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Integrated Evaluation Land Suitability and Local Land Management Shallot in Larangan District, Brebes Regency: An Applied Agricultural Science Approach

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Abstract: Larangan District as one of the centers of shallot production with the highest potential in Brebes Regency, Indonesia shows that the intensive land management system practiced by local farmers with excessive agrochemical inputs has caused negative environmental impacts and a decline in shallot production. This study aims to integrate agricultural land suitability evaluation with local land management of shallot, through the agricultural science technology approach for increase productivity of shallot and preserving local land management. The research methods include soil sampling, laboratory analysis, spatial data analysis using the matching and overlay method employing Inverse Distance Weighting Interpolation (IDW), as well as an social data analysis with ethnographic approach through in-depth interviews and participatory observation, and also descriptive analysis. The results shows that the actual land suitability of shallot are 2,564.95 ha as S2 class with limiting factors of rainfall, root medium, nutrient retention, and available nutrients, 7,140.05 ha as S3 class and 6,284.99 ha as N class with limiting factor of rainfall. The integration of agricultural science technology with local land management practices, such as *gilir giring* water management and *mupuk* organic fertilization, offers a sustainable pathway to address limiting factors with implementation of GIS-based zoning programs combined with farmer field schools for knowledge transfer that synthesizes scientific innovation, without compromising local farming community.

Keywords: Agricultural science technology approach; Land suitability; Limiting factor; Local land management; Shallot.

Introduction

Brebes Regency is a strategic area in Central Java Province, Indonesia that contributes significantly to national horticultural production as the center of Indonesia's shallot commodity. With a total area of 1.769,62 km², the regency allocates 40,89% of its land for agricultural activities and is home to 2.043.077 people, the majority of whom work in the agricultural sector (BPS Brebes Regency, 2024a). Shallot productivity in Brebes Regency faces complex challenges related to land suitability. An evaluation of land suitability at the Brebes Regency level shows that 29,3% (50.440,7 hectares) of the land falls into the Moderately Suitable (S2) category, 55,5% (95.819,9 hectares) into the Marginally Suitable (S3) category, and 14,8% (25.678,3 hectares) in the Unsuitable (N) category (Susilawati et al., 2019). These data indicate that the majority of shallot land in Brebes has marginal suitability, requiring improved management to optimize productivity.

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Larangan District, one of 17 districts in Brebes Regency, plays a strategic role in supporting national food security as a shallot producer. This district has an area of 160,25 km² with a population density of 1.019 people per km², consisting of 11 villages with 20.367 farming households, the highest in Brebes Regency. The average land ownership of small farmers in this area ranges between 1-2 hectares (Baperlitbangda Brebes Regency, 2023; BPS Brebes Regency, 2023, 2024b). The demographic and geoghrapic characteristics indicate the dominance of small-scale agriculture. Data from the Brebes District Communication, Information, and Statistics Office shows that in Larangan District, there was a decline in shallot production from 101.725 tons in 2021 to 95.167 tons in 2022, and a significant drop to 77.324 tons in 2023.

The implementation of land management in Larangan District shows a pattern of intensive agriculture that has been practiced for generations, characterized by massive use of agrochemical inputs. The shallot cultivation system practiced by local farmers uses key production factors such as land area, seeds, fertilizers, pesticides, and labor with high intensity (Permana et al., 2021). This intensive agricultural practice results in an average technical efficiency of 91,8%, allocative efficiency of 79,9%, and economic efficiency of 72,1%, indicating that there is still room for improvement in optimizing production resources (Fauzan et al., 2015). However, the existing land management system faces the problem of agrochemical use exceeding recommended doses. Excessive pesticide use has contaminated onion fields in Brebes District (Wahyuni et al., 2019). The negative impacts of this practice have been felt by farmers, but pesticide use behavior has not changed significantly. The use of pesticides in agricultural activities has caused serious impacts on the environment and public health, with pesticide residues continuing to accumulate in agricultural land (Sinambela, 2024).

Farmers in Larangan District, Brebes Regency, have cultivated shallot for generations as an integral part of their daily agricultural life and culture. Shallot cultivation has even become a hallmark of the community, reflecting local wisdom in agricultural resource management. Local land management in local agricultural systems has proven to have high conservation value and has the potential to be integrated with modern technology. With development, local agricultural systems face significant threats due to agricultural modernization that adopts conventional technology based on synthetic chemical inputs. Additionally, changes in the demographic structure of farmers, with an aging population and economic pressures pushing farmers to prioritize short-term productivity, further exacerbate the challenges faced (Bahar, 2016).

The complexity of agricultural issues in Larangan District, Brebes Regency, requires research aimed at integrating the evaluation of agricultural land suitability with local shallot land management, through an applied agricultural science technology approach to increase shallot productivity and maintain local land management. This approach is expected to optimize shallot productivity while maintaining ecosystem sustainability. The integration of agricultural science technology with local land management can be implemented to develop adaptive and responsive agricultural policies that address the ecological, social, and economic dynamics of the community.

