₃ -b	N ₁ -c,e	N ₁ -c	N ₁ -cej	-	2,493.5
19.	Cassava	S ₃ -c,f	S ₃ -c,f	S ₃ -bf	S ₃ -b,h	N ₁ -c	N ₁ -c	N ₁ -bcj	-	2,493.5
20.	Sweet potato	S ₃ -c	S ₃ -c	S ₃ -b	S ₃ -b,h	N ₁ -c	N ₁ -c	N ₁ -bcj	-	2,493.5
21.	Soybean	S ₃ -h	S ₂ -bcfghi	S ₃ -bh	S ₃ -b	S ₃ -bcj	S ₃ -bcj	N ₁ -bcj	570.4	4,598.1
22.	<i>Amorphophallus muelleri</i>	S ₃ -b,h	S ₃ -f	S ₃ -f	S ₃ -bf	S ₃ -bcfj	S ₃ -bcj	N ₁ -bcj	-	5,168.5
23.	Red ginger	S ₃ -b,h	S ₂ -cgh	S ₂ -bcgh	S ₃ -b	S ₂ -cghk	S ₂ -bcegh	N ₁ -bcj	4,132.2	1,036.3

Remark: S/N = suitability order follows (FAO 1976), S=suitable; N: not suitable; S₁-3: highly, moderately, and marginally suitable; N₁: currently not suitable; lower case letters follow the suitability class = kinds of limitations, such as solum (b), slope (c), etc, see Table 5 for the details.

Table 5. Limiting Factors of land characteristics in AF Block of KHDTK UGM for each plant's suitability

No.	Type of plants	Characteristics of land limiting growth	
		Symbol	Symbol Description
1.	Teak	b, f, c, h, g	Solum, soil pH, slope, phosphate, total N
2.	Mahogany	b, f, c, e, h	Solum, soil pH, slope, soil texture, phosphates
3.	Paraserianthes falcataria	b, c, f, j, h	Solum, slope, soil pH, drainage, phosphate
4.	Eucalyptus	b, e, f, c, h	Solum, soil texture, soil pH, slope, phosphate
5.	<i>Malaleuca cajuputi</i>	c, b, j, f, h	Slope, solum, drainage, soil pH, phosphate
6.	<i>Manilkara zapota</i>	b, c, j, h, f	Solum, slope, drainage, phosphate, soil pH
7.	Rambutan	b, c, e, f, h	Solum, slope, soil texture, soil pH, phosphate
8.	Jackfruit	e, b, f, h, c	Soil texture, solum, soil pH, phosphate, slope
9.	Petai	b, c, j, e, f	Solum, slope, drainage, soil texture, soil pH
10.	Avocado	b, c, e, j, f	Solum, slope, soil texture, drainage, soil pH
11.	Mango	b, c, j, f, h	Solum, slope, drainage, soil pH, phosphate
12.	Cashew	b, c, e, j, h	Solum, slope, soil texture, drainage, phosphate
13.	Cocoa	b, c, j, f	Solum, slope, drainage, soil pH
14.	Lamtoro	b, c, e, g, h	Solum, slope, soil texture, N-total, pospat
15.	<i>Gliricidia sepium</i>	b, e, f, k, j	Solum, soil texture, soil pH, inundation, drainage
16.	Pineapple	b, e, c, f, j	Solum, soil texture, slope, soil pH, drainage
17.	Banana	b, c, j, f, g	Solum, slope, drainage, soil pH, N-total
18.	Corn	c, e, j, b, h	Slope, soil texture, drainage, solum, phosphates
19.	Cassava	c, b, j, f, h	Slope, solum, drainage, soil pH, phosphate
20.	Sweet potato	c, b, j, h	Slope, solum, drainage, phosphate
21.	Soybean	b, c, j, h, f	Solum, slope, drainage, phosphate, soil pH
22.	<i>Amorphophallus muelleri</i>	b, c, j, h, f	Solum, slope, drainage, phosphate, soil pH
23.	Red ginger	b, c, g, h, j	Solum, slope, N-total, phosphate, drainage

provide the required optimum growing conditions for each species. Various soil conservation techniques could be pursued based on the characteristics of each LMU. For example, on an LMU with severe degradation, changing the planting pattern along the contour and establishing dikes or terracing could become the start.

