

# SPATIAL ANALYSIS OF LAND SUITABILITY IN THE DEVELOPMENT OF INTEGRATED AGRICULTURE-LIVESTOCK SYSTEM IN GIRIMULYO DISTRICT KULON PROGO REGENCY, SPECIAL REGION OF YOGYAKARTA, INDONESIA

Nurulia HIDAYAH <sup>1</sup><sup>\*</sup>, Adhitya Yoga PURNAMA <sup>1</sup>, Febri ARIYANTI <sup>1</sup>  
& Probo SANTOSO <sup>1</sup>

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## ABSTRACT

This study develops a spatial framework for identifying Calliandra calothyrsus land suitability and operational priority for integrated crop-livestock systems in Girimulyo District, Kulon Progo Regency. The analysis covered 5,372.38 ha and combined commodity screening, Analytical Hierarchy Process (AHP), Spatial Multi-Criteria Analysis (SMCA), and livestock accessibility. Seven plantation commodities were screened before the detailed suitability analysis was focused on Calliandra. Four biophysical criteria, namely elevation, slope, annual rainfall, and land surface temperature (LST), were standardized and weighted using AHP. Slope received the highest weight at 42.36%, followed by rainfall and LST at 22.70% each, and elevation at 12.23%. The SMCA results identified 766.22 ha as S1, 4,340.87 ha as S2, and 265.29 ha as S3, with no N class. To develop the recommendation map, S1 and S2 areas were retained as candidates and combined with Euclidean distance to livestock pens and existing forage-land locations. The operational priority index assigned weights of 60% to biophysical suitability, 25% to proximity to livestock pens, and 15% to proximity to forage land. The resulting primary recommendation zone covered 120.83 ha, comprising 37.09 ha of Very High Priority and 83.74 ha of High Priority. Field accessibility assessment based on 18 unique pen-forage-land observation pairs showed that 13 pairs (72.2%) were within 200 m, with a median distance of 41.3 m. The results demonstrate that integrating biophysical suitability with livestock accessibility can translate land suitability assessment into a more operational spatial recommendation for integrated crop-livestock development. The recommended areas remain subject to site-level verification of land conditions, ownership, water availability, access, actual land use, and livestock feed requirements.

**Keywords:** *Spatial Multi-Criteria Analysis (SMCA); GIS; Analytical Hierarchy Process (AHP); Land suitability; Integrated crop–livestock system; Calliandra calothyrsus.*

## 1. INTRODUCTION

Kulon Progo Regency holds a crucial geostrategic position as the main gateway to the western part of the Special Region of Yogyakarta (DIY), directly connecting it to Central Java, particularly the Borobudur area, designated a National Tourism Strategic Area (KSPN) and a Super Priority Tourism Destination (DPSP). This strategic position is further strengthened by the operation of Yogyakarta International Airport (YIA), which has accelerated infrastructure development, investment, and new economic activities in Kulon Progo. The development of the airport area has triggered significant changes in land use and land cover (LULC), characterized by an increase in built-up areas and rising land values (Rahmawati, 2025). These spatial changes are gradually shifting the region's character from an eco-agrarian base to an eco-tourism and aerotropolis-based area. This situation poses a serious challenge for the farming communities of Kulon Progo. Agriculture remains the backbone of the rural economy. However, development pressures increase the risk of conversion of productive agricultural

<sup>1</sup>Vocational School, Gadjah Mada University, Yogyakarta, Indonesia: [adhitya.yoga.p@mail.ugm.ac.id](mailto:adhitya.yoga.p@mail.ugm.ac.id), [febri.ariyanti@mail.ugm.ac.id](mailto:febri.ariyanti@mail.ugm.ac.id), [probosantoso@ugm.ac.id](mailto:probosantoso@ugm.ac.id)

<sup>\*</sup>Corresponding author [nurulia.hidayah@ugm.ac.id](mailto:nurulia.hidayah@ugm.ac.id)

land to residential areas, trade, and tourism and transportation infrastructure. Without proactive spatial planning interventions, this could reduce agricultural productivity and exacerbate the economic vulnerability of farming households. The Kulon Progo Regency Government, through its Medium-Term Development Plan (RPJMD), has designated the development of agropolitan areas in Kalibawang, Nanggulan, Samigaluh, Kokap, and Wates Districts as an agriculture-based development strategy. Implementation of this policy has not significantly improved the welfare of rural communities. This is due to the lack of integration of local resource potential management with planning that considers the spatial variations in biophysical characteristics of each zone.

The Integrated Crop-Livestock System (ICLS) is an approach to supporting sustainable agricultural development in Kulon Progo Regency. This system integrates crop cultivation and livestock farming in a mutually supportive cycle, where agricultural waste is used as animal feed, while livestock manure is processed into organic fertilizer to improve soil fertility. Various studies have shown that the implementation of ICLS can improve resource efficiency, diversify household incomes, and strengthen environmental sustainability in small-scale farming systems (Devendra & Thomas, 2002; Lemaire et al., 2014).

The potential for livestock development in Kulon Progo is significant, particularly for small ruminants such as goats. Susilo's (2012) research showed that goat herds exhibit a clustered distribution pattern concentrated in Girimulyo and confirmed that GIS-based spatial analysis is highly effective in identifying herd accessibility and potential forage land. Land suitability studies in the coastal area of Kulon Progo also indicate that each sub-region has distinct biophysical characteristics, requiring tailored land-use planning (IPB Repository, 2021). Therefore, the development of an integrated crop-livestock spatial planning framework (ICLS) cannot be carried out uniformly without prior spatial land suitability assessment.

The application of spatial technologies such as GIS, Web-GIS, and precision agriculture is increasingly important in supporting land management and regional planning. Web-GIS-based participatory mapping has proven effective in agricultural land management and participatory District development decision-making (Hamzah et al., 2025). The Indonesian Ministry of Agriculture also emphasizes the importance of integrating digital technology, GIS, IoT, and spatial analysis to support efficient and sustainable modern agricultural development (Ministry of Agriculture, 2023). The GIS-based land suitability index method has been proven to prioritize agricultural development zones objectively and measurably (Fahma & Febriandi, 2024), while the use of multi-temporal satellite imagery has demonstrated its benefits in monitoring changes in the LULC in agriculturally and ecologically important areas (Gambo et al., 2018).