Method

Time and Place of Research

Soil sampling and field observations were conducted in Larangan District, located southwest of the capital of Brebes Regency, Central Java. Soil sample collection was carried out in December 2023, while spatial data and socio-economic data collection were conducted from November to December 2024. Soil analysis was conducted at the Soil Chemistry and Fertility Laboratory, Department of Soil Science and Land Resources, Institut Pertanian Bogor.

Tools and Materials

The research utilized various tools and materials for data collection and analysis. Field equipment included soil augers for soil sample collection, GPS devices for coordinate recording, cameras for visual documentation of agricultural activities, and questionnaire form as a guide for interaction and interview activities with experts, as well as spatial conditions of agricultural land. Laboratory equipment and chemicals required for soil analysis were available at the Soil Chemistry and Fertility Laboratory, Department of Soil Science and Land Resources, Bogor Agricultural University. Spatial analysis software included Quantum GIS (QGIS) for implementing the Inverse Distance Weighting (IDW) interpolation method and a set of computer equipment with Microsoft Office.

Research Stages

Preparation Phase

The research preparation phase began with a literature review of data related to the research location as a general overview. The data reviewed included climate (temperature and rainfall) from the Meteorology, Climatology, and Geophysics Agency (BMKG), soil depth and slope data from the Brebes Regency One Data Portal, and administrative maps of the area from the Indonesian Topographic Map (RBI). An examination was also conducted on the physical characteristics of the conditions of agricultural land management carried out by the local community.

Field Data Collection Phase

Soil sampling involved farmers and was conducted at six points spread across five villages, namely Kamal, Pamulihan, Sitanggal, Larangan, and Rengaspendawa, with shallot as the main commodity. The method used was purposive random sampling, considering the suitability of shallot land for analyzing soil chemical and physical properties. Data was collected from local agricultural experience and knowledge through observation activities and described using descriptive analysis methods.

Laboratory Analysis

Soil sample analysis included comprehensive physical and chemical property determination using standardized laboratory methods. Laboratory analysis employed the pipette method for soil texture analysis, ammonium acetate (NH_4OAc) 1N pH 7.0 extraction method for cation exchange capacity (CEC) and base saturation (BS), H_2O 1:5 method for pH measurement, Walkey and Black method for organic carbon determination, Kjeldahl method for total nitrogen analysis, and 25% HCl method for P_2O_5 and K_2O analysis. These standardized analytical methods ensured accurate determination of soil physical and chemical properties essential for land suitability evaluation (Eviati & Sulaeman., 2009).

Spatial Data Analysis

The chemical and physical properties of the soil and secondary data from literature studies were interpolated using the Inverse Distance Weighting (IDW) method in Quantum GIS. The IDW method calculates the distance from the data point to the block to be estimated as a weight, based on the principle that the closer the distance, the greater the weight (Susilawati et al., 2019).

Land suitability evaluation was conducted at a semi-detailed level using the matching method, which involves matching interpolated land characteristic and quality data with land suitability criteria for shallot based on guidelines from the Center for Agricultural Land Resources 2016 (BBSDLP, 2016). The evaluation used the principle of minimum law, whereby the suitability class is determined by the most restrictive factor. The evaluation results produced an order classification (S = suitable, N = unsuitable), class (S1 (very suitable); S2 (moderately suitable); S3 (marginally suitable); and N (unsuitable)) and subclass indicating the dominant limiting factor. This spatial analysis enabled the creation of land suitability maps and identification of limiting factors across different zones (Widiatmaka & Hardjowigeno, 2015).

Social Data Analysis

A qualitative approach was applied using ethnographic methods involving in-depth interviews and participatory observation to explore social realities in a structured manner in order to understand the perspectives, traditions, activities, and dynamics occurring within the community (Putri & Kusno, 2025). The interview technique was semi-structured based on a prepared guideline framework, with the results documented and described through a qualitative approach. Respondents were selected using purposive sampling techniques, covering various experts or stakeholders in the agricultural sector in Larangan District, including Larangan District agricultural extension workers, delegates from the Indonesian Shallot Association (ABMI), members of the KTNA (Farmer and Fisherman Group), village heads, heads of farmer groups (Gapoktan), and farmers who hold positions as community leaders.

The validity of data interpretation is ensured through a verification process by confirming the findings with the main sources. The documentation process is carried out by collecting visual documentation in the form of photographs of agricultural activities, interaction and interview activities with experts, as well as the spatial conditions of agricultural land, which serve as supporting data in the analysis process (Prasetyo et al., 2025). Qualitative data from interviews and observations were analyzed using descriptive analysis methods to understand local land management practices and local knowledge systems.