Besides technical soil conservation, land rehabilitation by planting vegetation in an agroforestry system could contribute to soil conservation and provide financial benefits for the community surrounding forest areas. Agroforestry contributed significantly to land management by integrating agriculture and forestry in the same space and time (Widianto et al. 2003). For this reason, Senawi et al. (2018) suggested the formation of the AF Block in KHDTK UGM. The species combination between forest trees and crops could minimize erosion, control weeds, and provide renewable energy, food for the community (Ellis et al. 2000; Rachmawati, 2011), and fodder. The community combined forest trees and crops in various forms, such as community forests, home gardens, and mixed farms (Soraya,

2017). Communities could implement an agroforestry system with their local wisdom, creating optimism and opportunity for developing, empowering, and conserving land and forest resources.

Table 5 lists all species in the analysis suitable for cultivation in the AF Block. Technical soil conservation, land rehabilitation with vegetation, and additional fertilizers (phosphate and dolomite) to improve solum were required to avoid further degradation and improve land productivity. These efforts would improve the condition of marginal land (S₃) to moderate suitability (S₂).

The detailed productivity calculation on the research area could improve the results of the financial feasibility analysis. When detailed data with sufficient resolution were available, land suitability analysis could include the productivity of each species and employ a non-deterministic approach. For example, Nabati et al. (2020) modeled crop suitability in semi-arid regions of Iran using GIS and a fuzzy approach. The KHDTK UGM should design the post-harvest processing for the products of the AF Block.

The analysis indicated that all species were

suitable for combined cultivation in an agroforestry pattern. There is no available research on adopting these species by the community to complement the recommendation on the suitability of the species. Establishing demonstration plots could provide best-practice examples of the agroforestry system based on the species-land suitability and provide complete information for detailed financial feasibility analysis.

Teak could produce high-quality timber and profits for its producers. All parts of the teak tree, such as timber, bark, roots, leaves, and fruit, could be used for shipbuilding, building materials, food wrapping, and decorations (Heyne 1987). The KHDTK UGM was a teak plantation forest under Perhutani, a state-owned enterprise. The KHDTK UGM also used teak for land rehabilitation of unproductive lands. Setiawan & Lahjie (2011) revealed that cultivating short-rotation teak (25 years) in an agroforestry system combined with elephant grass resulted in almost IDR 80 million. Riyanto (2012) analyzed the prospect of cloned teak cultivation with a 20-year cycle around the study location and showed promising financial benefits.

Besides teak and pine, mahogany became one of the species planted and managed by Perhutani. Mahogany could grow well in areas that lack water. It often became the roadside shade trees, air filters to reduce pollution, and hydrological regulators (Mukson et al. 2021). Mahogany fruit could improve blood circulation, reduce cholesterol, and act as an antioxidant to eliminate free radicals. Mahogany produced high-economic-value timber, reaching more than IDR 3 million per meter cubic. The timber was hard and suitable for furniture, carvings, and handicrafts. The wood was easy to work with and was the second favorite in the timber market after teak (Widyorini 2014; Listyanto et al. 2016). The bark was a source of clothing dye, and the leaves were a source of fodder.

Melaleuca cajuputi was a crucial species in marginal land rehabilitation. It could adapt to acidic, water lock, and dry soils (Mansur 2013). It could repair degraded into more productive land (Kartikawati et al. 2014) and mainly cultivated in agroforestry and Taungya systems (Suryanto et al. 2017). Sadono et al. (2019) and Budiadi et al. (2005) also reported that *Melaleuca cajuputi* could live and produce essential oils on various soil chemical properties and planting patterns.

Jackfruit was originally from India and spread to tropical areas, including Indonesia. Its fruits could be consumed directly or made into flour for the food industry. The leaves could become fodder, and the timber was suitable for building construction, wood moldings, and musical instruments (Prihatman 2015).

Mango became a potential export commodity. Its seeds could be used as fodder, while the young leaves were edible. The timber was relatively strong, hard, and had a high calorific value, making it suitable for charcoal material (Supriatna & Sudana 2018).