Previous GIS-based land suitability studies in Indonesia have focused on single sectors in isolation, such as cattle grazing suitability in Aceh Besar (Samadi et al., 2021), fish and rice development in Cianjur (Cahyaningrum et al., 2014), and agricultural land evaluation in Ternate (Saleh et al., 2016). Studies that integrate agricultural and livestock land suitability within a single spatial decision support system, particularly in the context of rapid land-use change dynamics, are still very limited. This research gap is the basis for this study. This study evaluates seven plantation commodities in Girimulyo District to produce spatially specific land suitability maps. The research results are expected to serve as a basis for future land-use development.

## 2. STUDY AREA

The final study area for the spatial analysis is Girimulyo District, Kulon Progo Regency, Special Region of Yogyakarta, covering 5,372.38 ha within the final GIS analysis extent. **Fig 1** shows the spatial hierarchy from the Special Region of Yogyakarta to Kulon Progo Regency and Girimulyo District as the geographic unit used for the final suitability and recommendation analysis. Field observations focused on livestock activities were used to support the accessibility analysis, while all final spatial analyses were conducted within the Girimulyo District extent. All Calliandra suitability areas and recommendation zones reported in this manuscript use the 5,372.38 ha Girimulyo District extent.

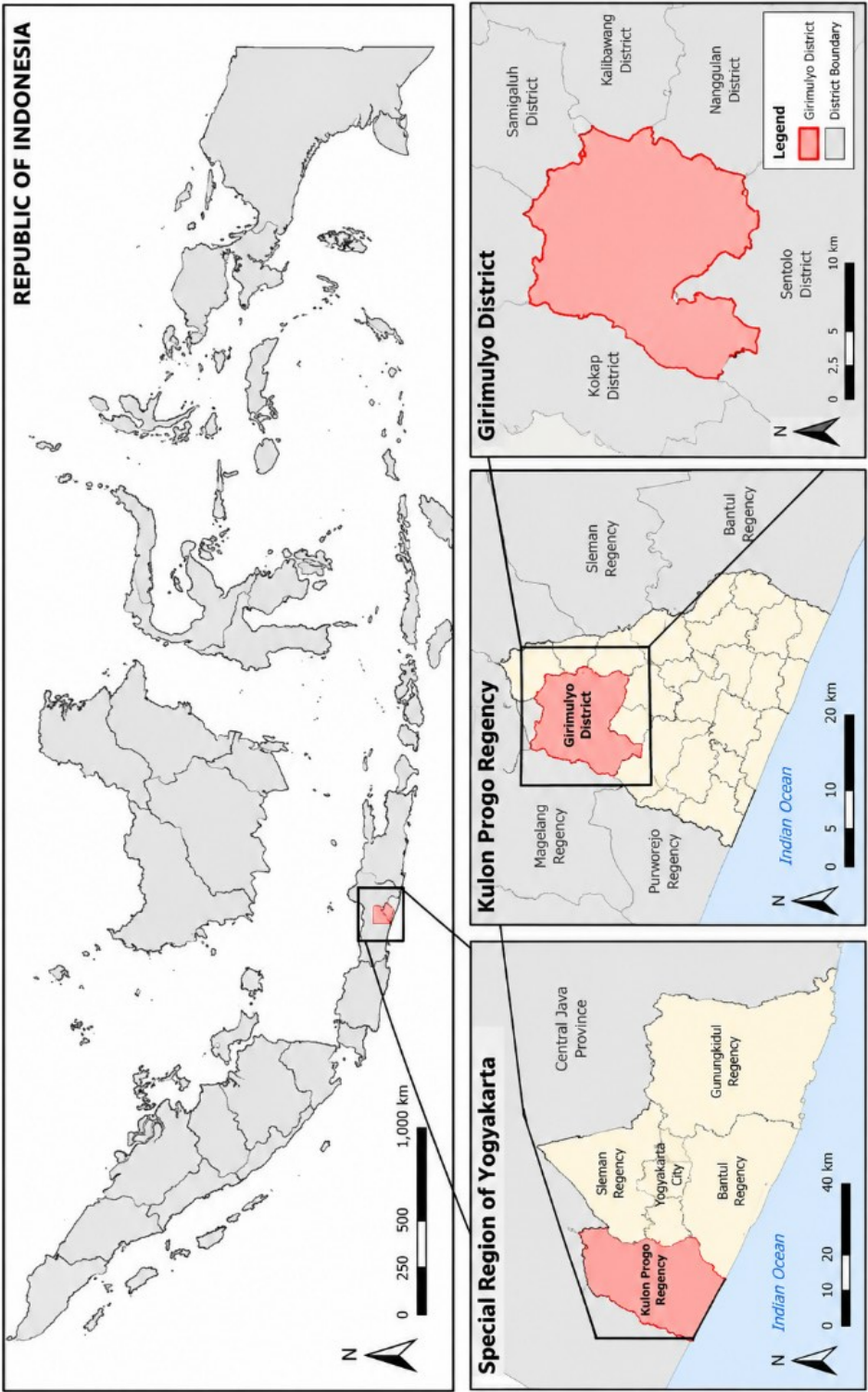


Fig. 1. Map of research location.

## 2.1. Conceptual Framework

Sustainable ICLS development must consider three interrelated dimensions: environmental, economic, and social, which are regulated through regional policies and community traditions. GIS-based spatial analysis was used to evaluate agricultural land suitability, existing LULC patterns, and livestock development potential. Multi-criteria analysis was applied to determine the best land use alternatives and formulate policy recommendations. This study used GIS as the primary spatial framework, consistent with its application in integrated farming-livestock systems research in Indonesia (Samadi et al., 2021; Cahyaningrum et al., 2014; Saleh et al., 2016).

## 3. DATA AND METHODS

### 3.1. Data Collection

#### 3.1.1. Primary Data

Primary data was collected through three field activities: (1) In-depth interviews with farmers, livestock breeders, District officials, and relevant stakeholders; (2) a questionnaire survey to obtain community perceptions, readiness levels, and land use preferences; and (3) a geospatial survey to verify actual land use conditions, agricultural and livestock business locations, accessibility, and validate GIS interpretations.