Result and Discussion

Land Characteristics and Quality

The assessment of land characteristic parameters in the land evaluation is presented in **Table 1.** The physical properties of the soil in Larangan District, Brebes Regency generally have an average temperature across all locations in the range of 26°C, which is considered optimal, with annual rainfall varying between 1,500 and 3,000 mm/year. soil texture is dominated by fine texture ranging from sandy to clay, soil depth is around 200 cm, slope gradient between <3%, 3 to 8%, categorized as flat to undulating land. Meanwhile, the chemical properties of the soil have a neutral to slightly alkaline pH H_2O between 6.8 and 8.0, with low organic carbon content between 0.98% and 1.70%, and low total nitrogen content between 0.11 and 0.17%. Conversely, the availability of P_2O_5 and K_2O is very high, ranging from 100.40–284.40 mg/100g and 45.60–140.30 mg/100g, respectively. The cation exchange capacity (CEC) is very high, ranging from 41.74 to 52.49 cmol (+)/kg, and the base saturation level (BS) is very high, ranging from 102.94 to 172.80%.

Table 1. Land characteristics and quality with actual land suitability class in Larangan District, Brebes Regency

Land use requirements/characteristics		Actual Class
Temperature (tc)		S1
Average annual Temperature (°C)	25.80 – 26.39	S1
Water availability (wa)		N
Annual rainfall (mm/year)	1,500 – 2,000	S2
	2,000 – 2,500	S3
	2,500 – 3,000	N
Root medium (rc)		S2
Texture	dusty – clay (fine)	S2
Soil depth (cm)	200 (very deep)	S1
Nutrient retention (nr)		S2
CEC (cmol/kg)	41.74-52.49 (very high)	S1
BS (%)	102.94-172.80 (very high)	S1
pH H_2O	6.80-7.50 (neutral)	S1
	7.50-8.00 (slightly alkalin)	S2
Organic carbon (%)	0.98-1.70 (low)	S2
Available nutrients (na)		S2
N-total (%)	0.11-0.17 (low)	S2
P_2O_5 (mg/100g)	100.40-284.40 (very high)	S1
K_2O (mg/100g)	45.60-140.30 (high-very high)	S1
Erosion hazard (eh)		S1
Slope (%)	<3 (flat)	S1
	3-8 (wavy)	S2
Actual class		N (wa)

Actual Suitability of Land of Shallot

The evaluation of the actual land suitability with limiting factors, based on the characteristics of shallot land is presented in **Table 1** and the visualization map in **Figure 1**. Meanwhile, the area of shallot land suitability classes in Larangan District, Brebes Regency is presented in **Table 2**. The evaluation of shallot land suitability in shows spatial variations of three land suitability classes in three zones. The distribution of land suitability consists of 16.04% or an area of 2,564.95 ha of the Moderately Suitable (S2) class with limiting factors of rainfall (wa), root medium (rc), nutrient retention (nr), and available nutrients (na), 44.65% or 7,140.05 ha of Marginally Suitable (S3) class with limiting factors of rainfall (wa), and 39.30% or 6,284.99 ha of Unsuitable (N) class with limiting factors of rainfall (wa). This is consistent with (Darsiti et al., 2024), who stated that in the evaluation of land suitability for shallot cultivation in Cibeureum District, Sukabumi City, the dominant limiting factors were water availability (wa), nutrient retention (nr), and erosion hazard (eh).