Lamtoro and *Gliricidia sepium* contained high protein and became suitable for fodders. Leguminosae could improve soil conditions and prevent soil erosion due to deep roots (Nasjum 2020). These plants reached a height of 10-20 m with low and abundant branches. The young lamtoro fruits were edible, while the wood had a calorific value of 4,168 kcal/kg (Cahyono et al. 2008) that suitable for charcoal. The financial feasibility analysis for Lamtoro and *Gliricidia sepium* was unavailable, and their financial benefits were unknown. However, their potential contribution to improving soil nutrients and fodder indicated a productive investment, although this needed further research.

Pineapple could only regenerate vegetatively with its crown. It was pseudo, a collection of fruits that looked like scales with a sweet taste and was rich in vitamin C (Pratiwi et al. 2016). Lampung Province

hosted large-scale pineapple cultivation with several fruit processing factories. The KHDTK UGM could adopt this pineapple industry as a small-medium enterprise.

Amorphophallus muelleri was a tuber plant that grew in the forest. Its tubers contained glucomannan with healthy and high economic values and became a potential export commodity (Rahayuningsih & Isminingsih 2021). The processed product of *Amorphophallus muelleri* was konjac flour, a raw material for the jelly-making industry, capsule shells, adhesives in paper making, and others (Nugraha 2016).

The red ginger rhizome was used in traditional medicine because it contained various active compounds (Sujianto & Wahyudi 2015). Ginger rhizome extract became an active antioxidant consisting of polyphenol components as a contributor to hydrogen atoms or electrons to capture free radicals (Stoilova et al. 2007) and lowers blood sugar levels (Taghizadeh et al. 2007).

Soybean became the primary source of vegetable protein and the essential ingredient for soy sauce, tofu, and soy cake. The cultivation of soybeans could occur in dry farms or wet paddy fields at the end of the rainy season, after the rice harvest, and involve minimum land preparation. Its nodule roots could fix free nitrogen. Soybeans become an essential source of fodders and green manure. Soybean consumption in Indonesia was still relatively high, and its supply was mainly from imports (Zakaria et al. 2010). Its prices were quite reasonable due to the high demand. Therefore, it opened an opportunity to cultivate soybean in the AF Block.

Cassava tubers and leaves became a source of carbohydrates and vegetables. It also contained the amino acid methionine as a source of protein (Noviadi et al. 2014). Its tubers had a short shelf life, even in the refrigerator. Symptoms of damage included the

development of a dark blue color because of the formation of toxic cyanide. This plant could be harvested at any time and was often called an underground food supply warehouse. Cassava became one of the staple food ingredients, after rice and corn. Its cultivation increased following its demands (Zaini & Bustomi 2017). On Java Island, tapioca flour became the main product of processed cassava. Cassava production could become an opportunity for KHDTK UGM to increase community income and improve local food security.

Corn production adopted an agribusiness approach (Suryana & Agustian 2014) and could increase farmers' income because of its short production period of three to four harvests a year. It was a relatively easy plant and could grow under forest trees to avoid monoculture plantations and to control pests and diseases (Elonard 2015). The trees could improve the corn's microclimate, soil condition, and water availability (Yuhono & Suhirman 2006). The community surrounding the forest had planted corn.

Recommendations for planting patterns

The Agroforestry planting patterns combined the recommended species in Table 6 and visualized them in Figure 4. LMU-1, LMU-2, LMU-3, and LMU-6 could combine teak or mahogany as the primary commodity and lamtoro or *Gliricidia sepium* as the borders. LMU-4 with suitability class S₂ could combine one or more MPTS, such as jackfruit or mango, as borders or intercrop with crops such as *Amorphophallus muelleri*, pineapple, soybean, and red ginger. LMU-5, with marginal suitability class S₃ for teak, mahogany, and MPTS, could apply a similar planting pattern. LMU-5 needed more rehabilitation efforts than LMU-1, LMU-2, LMU-3, and LMU-6. LMU-5 required species from the Leguminosae family that could improve soil nutrients and become the source of fodder, such as lamtoro and *Gliricidia sepium*. Red

ginger was more suitable for LMU-5 (S2) than other species (Table 4). For this reason, LMU-5 could host an intensive red-ginger cultivation.