#### 3.1.2. Secondary Data

Secondary data was obtained from relevant government agencies, including: (1) rainfall data from BMKG/BIG; (2) slope data from the SRTM Digital Elevation Model (DEM); (3) soil type data from Bappeda/BBSDLP; (4) land use and land cover data; (5) distance from roads, rivers, and settlements; and (6) data on the location of livestock groups and existing agricultural businesses.

### 3.2. Land Suitability Analysis

Land suitability analysis was conducted using Spatial Multi-Criteria Analysis (SMCA) in a GIS environment using ArcGIS software. The results of the spatial analysis were integrated with interview data to form a continuous planning process, from actual conditions and stakeholder aspirations to the recommendation development stage.

#### 3.2.1. Spatial Multi-Criteria Analysis (SMCA)

SMCA is a method that combines various biophysical, environmental, and socio-economic spatial criteria, normalized and weighted into a single suitability index in map form. This method has been applied in various sectors: public services (Kurniadhini & Roychansyah, 2020a), industry (Wibowo & Semedi, 2011), and health (Widayani & Yuliantari, 2017). The SMCA process in this study includes: (1) establishing criteria; (2) determining relationships between criteria; (3) weighting using AHP; and (4) determining suitability through weighted criteria scoring.

#### 3.2.2. Criteria Selection

Relevant criteria were established based on the research objectives, characteristics of the study area, and previous literature. Factors considered included: proximity to settlements, distance from livestock pens to forage areas, land cover, and accessibility. Point data (livestock pens, social facilities, settlements) were spatially expanded using Euclidean distance with a 500-meter buffer zone (Kurniadhini & Roychansyah, 2020b). Vegetation density was calculated using the Normalized Difference Vegetation Index (NDVI) from Landsat imagery. A multilevel criteria tree was constructed as a component of a decision support system to focus the research objectives (Misran, Roslin, & Nur, 2020). Biophysical limiting factors for each commodity, including elevation, slope, rainfall, air temperature, soil pH, and land cover, were classified into suitability classes S1 to N2.

#### 3.2.3. AHP Weighting and Consistency Test

Criteria weights were estimated through expert judgment involving professionals in agriculture, animal science, and regional planning (Benítez et al., 2011). Priorities were assessed on a scale of 1–

9 in a pairwise comparison matrix (Saaty, 2008). Consistency was verified using the Consistency Index (CI) and Consistency Ratio (CR < 0.1):

$$CI = (\lambda_{max} - n) / (n - 1) \quad (1)$$

$$CR = CI / RI \quad (2)$$

where n is the number of criteria and RI is the Random Index (**Table 1**).

The weighting procedure used expert judgment from agriculture, animal science, and regional planning. The current study record provides the final criterion weights but does not preserve the respondent count, individual respondent identities, or the original pairwise comparison matrix. These values must be inserted from the original AHP worksheet before final submission and are not reconstructed here. The reported biophysical weights are slope 42.36%, rainfall 22.70%, LST 22.70%, and elevation 12.23%. For the stakeholder AHP, the aspect weights are economic 31.0%, livestock business 22.4%, human resources 20.7%, accessibility 11.2%, environmental 8.7%, and sociocultural 6.1%.

**Table 1.**

**Random Index (RI) values based on matrix size.**

| n  | 1 | 2 | 3    | 4    | 5    | 6    | 7    | 8    | 9    | 10   |
|----|---|---|------|------|------|------|------|------|------|------|
| RI | 0 | 0 | 0,52 | 0,89 | 1,11 | 1,25 | 1,35 | 1,40 | 1,45 | 1,49 |

#### 3.2.4. Suitability Classification

After all criteria were converted to raster format, each criterion was standardized to a common 0–1 suitability scale before weighted linear combination. For benefit criteria, higher normalized values indicate greater suitability, while limiting criteria were transformed so that higher values also represent greater suitability. The AHP weights sum to 1 and control the relative contribution of each normalized criterion. The weighted linear combination (WLC) therefore produces a dimensionless suitability index between 0 and 1, which is expressed as a percentage and classified using **Table 2**. This normalization step prevents criteria measured in different units, such as metres, millimetres per year, and degrees Celsius, from dominating the composite index because of their numerical scale.

$$S = \sum w_i \times x_i \quad (3)$$

where  $w_i$  is the weight of the  $i$ -th criterion and  $x_i$  is the normalized score for each criterion.

The resulting composite score is classified into five suitability categories (**Table 2**).

**Table 2.**

**Land suitability classification system.**

| Normalized suitability | Percentage of maximum | Suitability Class             | Description                                                                      |
|------------------------|-----------------------|-------------------------------|----------------------------------------------------------------------------------|
| 0.80–1.00              | 80%–100%              | S1 (Highly Suitable)          | No significant limiting factors for sustainable land use.                        |
| 0.60–<0.80             | 60%–<80%              | S2 (Moderately Suitable)      | Moderate limiting factors requiring specific management inputs.                  |
| 0.40–<0.60             | 40%–<60%              | S3 (Marginally Suitable)      | Severe limiting factors requiring intensive inputs for sustainable productivity. |
| 0.20–<0.40             | 20%–<40%              | N1 (Currently Not Suitable)   | Very severe limiting factors; technically improvable but at very high cost.      |
| <0.20                  | <20%                  | N2 (Permanently Not Suitable) | Permanent limitations; all biophysical indicators are at minimum values.         |

### 3.3. Recommendation Stage

The recommendation stage is the final analysis phase that synthesizes the results of the land suitability maps to formulate spatial development guidelines for the ICLS. Areas within each suitability category (S1, S2, S3, N1, and N2) are analyzed to determine priority development zones. These results form the basis for land use guidelines, regional development strategies, and recommendations for the local government and community for the implementation of a sustainable and spatially appropriate ICLS in Kulon Progo.