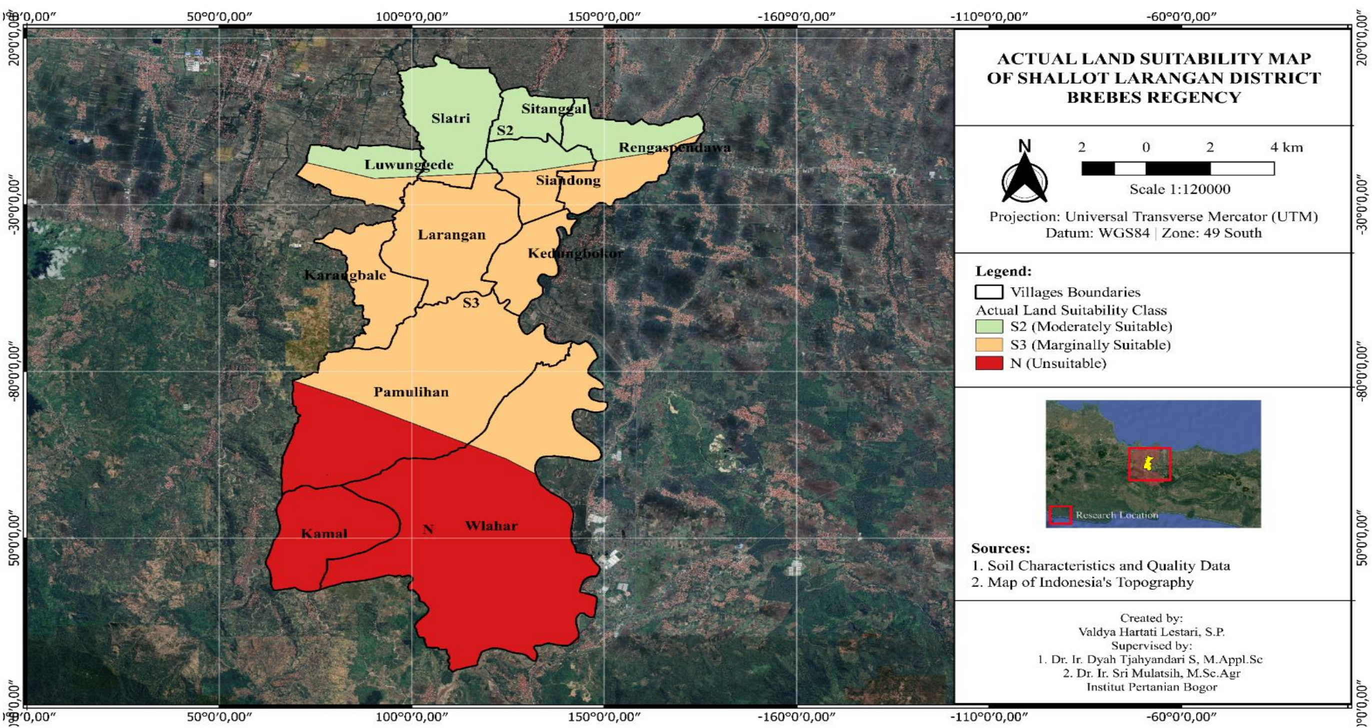

Figure 1. Actual land suitability map of shallot in Larangan District, Brebes Regency

Overall, land suitability for shallot indicates actual conditions of N(wa). The physical and chemical characteristics of the soil identified in Larangan District show great potential for shallot farming development, but further efforts to improve soil management are needed. Land characteristics with nutrient retention (nr) as the limiting factor require the addition of organic matter, while available nutrients (na) with total nitrogen require the addition of nitrogen fertilizer. Limiting factors for water availability (wa) include rainfall, which requires improved irrigation, and erosion hazards (eh) include slope gradient, which requires improved soil conservation practices. These practices are implemented to reduce erosion rates, maintain soil moisture, and sustain long-term productivity. Root medium limiting factors (nr) include texture, which cannot be improved, indicating physical limitations that are difficult to address with available technology (Widiatmaka & Hardjowigeno, 2015). Overall, proper soil improvement and management efforts are crucial for enhancing land suitability for various crop types, particularly on lands with low soil quality (Suryaningtyas et al., 2025).