LMU 2, 3, and 4 could combine *Melaleuca cajuputi* and corn with a cropping pattern proposed by Kartikawati et al. (2014) and Arisandi & Andriani (2006). This pattern consisted of *Melaleuca cajuputi* as the primary commodity and corn as the agricultural crop. The spacing of *Melaleuca cajuputi* trees was 3x1 m, and the corn should have a minimum radius of 0.5 m from the trees (Arisandi & Andriani 2006). Corn harvesting occurred three to four times annually. The harvesting of *Melaleuca cajuputi* used a coppice

system to provide maximum sunlight for the corn. The *Melaleuca cajuputi* cultivation could contribute to land conservation, marginal land utilization, and farmers' income generation. *Melaleuca cajuputi* leaves could also be harvested in relatively short rotations and produce high-economic-value essential oil (Alpina et al. 2013). Alternative combinations within these LMUs were pineapple, soybean, and red ginger as crops with jackfruit or mango as intercrops.

LMU-6 could host the cultivation of *Melaleuca cajuputi* with heavier limiting factors, red ginger with a moderate suitability class, and legumes as borders to improve soil quality and produce fodders. Research

Table 6. Planting pattern for AF Block of KHDTK UGM

LMU	Plants			
	Main	Border	Intercrops	Crops
1	Teak/Mahogany	Lamtoro/ <i>Gliricidia sepium</i>	Jackfruit/Mango	<i>Amorphophallus muelleri</i> , pineapple, soybean, and red ginger
2	Teak/Mahogany	Lamtoro / <i>Gliricidia sepium</i>	Jackfruit/Mango	<i>Amorphophallus muelleri</i> , pineapple, soybean, and red ginger
3	<i>Melaleuca cajuputi</i>	Lamtoro / <i>Gliricidia sepium</i>	Jackfruit/Mango	Red ginger
	Teak/Mahogany	Lamtoro / <i>Gliricidia sepium</i>	Jackfruit/Mango	<i>Amorphophallus muelleri</i> , pineapple, soybean, and red ginger
4	<i>Melaleuca cajuputi</i>	Lamtoro / <i>Gliricidia sepium</i>	Jackfruit/Mango	Red ginger
	<i>Melaleuca cajuputi</i>	Lamtoro / <i>Gliricidia sepium</i>	Jackfruit/Mango	Corn, pineapple, soybean, or red ginger
	<i>Melaleuca cajuputi</i>	Lamtoro / <i>Gliricidia sepium</i>	Jackfruit/Mango	Red ginger
5	Teak/Mahogany	Lamtoro / <i>Gliricidia sepium</i>	-	Red ginger
6	Teak/Mahogany	Lamtoro / <i>Gliricidia sepium</i>	Jackfruit/Mango	<i>Amorphophallus muelleri</i> , pineapple, soybean, or red ginger
	<i>Melaleuca cajuputi</i>	Lamtoro / <i>Gliricidia sepium</i>	Jackfruit/Mango	Red ginger
7	Lamtoro / <i>Gliricidia sepium</i>	Lamtoro / <i>Gliricidia sepium</i>	Short rotation Fruit	-