## 4. RESULTS AND DISCUSSIONS

### 4.1. Existing Conditions of Agriculture and Livestock in Girimulyo District

This research was conducted in Girimulyo District, Kulon Progo Regency, Yogyakarta Special Region, Indonesia. This area is part of the Menoreh hills region, characterized by undulating to hilly topography with elevations ranging from 200–800 m above sea level, annual rainfall of 2,000–2,500 mm, and sandy loam soil with an average pH of 5.5–6.5. Administratively, Girimulyo District is located in Girimulyo District, which is the largest concentration of goat herds in Kulon Progo Regency (Susilo, 2012). The existing livestock sector in Girimulyo District demonstrates that goat farming is a complementary economic activity deeply rooted in the community. Goats are raised in a semi-intensive system, housed in permanent pens in residents' yards or gardens. The primary feed comes from natural forage grown in surrounding plantations. However, calliandra plantations are generally located quite far from the pens, requiring farmers to expend extra time and effort collecting feed daily. Part of the manure produced is used as organic fertilizer for the plantations, while the remainder is sold to nearby farmers. This demonstrates that an integrated organic farming-livestock system is already in place, but has not been spatially planned, thus limiting its efficiency. From an agricultural perspective, land in Girimulyo District is dominated by mixed smallholder plantations consisting of coconut, cocoa, coffee, calliandra, sengon, and cardamom. The existing cropping pattern remains extensive and does not consider optimal multi-strata configurations. The dense vegetation cover in the central and western parts of the District indicates significant potential for agroforestry development, while the concentration of agricultural land in the eastern and southeastern parts offers opportunities for direct integration between agricultural residues and livestock feed needs. These existing conditions formed the basis for the SMCA and AHP analyses to identify the optimal configuration for ICLS development in this District.

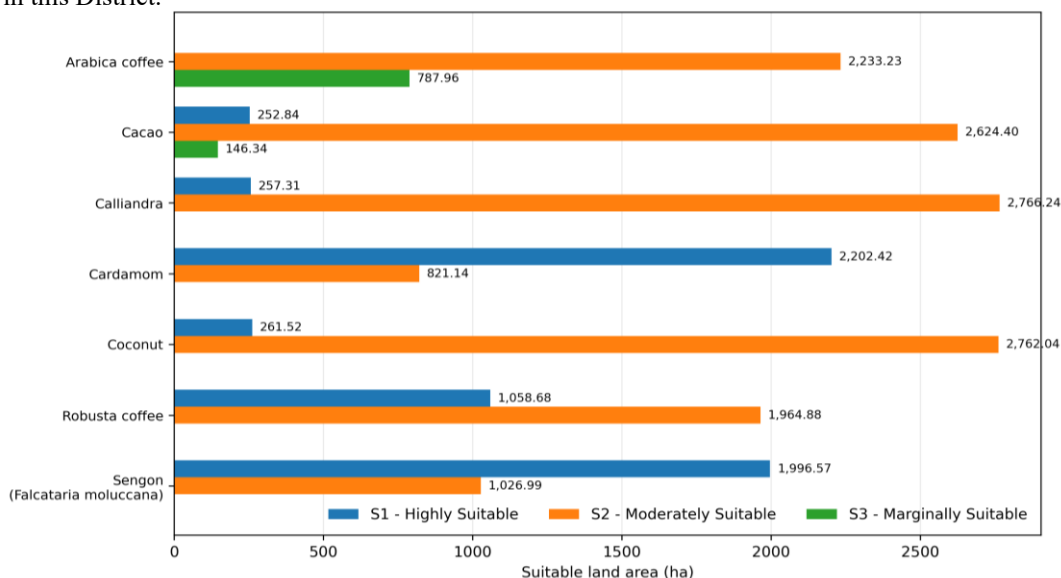


Fig. 2. Potential land suitability area (ha) by commodity and suitability class.

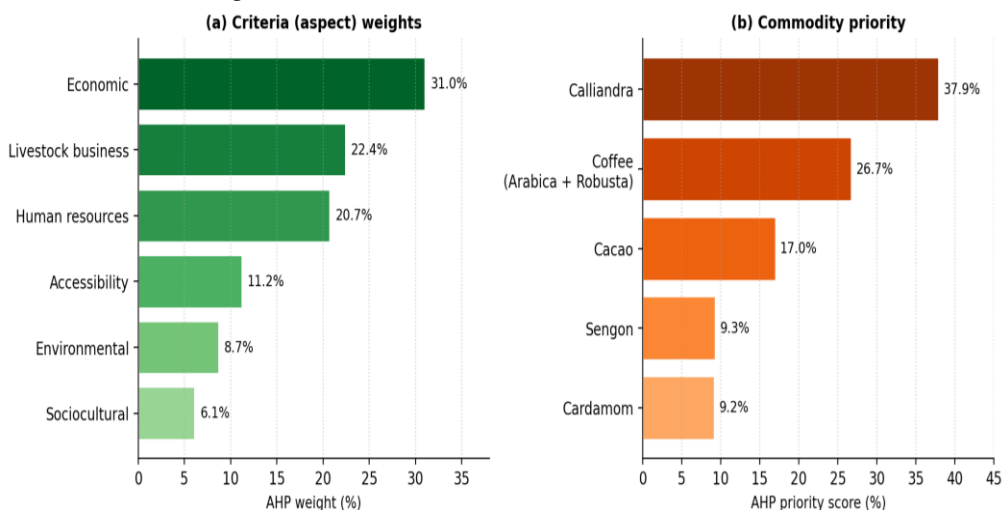
#### 4.2. SMCA Analysis Results: Land Suitability per Commodity

Seven plantation commodities were screened in the initial spatial comparison: Arabica coffee, cacao, Calliandra, cardamom, coconut, Robusta coffee, and sengon (*Falcataria moluccana*). This initial comparison used the 5,372.38 ha Girimulyo District analysis extent. The biophysical parameters included elevation, slope, rainfall, air temperature, soil pH, and land cover. Cardamom recorded the largest S1 area in the initial screening, followed by sengon (*Falcataria moluccana*). Calliandra had 257.31 ha of S1 and 2,766.24 ha of S2, with only 0.02 ha of S3 and no N class in the initial screening. The commodity screening and the focused Calliandra SMCA serve different spatial purposes and therefore should not be compared as if they used identical analytical configurations (**Fig. 2**).