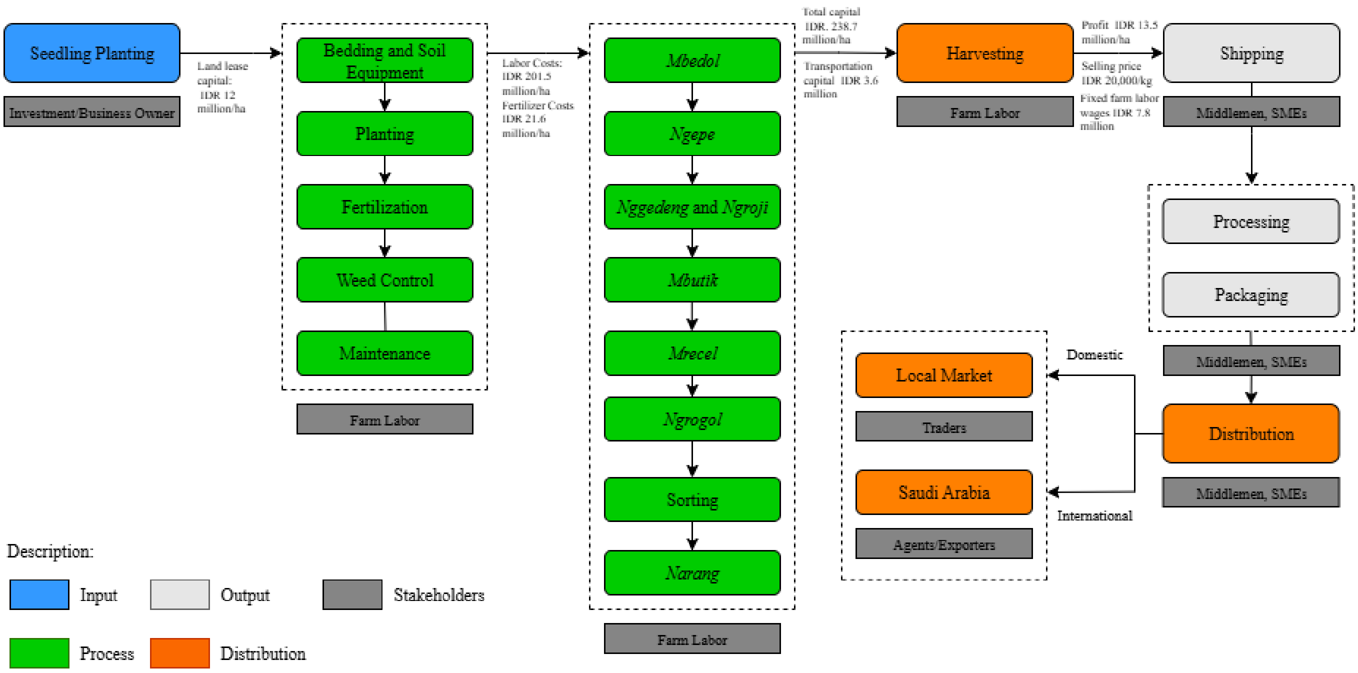

Figure 2. Value chain diagram of local land management for shallot
Source: (Baperlitbangda Brebes Regency, 2023)

Table 2. Land suitability class area with limiting factors of shallot in Larangan District, Brebes Regency

Actual class	Limiting factor	Area	
		ha	%
S2	wa, rc, nr, na	2,564.94	16.04
S3	wa	7,140.05	44.65
N	wa	6,284.99	39.31
Larangan district		15,989.99	100.00

Description: wa (water availability); rc (root medium); nr (nutrient retention); na (available nutrients); S1(very suitable); S2 (moderately suitable); S3 (marginally suitable); and N (unsuitable).

Local Land Management for Shallot

Land management using local knowledge in the shallot farming system in Larangan District. These practices are not only cultural heritage but also forms of local technology that have evolved to adapt to the local agro-ecological conditions. This system demonstrates the application of soil physics, plant biology, chemistry, and environmental science through indigenous knowledge systems that have evolved to optimize productivity while maintaining ecological sustainability. Local land management for shallot is divided into several stages, namely, pre-planting phase, planting phase, and post-planting phase.

Pre-Planting Phase

The soil management process begins with plowing or hoeing to form ridges as an application of soil mechanics to improve soil structure and enhance land drainage efficiency. Soil preparation is carried out 2–4 weeks before planting with a drying cycle of 1–2 weeks for soil structure stabilization and repeated processing up to 3 times to achieve optimal consistency. Farmers calculate land area by multiplying length and width in cengkal units, demonstrating an understanding of rectangular geometry, with one plot of land equivalent to 100 cengkal (3,75 m per cengkal) as the local community's measurement system. Drainage systems are established by digging ditches 50–60 cm deep with ridges measuring 120–150 cm wide and spaced 50–60 cm apart (Bahar, 2016), using measurements (*ngrucik*) with bamboo instruments, PVC pipes, and plastic ropes (Putri & Kusno, 2025). Before planting, basal fertilization is carried out using manure or fermented compost as part of the implementation of soil biogeochemical and microbiological cycles in sustainable agronomy. Planting techniques involve moistening the ridges, creating planting holes using a tugal to the depth of the tuber, and applying a planting distance of 15x15 cm (rainy season) or 15x10 cm (dry season) as spatial optimization based on specific environmental conditions (Bahar, 2016).

Figure 3. Land management stage

The practice of *nyuwat* the principles of agricultural hydrology and applied mathematics through the creation of irrigation systems that follow measurement lines (Putri & Kusno, 2025). After *nyuwat*, the land is processed through a rempug process involving the mixing of plowed soil with native soil and stirring to prevent compaction as an application of soil mechanics physics. The process continues with deepening irrigation channels using the *jeblos* technique, where channel depth positively correlates with plant growth because larger water volume results in healthy growth, while low water volume causes slow growth and reduced vigor (Putri & Kusno, 2025).

Figure 4. The practice of *nyuwat* or irrigation construction

Planting phase

The practice of *nyocrok* is the principles of precision agronomy by planting tubers one by one at a depth of 2-3 cm and spacing them according to the variety and soil conditions for efficient crop management and even seed distribution. Farmers carefully ensure the optimal position for plant growth. Brebes Regency uses the local *Bima Brebes* variety with conventionally produced seeds through selection from harvest results, and even the selected seeds are the third generation of the original seeds (Bahar, 2016). Before planting, seeds undergo a 1-2 day *rimpes* process with tip cutting to accelerate and standardize germination as an application of plant physiology and biochemical dormancy.

Figure 5. The practice of *nyocrok*

The irrigation system implemented is the concept of gilir giring as semi-traditional irrigation through secondary and tertiary channels that are opened in turns based on local knowledge of mutual cooperation for fair and efficient water management. The distribution of irrigation time and duration is adjusted according to land area, crop type, and growth phase as an application of agricultural hydrology and water resource management. Water availability is met through irrigation water or surface water during the rainy season, while the dry season requires water pumps from water bodies (rivers, lakes, and reservoirs) or groundwater with significant operational costs and challenges in finding water sources (Bahar, 2016).