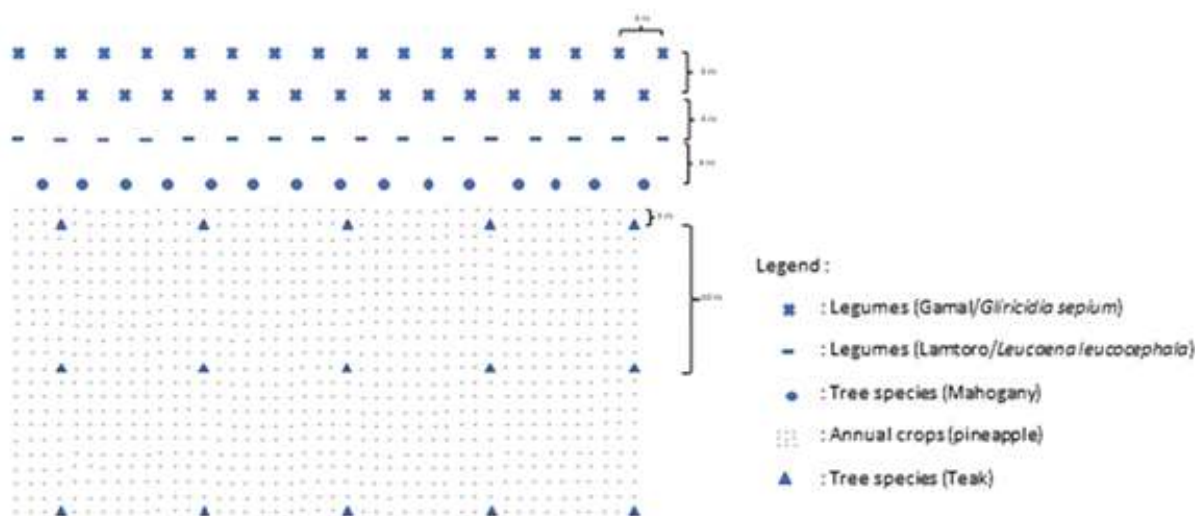


Figure 4. Example of planning pattern for Agroforestry Block area of Gadjah Mada University's Teaching Forest, particularly in LMU 1, 2, 3, dan 6

suggests that *Melaleuca cajuputi* could grow on highly degraded land (ex-coal mines) with relatively cheap inputs, using compost from palm oil waste (Subagio et al. 2018). The community made compost from agricultural and livestock waste in the research area. Combining the species with marginal suitability in this LMU, such as mango, jackfruit, pineapple, and soybean, required further research using detailed primary and supporting data to ensure the financial feasibility of the farming.

Senawi et al. (2018) suggested that some areas of the AF Block (LMU-7) should become a Limited Agroforestry Block due to its marginal suitability. LMU-7 required immediate rehabilitation to improve soil nutrients, using inputs or planting Leguminosae and MPTS to produce fruits. LMU-7 was adjacent to the Protection Block and played a crucial role as the community's buffer zone and source of food and fodders.

There was scant land suitability modeling for agroforestry systems, land rehabilitation, and community welfare. Ahmad et al. (2017) and Ahmad et al. (2019) modeled land suitability for agroforestry in India based on only land characteristics, namely soil nutrients. Rahmawaty et al. (2020) modeled land suitability for one MPTS species (*Lansium domesticum*) in the agroforestry of Langkat Regency, South Sumatra. This research contributed to the spatial modeling of species suitability in AF Block KHDTK UGM by matching the land's main characteristics and the species' growing requirements. However, this research was still explorative and indicative. Further research should consider a detailed spatial database on land characteristics to increase accurate information to support decision-making, particularly in setting management priorities for optimum yields of agroforestry (Ahmad et al. 2017). Mapping the detailed compartments or parcels at the cadaster level could also be done in the future.

Conclusion

Land capability class-IV dominated the biophysical conditions of the lands in AF Block KHDTK UGM, which were unsuitable for intensive utilization and indicated rehabilitation requirements. The suitability analysis showed that no species was highly suitable (S₁) for the AF Block. Around 26.64% of the total block area was moderately suitable (S₂) for forest trees, fruit trees, and annual crops. The remaining area was marginally suitable (S₃) with severe limiting factors or inhibitors. The main inhibitors were solum depth, slope, soil texture, pH, total N, P₂O₅, and drainage. Implementing the agroforestry system could address the technical and socio-economic problems of rehabilitation. Species with moderate suitability (S₂) gained priority for agroforestry implementation in the AF Block. These included forest trees (teak and mahogany), Leguminosae (lamtoro or *Gliricidia sepium*) for fodder and soil nutrients, MPTS or fruit trees as intercrops (jackfruit and mango), and crops (pineapple, cassava, *Amorphophallus muelleri*, and red ginger). LMUs with moderate suitability (S₂) could combine *Melaleuca cajuputi* and corn. Further study should consider detailed information for spatial, species suitability, and financial feasibility analyses to support the participatory decision-making process in KHDTK UGM management.

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