#### 4.3. AHP Analysis Results: Validation of Leading Commodities

The stakeholder AHP evaluated five alternatives, namely Calliandra, coffee, cacao, sengon, and cardamom, based on six aspects: economic, livestock business, human resources, accessibility, environmental, and sociocultural. Seven commodities were retained in the initial spatial screening: Arabica coffee, cacao, Calliandra, cardamom, coconut, Robusta coffee, and sengon. Arabica and Robusta were subsequently aggregated as one coffee alternative in the stakeholder AHP because the questionnaire treated coffee as a single commodity. Coconut remained in the spatial screening as an existing plantation commodity but was not included as a competing candidate in the stakeholder ranking. Thus, seven commodities were screened spatially and five alternatives were evaluated by stakeholder AHP, reflecting two analytical stages rather than an inconsistency.

The economic aspect (**Fig. 3**) received a weight of 31.0% in the stakeholder AHP, followed by livestock business (22.4%), human resources (20.7%), accessibility (11.2%), environmental factors (8.7%), and sociocultural factors (6.1%). The alternative priorities were Calliandra 37.9%, coffee 26.7%, cacao 17.0%, sengon 9.3%, and cardamom 9.2%.



**Fig. 3.** Results of the AHP analysis of the most suitable commodities and aspects.

Accessibility received a weight of 11.2% in the stakeholder AHP, but the final spatial model did not allow accessibility to remain only as a qualitative weighting. Instead, proximity to livestock pens and proximity to existing forage land were explicitly integrated into a separate operational-priority surface. This distinction strengthens the analysis because stakeholder preference and measurable spatial accessibility represent two different forms of evidence.

The stakeholder AHP identified Calliandra as a relevant forage commodity for the subsequent analysis. This selection was based on the initial commodity comparison and stakeholder priorities, after which Calliandra was independently evaluated across the entire Girimulyo District raster.

#### 4.4. Calliandra Suitability, Accessibility, and Spatial Implications for ICLS

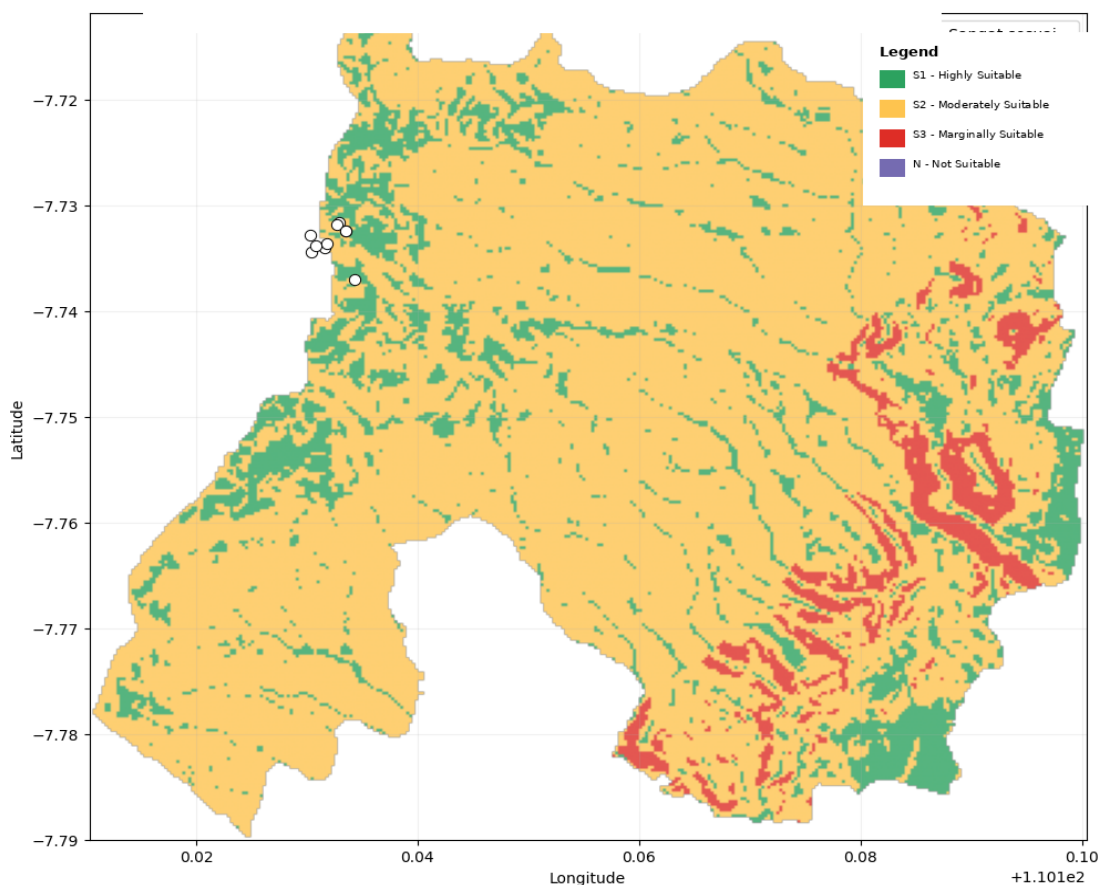
*Calliandra calothyrsus* was retained as the main forage commodity. The final biophysical SMCA used elevation, slope, annual rainfall, and LST across the 5,372.38 ha Girimulyo District analysis extent. The resulting map classified 766.22 ha (14.26%) as S1, 4,340.87 ha (80.80%) as S2, 265.29 ha (4.94%) as S3, and 0 ha as N. Area statistics are summarized in **Table 3**. The dominance of S2 indicates broad development potential, while also showing that most of the landscape has moderate limitations according to the model.