Figure 6. Irrigation system

The practice of *mupuk* reflect the empirical knowledge of local farmers regarding the nutritional needs of shallot at each stage of growth, particularly the Bima Brebes variety, which shows a positive response to the application of concentrated organic fertilizer.

Fertilization is carried out 2-3 times during the growth cycle, with dosage and application timing adjusted based on plant condition and phenological stage using visual indicators of leaf development and bulb formation as applications of plant nutrition and growth physiology. Farmers apply a fertilization schedule with basal fertilizer 7-10 days before planting (organic fertilizer 5.000 kg/ha, NPK 300 kg/ha, ZA 100 kg/ha), first top-dressing fertilizer 10-15 days after planting (NPK 250 kg/ha, ZA 150 kg/ha), and second top-dressing fertilizer 30 days after planting (NPK 250 kg/ha, ZA 150 kg/ha) as part of nutrient management based on the plant's temporal nutrient requirements (Bahar, 2016).

Figure 7. The practice of *mupuk*

The practice of *nyulam* at points of failure reflects farmers adaptive strategies to optimize plant population per unit area in order to maximize land productivity. This activity is generally carried out 7–14 days after initial planting, after identifying seeds that have not grown or have died, with success highly dependent on the quality of replacement seeds, environmental conditions, and the speed of farmers response in taking corrective action (Bahar, 2016).

Figure 8. The practice of *nyulam*

Post-planting phase

The practice of *mbedol* or harvesting shallot is carried out by pulling up the entire plant when the bulbs reach optimal maturity, which is indicated by 60-70% of the leaves drying out and the stems falling over. This requires precision on the part of farmers in observing visual indicators as an application of plant physiology and growth phenology (Baperlitbangda Brebes Regency, 2023). Harvesting is carried out carefully to prevent physical damage to the bulbs, which reduces quality and storage life, during the period of 55-70 days after planting under dry conditions and sunny weather to prevent bulb rot as part of post-harvest practices and plant pathology (Bahar, 2016).

Figure 9. The practice of *mbedol*

The practice of *mikul*, or transporting harvested crops, is an important part of the post-harvest chain for moving tubers from the field to the drying or processing area as an application of agricultural logistics and supply chain management (Baperlitbangda Brebes Regency, 2023). The process requires effective coordination among workers and the selection of appropriate transport equipment to minimize physical damage to the product. Local management methods rely on manual labor using baskets or sacks, while large-scale operations utilize carts or small vehicles, with efficiency being critical to maintaining quality and reducing yield losses, especially under unfavorable weather conditions.

Figure 10. The practice of *mikul*

The practice of *ngepe* or drying is a process of reducing the water content of shallot to an optimum level so that the skin of the shallot becomes redder and shinier for storage and marketing as an application of post-harvest technology and biochemical dehydration (Baperlitbangda Brebes Regency, 2023). Drying is carried out using direct sunlight for 6–12 days, with the bulbs turned every 2–3 days on mats or drying floors to ensure even drying through the application of heat and mass transfer physics (Bahar, 2016). The success of the drying process significantly influences the final quality, shelf life, and market value of shallot as part of quality management and agricultural economic implementation.

Figure 11. The practice of *ngepe*

A The practice of *nggedeng* or gradual binding is carried out after shallot reach optimal dryness after *ngepe* to facilitate handling and marketing as an application of packaging technology and product quality management (Baperlitbangda Brebes Regency, 2023). The technique involves tying 5–7 small bundles into one large unit, considering the homogeneity of weight, size, and quality of the bulbs through product standardization, which requires proportional skills to maintain quality standards and price consistency as an implementation of agricultural economics and supply chain management.

Figure 12. The practice of *nggedeng*

The practice of *ngroji* (Baperlitbangda Brebes Regency, 2023) which is the merging of two or more *nggedeng* into one big bond, is a further stage of *nggedeng* that reflects the gradation and standardization system of products in the Brebes shallot trade tradition. This technique is designed to meet the logistics efficiency of distribution to large-scale markets, taking into account the convenience of transportation and the preferences of the target market. Although more efficient for long-distance distribution, kneading requires more careful handling in order not to damage of product quality.

Figure 13. The practice of *ngroji*

The practice of *mbutik* (Baperlitbangda Brebes Regency, 2023) is a process of cleaning shallot bulbs from the remaining roots and soil in order to improve the visual quality and extend the shelf life of the product. This activity is done manually with a simple tool like a small knife to cut the roots and clean the dirty outer skin. Expertise in picking has a great influence on the final quality of the product, because mistakes in cleaning can damage the surface of the tuber and reduce the storage quality.