**Table 3.**

**Area of land suitable for Calliandra in Girimulyo District.**

| District  | S1 – Highly Suitable (ha) | S2 – Moderately Suitable (ha) | S3 – Marginally Suitable (ha) | N1 (ha) | Total (ha) |
|-----------|---------------------------|-------------------------------|-------------------------------|---------|------------|
| Girimulyo | 766.22                    | 4,340.87                      | 265.29                        | 0.00    | 5,372.38   |

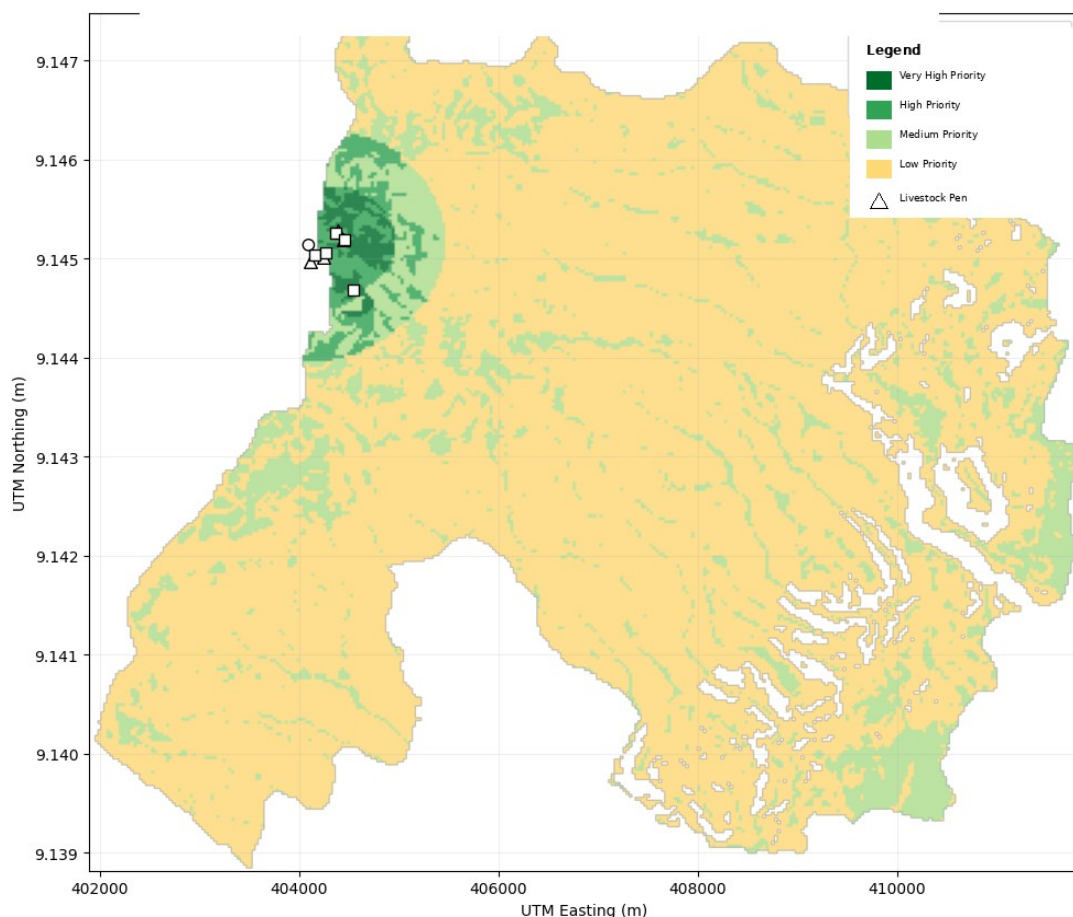
Slope was the dominant criterion because it had the highest AHP weight at 42.36%, followed by rainfall and LST at 22.70% each, and elevation at 12.23%. The factor summary shows that 100% of valid rainfall pixels were in S1, while elevation was distributed between S1 and S2 and LST was predominantly S1 with a smaller S2 component. Thus, slope was the principal source of spatial differentiation in the composite surface, consistent with the topographic pattern shown in **Fig. 4**.



**Fig. 4.** Land suitability map for Calliandra in Girimulyo, Kulon Progo.

Weight sensitivity analysis. A one-at-a-time  $\pm 20\%$  perturbation of each biophysical weight was performed followed by renormalization of the remaining weights. Slope remained the highest-weight criterion under all tested perturbations, ranging from 37.03% to 46.87%, while rainfall and LST remained secondary criteria and elevation remained the lowest-weight criterion. This sensitivity test evaluates the stability of the weighting structure; spatial-area sensitivity should be recomputed from the original raster layers if the journal requires class-area changes under alternative weight sets.

**Fig. 5** was developed in stages using the biophysical SMCA result in **Fig. 4** as the initial screening basis. S1 and S2 areas were retained as development candidates, while S3 and N areas were excluded from the primary candidate set. Euclidean distance surfaces were then generated within the candidate areas from livestock-pen points and existing forage-land locations. Each distance surface was normalized into a proximity score so that shorter distances received higher priority values. This process produced two accessibility components, P\_pen as the proximity score to livestock pens and P\_forage as the proximity score to forage land.



**Fig. 4.** Calliandra land recommendation zones based on biophysical SMCA, proximity to livestock pens, and proximity to existing forage land.

The two accessibility components were then combined with the biophysical suitability index through the operational priority index,  $PI = 0.60(SI_{bio}) + 0.25(P_{pen}) + 0.15(P_{forage})$ .  $SI_{bio}$  represents the normalized biophysical suitability index, while  $P_{pen}$  and  $P_{forage}$  are normalized proximity scores. The resulting PI values were classified into Very High, High, Medium, and Low Priority (**Table 4**). Very High and High Priority were combined as the primary recommendation zone.

Table 4.