Figure 14. The practice of *mbutik*

The practice of *mrecel* (Baperlitbangda Brebes Regency, 2023), is a process of separating individual tubers from clusters or clumps of harvest that aims to facilitate sorting and packaging activities. This process is done with the technique of twisting and pulling the tuber to minimize the risk of damage, especially in the part of the base that is prone to injury. A small part of the root is deliberately preserved as a natural protector. The skill of the farmer in doing mrecel determines the success of maintaining the physical integrity of the tuber as well as the visual quality of the product.

Figure 15. The practice of *mrecel*

The practice of *ngrogol* or cutting off the remaining leaves and stems of shallot is carried out to improve the visual appearance of the product and reduce water loss through transpiration as a post-harvest physiological application (Baperlitbangda Brebes Regency, 2023). The cutting is performed by leaving 2–3 cm of the upper part of the bulb to protect the growth point and prevent pathogen entry, using sharp and clean cutting tools through the application of sanitation and phytopathology. The timing of *ngrogol* is critical because cutting too early can affect the weight and quality of the bulb as part of post-harvest management implementation.

Figure 16. The practice of *ngrogol*

The practice of *nyortir* or sorting is a local management quality control system that classifies shallot based on size, color, and physical condition in an effort to maintain the genetic quality of seeds from generation to generation through the application of plant breeding and population genetics (Baperlitbangda Brebes Regency, 2023). Seed selection is conducted visually, considering bulb density, shiny skin color, and the absence of disease symptoms as quality indicators that support productivity and sustainability through seed self-reliance and the preservation of local genetic resilience. Sorting criteria include tuber diameter, density, skin color, and the absence of physical defects and disease symptoms, where sorting expertise determines the product's market position and optimizes selling prices through different grade segmentation as part of agricultural economics and marketing management.

Figure 17. The practice of *nyortir*

Seed storage or the practice of *narang* (Baperlitbangda Brebes Regency, 2023) is a local management system that is done by hanging shallot bundles in a well-ventilated place and protected from rain, using gravity and natural airflow to maintain seed quality for 3-6 months until the next planting season. The nesting location is usually chosen under the basement of the house, a special warehouse, or a local management structure that supports optimal ventilation. The success of storage depends on the selection of quality tubers, humidity control, and routine monitoring to prevent damage.

Figure 18. The practice of *narang* or seed storage

Integrated Land Evaluation of Shallot and Local Land Management in Larangan District with Agricultural Science Technology Approach

Holistic Approach to Limiting Factor Management

The integration of land evaluation with local land management systems presents a unique opportunity for sustainable agricultural development. These practices, which have evolved over generations, implement the principles of soil physics, plant biology, and environmental science through indigenous knowledge systems that have optimizing productivity while maintaining ecological balance.

The limiting factors identified from land evaluation, particularly water availability constraints affecting 39.31% of unsuitable land, require immediate intervention through improved irrigation infrastructure integrated with the lacal management practice of *gilir giring*. This integration enables implementation of modern efficiency measures, such as soil moisture monitoring and precision irrigation scheduling, while maintaining social cohesion and the values of cooperation inherent in local water management. As support of this, Albar et al. (2025) that integrating local wisdom with modern scientific knowledge through practices such as water conservation, local forest management, and local agricultural systems within the Bunggu Indigenous Community strengthens adaptive and sustainable environmental management strategies. This insight reinforces the argument that the synergy between modern agricultural innovation and local management practices not only addresses productivity constraints but also maintains ecological balance and strengthens cultural and social solidarity(Albar et al., 2025).

Limited soil fertility, particularly low levels of organic carbon (0.98–1.70%) and total nitrogen (0.11–0.17%), highlights the urgent need for better organic matter management. Overreliance on synthetic fertilizers by shallot farmers has been shown to degrade the physical, chemical, and biological properties of soil over time, reducing its long-term resilience and productivit (Purnomo, 2024). Conversely, local management practices such as the practice of *mupuk* (fertilization) with organic inputs have historically maintained soil fertility in integrated crop-livestock farming systems, demonstrating their ecological value. Composting practices with modern innovations such as decomposition agents and biochar technology offer significant opportunities to improve soil quality and shallot yields (Aritonang et al., 2025). Biochar application has been proven to enhance soil water-holding capacity (Adekiya et al., 2020; Adhikari et al., 2022; Wei et al., 2023). The strategic integration of biochar production and subsequent land application yields a range of benefits, including improved soil physical properties, enhanced nutrient retention and availability, and increased biological activity leading to higher agricultural yields (Pandian et al., 2024). Additionally, sustainable fertilization practices emphasize the provision of balanced nutrients according to crop type, soil conditions, and planting season, paving the way for precise nutrient management (Purnomo, 2024). This integration respects farmers' customs and socio-cultural values while introducing innovations that optimize fertilization timing and dosage according to plant phenology, ensuring sustainable intensification of shallot production in Brebes.