## Calliandra land area by operational recommendation priority.

| Priority class     | Area (ha) | Interpretation                                                       | Role in recommendation  |
|--------------------|-----------|----------------------------------------------------------------------|-------------------------|
| Very High Priority | 37.09     | High biophysical suitability and close livestock/forage proximity    | Primary recommendation  |
| High Priority      | 83.74     | Suitable land with strong operational accessibility                  | Primary recommendation  |
| Medium Priority    | 772.41    | Suitable land with moderate accessibility or lower suitability       | Secondary consideration |
| Low Priority       | 4,213.84  | Low operational priority despite inclusion in the analysis landscape | Not prioritized         |

Therefore, **Fig. 5** is not a direct output of the biophysical SMCA, but a subsequent output that integrates biophysical suitability with operational accessibility to livestock pens and existing feed sources. The latest field dataset provides a stronger operational assessment of the accessibility component. A total of 18 unique household pen-forage-land pairs were identified after one duplicate pen record was consolidated and each pen was matched with its recorded forage location. Thirteen households (72.2%) had their nearest forage location within 200 m, one household (5.6%) was in the 200–350 m range, and four households (22.2%) had their nearest forage location more than 500 m away. Straight-line distances ranged from 6.3 to 1,176.9 m, with a mean of 209.8 m and a median of 41.3 m. These data are not a statistically representative census of all livestock households in Girimulyo District, but they provide field evidence that pen-to-forage accessibility is heterogeneous and should be treated explicitly in spatial planning. The latest observations show that the 200 m accessibility range includes 13 of the 18 paired households, while 5 households have their nearest forage location more than 200 m away (**Table 5**).

Table 5.

## Nearest livestock-pen distance to forage land measured for 18 GPS-based household pairs in the latest field dataset.

| Respondent | Pen elevation (m asl) | Forage elevation (m asl) | Elevation difference (m) | Nearest distance (m) | Accessibility band |
|------------|-----------------------|--------------------------|--------------------------|----------------------|--------------------|
| R1         | n/a                   | 777.8                    | n/a                      | 6.3                  | 0–200 m            |
| R2         | 788.2                 | 786.1                    | -2.1                     | 8.9                  | 0–200 m            |
| R3         | 616.8                 | 615.1                    | -1.7                     | 19.9                 | 0–200 m            |
| R4         | 782.9                 | 783.6                    | +0.6                     | 20.3                 | 0–200 m            |
| R5         | n/a                   | n/a                      | n/a                      | 27.2                 | 0–200 m            |
| R6         | 789.7                 | 793.8                    | +4.1                     | 27.7                 | 0–200 m            |
| R7         | 615.3                 | 609.7                    | -5.6                     | 29.8                 | 0–200 m            |
| R8         | n/a                   | n/a                      | n/a                      | 30.8                 | 0–200 m            |
| R9         | n/a                   | n/a                      | n/a                      | 34.8                 | 0–200 m            |
| R10        | 774.4                 | 780.6                    | +6.2                     | 47.8                 | 0–200 m            |
| R11        | n/a                   | n/a                      | n/a                      | 51.0                 | 0–200 m            |
| R12        | 603.8                 | 589.1                    | -14.7                    | 82.2                 | 0–200 m            |
| R13        | n/a                   | n/a                      | n/a                      | 151.5                | 0–200 m            |
| R14        | 693.5                 | 714.0                    | +20.5                    | 329.6                | 200–350 m          |
| R15        | 772.8                 | 749.2                    | -23.5                    | 514.4                | >500 m             |
| R16        | 720.9                 | 754.3                    | +33.4                    | 535.5                | >500 m             |
| R17        | 703.5                 | 752.4                    | +48.9                    | 681.4                | >500 m             |
| R18        | 608.6                 | 521.2                    | -87.4                    | 1176.9               | >500 m             |

Four households are more than 500 m away, with the maximum distance reaching 1,176.9 m. This distribution clarifies the earlier interpretation of spatial mismatch. Accessibility is not uniformly low because most sampled households already have relatively nearby forage sources, but a particular group faces substantially greater transport distances. Therefore, the proximity component of the recommendation model is most relevant for identifying suitable land that can reduce the burden for households with greater distances. This dataset remains a field sample rather than a census of all households in Girimulyo District.

4.5. Spatial Implications for ICLS in Girimulyo District

Feed requirements were recalculated on a dry-matter basis because the 30% inclusion rate refers to dietary DM rather than fresh feed weight. Feeding studies have reported the use of *C. calothyrsus* at up to 30% of the goat ration without negative production effects, while reviews indicate that forage inclusion should be interpreted on a DM basis because water content and leaf nutrient value vary substantially (Subagyo et al., 2024; Cakra & Trisnadewi, 2016). For a transparent planning scenario, adult goats weighing 35 kg were assumed to consume 3% of body weight as DM, equivalent to 1.05 kg DM head<sup>-1</sup> day<sup>-1</sup>. At a Calliandra inclusion rate of 30%, the Calliandra requirement is 0.315 kg DM head<sup>-1</sup> day<sup>-1</sup>.

For 10 goats over one 90-day cutting cycle, the required Calliandra biomass is 283.5 kg DM per cycle. With an average DM content of approximately 34.9% for fresh aerial *C. calothyrsus* biomass, this is equivalent to about 812 kg of fresh feed per cycle. If fresh-feed productivity is approximately 5,000–7,500 kg ha<sup>-1</sup> per 90-day cycle, the corresponding planting area requirement is approximately 0.11–0.16 ha for 10 goats. This value is a planning scenario rather than a universal requirement because animal body weight, DMI, feed moisture content, cutting interval, and actual land productivity vary among farms.

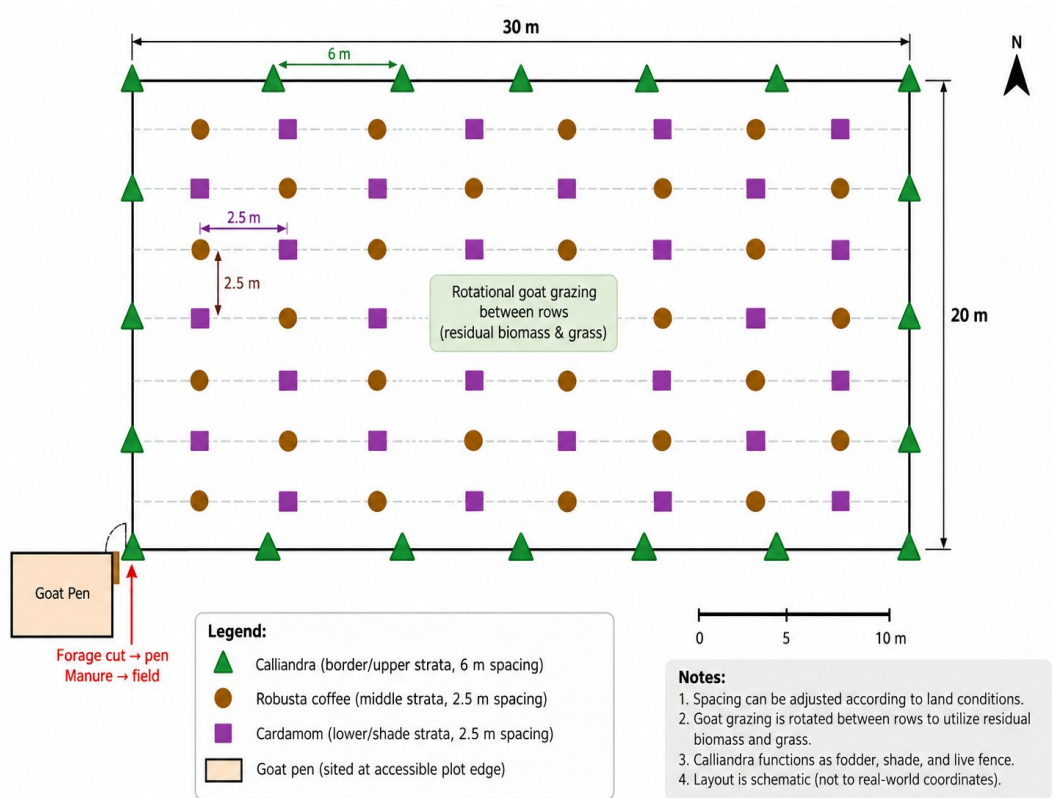


Fig. 5. Multi-strata spatial integration design for a Calliandra-based Integrated Crop-Livestock System.

Within the ICLS framework, Calliandra can function as the main forage tree, while coffee and cardamom serve as complementary production strata. Livestock manure can be returned to agricultural land as organic fertilizer, creating a nutrient cycle that spatially links forage production and livestock management rather than treating them as separate land uses. The spatial recommendation can then be translated into a multi-strata planting configuration at the household scale. In the proposed design, Calliandra is planted along the field boundary as the upper and edge stratum, with approximately 6 m spacing between trees. Robusta coffee occupies the middle stratum, while cardamom is placed in the lower, shade-tolerant stratum at approximately 2.5 m spacing within planting rows. This configuration allows the forage function of Calliandra to be integrated with existing plantation commodities without requiring complete conversion of agricultural land.

Placing the livestock pen at an easily accessible field edge is particularly relevant to the accessibility component of the recommendation model. Calliandra biomass can be harvested and transported directly to the pen, while livestock manure can subsequently be returned to the agricultural plot as an organic nutrient source. Rotational use of the space between crop rows also allows goats to utilize residual biomass and grass while reducing continuous grazing pressure on individual planting zones.

The 30 m × 20 m configuration shown in **Fig. 6** is a technical schematic of the spatial relationship rather than a fixed field design. Actual planting spacing and plot dimensions can be adjusted according to land ownership, existing vegetation, topography, access, and local management practices. The schematic provides an operational example of how priority areas identified by the SMCA can be translated into an integrated crop-livestock production unit.

## 5. DISCUSSION

The focused four-criterion SMCA indicates broad biophysical potential for Calliandra across the 5,372.38 ha Girimulyo District extent. The model classified 766.22 ha as S1, 4,340.87 ha as S2, and 265.29 ha as S3, with no N class. The dominance of S2 indicates moderate limitations across much of the landscape. The factor summary supports this interpretation because rainfall was entirely classified as S1, whereas slope showed the strongest mixture of S1–S3 classes.

The planning results became more operational after accessibility was explicitly incorporated. The recommendation model combined biophysical suitability with proximity to livestock pens and existing forage land and produced 120.83 ha as the primary recommendation zone, comprising 37.09 ha of Very High Priority and 83.74 ha of High Priority. The latest field dataset supports the operational interpretation of this surface. Thirteen of 18 households had their nearest forage location within 200 m, while five households exceeded 200 m and four exceeded 500 m. The maximum distance reached 1,176.9 m. The model therefore translates heterogeneous accessibility into a spatial-prioritization problem without assuming that all households face the same constraints. Because the recommendation raster was not recalculated solely from the latest CSV, the new field statistics update the interpretation and operational validation of the existing recommendation surface rather than the 120.83 ha area calculation.

The spatial recommendation can then be translated into an ICLS configuration at the household scale. The multi-strata design places Calliandra along the field boundary, Robusta coffee in the middle stratum, and cardamom in the lower stratum, while goat pens are positioned at an easily accessible field edge. This configuration links spatial accessibility results with the physical movement of feed to the pen and the return of manure to the field. The 30 m × 20 m schematic is therefore an operational example rather than a required plot size, and its dimensions can be adjusted to actual field conditions.

The methodological novelty of this study is deliberately positioned in application rather than algorithm development. SMCA and AHP are established methods. The additional contribution is their application within an integrated crop-livestock spatial framework in which accessibility is treated as an operational map criterion rather than only as qualitative discussion. This distinction is important for ICLS planning because the most biophysically suitable land is not necessarily the land that minimizes the daily burden of feed collection.

## 6. CONCLUSIONS

The study demonstrates that Girimulyo District has substantial potential for *Calliandra calothyrsus* development, with 766.22 ha (14.26%) classified as S1, 4,340.87 ha (80.80%) as S2, and 265.29 ha (4.94%) as S3. Slope was the dominant biophysical factor with an AHP weight of 42.36%. By integrating biophysical suitability with livestock accessibility, the study identified 120.83 ha as the primary recommendation zone, consisting of 37.09 ha of Very High Priority and 83.74 ha of High Priority.

The results demonstrate that integrating land suitability with proximity to livestock pens and existing forage land provides a more operational basis for ICLS spatial planning than biophysical suitability alone. Field observations showed that 13 of 18 pen–forage-land pairs (72.2%) were within 200 m, confirming spatial variation in accessibility. Thus, the main output of this study is a spatially explicit recommendation for *Calliandra*-based ICLS development, which should be further verified at the site level before implementation.

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