High cation exchange capacity (41.74–52.49 cmol/kg) and base saturation (102.94–172.80%) indicate strong nutrient retention potential, but these conditions can also have negative consequences if not balanced with sufficient organic matter input. Excessive retention can cause some nutrients to become bound, thereby reducing their direct availability to plants and causing nutrient imbalance in the soil. According to the findings Mulyati et al. (2022), effective nutrient availability is not only determined by soil chemical properties but also by organic matter management. Therefore, targeted organic matter addition is crucial for optimizing nutrient dynamics, maintaining soil fertility balance, and enhancing nutrient use efficiency for sustainable agricultural production. The addition of organic matter can aid the process of new soil formation from the decomposition of organic matter into the soil and improve soil structure so that the soil contains more clay. Soil containing more clay is better able to retain water (Maskumambang et al., 2021).

Root medium limitations related to fine soil texture, which cannot be improved through conventional methods, can be managed through local hill construction techniques that improve drainage and soil structure, as demonstrated in local *nyuwat* practices. Slope gradient is also one of the main limiting factors, as it directly affects erosion risk, soil stability, and the land's ability to support cultivation. In line with this, the steep topography significantly limits agricultural intensification and therefore requires the application of soil and water conservation technologies such as terracing, vegetative buffers, and contour farming practices to minimize land degradation (Darwis et al., 2024).

Agricultural Science Technology Approach

The implementation framework emphasizes the integration of technology that is compatible with existing local practices to create a sustainable and culturally acceptable agricultural system (Meilinda et al., 2023; Misbahuddin et al., 2024). The results of the land suitability evaluation show a distribution of 16.04% or an area of 2,564.95 ha of the Moderately Suitable (S2) class with limiting factors of rainfall (wa), root medium (rc), nutrient retention (nr), and available nutrients (na), 44.65% or 7,140.05 ha of Marginally Suitable (S3) class with limiting factors of rainfall (wa), and 39.30% or 6,284.99 ha of Unsuitable (N) class with limiting factors of rainfall (wa), which requires the development of a zoning program that integrates agricultural science technology approach with local management practices. A zoning program based on geographic information system (GIS) technology enables geospatial evaluation of agricultural suitability through a decision support system that considers key limiting factors such as rainfall, soil organic carbon, and total nitrogen. This system can be implemented through the development of technical management guidelines tailored to the suitability level of each zone, utilizing GIS technology for mapping and real-time monitoring. The implementation of land suitability-based zoning will assist farmers in making strategic decisions regarding planting times, commodity rotation patterns, and soil and water conservation strategies tailored to the biophysical potential and limitations of each zone, thereby achieving optimal input efficiency and agricultural adaptation (Nur & Armita, 2023), particularly in areas at risk of land conversion (Chairuddin, 2018).

Monitoring and Evaluation Framework

The success of integrated implementation requires a comprehensive monitoring system that tracks biophysical and socio-economic indicators. Soil health monitoring should combine local indicators used by farmers with modern soil testing to create a comprehensive understanding of changes in soil conditions over time. Water use efficiency monitoring can be built on local water allocation practices while integrating modern measurement techniques to optimize performance (Herrick, 2000; Sahu et al., 2025).

Social monitoring should assess the preservation of local knowledge and practices while evaluating the adoption and effectiveness of new technologies. Regular consultation with community leaders and local knowledge holders ensures that implementation efforts remain aligned with local values and priorities. Economic monitoring should track both farm-level profits and community-level economic development to ensure that improvements benefit all stakeholders (Febrianti et al., 2024; Hamidah et al., 2024).

The social dimension greatly influences the implementation of good agricultural practices because it shapes patterns of interaction, information exchange, and collective support among farmers. In rural communities, farmers hold communal values, which encourage open communication about agricultural challenges and solutions. Farmer group forums, often facilitated by agricultural extension officers, provide a platform for knowledge sharing and problem-solving. These extension activities also enhance farmers' skills and strengthen social networks that support successful innovation adoption (Wibowo & Isaskar, 2025). Previous studies confirm that the social dimension is a dominant factor in explaining the success of sustainable agricultural practices. Additionally, the role of effective agricultural instructors is crucial in empowering farmers through competency enhancement and continuous guidance (Bathaei & Štreimikienė, 2023; Bertola et al., 2021; Serebrennikov et al., 2020).

The establishment of farmer field schools that combine demonstration plots with participatory learning approaches provides an effective mechanism for knowledge transfer and system improvement. These schools can function as laboratories for testing integrated approaches while maintaining strong ties with local farming communities (Singh et al., 2020; Waddington et al., 2012). Routine evaluation and adjustment of implementation strategies based on farmer feedback and monitoring results ensure continuous improvement and adaptation to changing conditions.

This integrated implementation framework represents a paradigm shift from technology transfer to knowledge integration, recognizing that sustainable agricultural development requires a synthesis of scientific knowledge and local wisdom. The success of this approach depends on maintaining respect for local knowledge while introducing appropriate innovations that strengthen rather than replace effective local management practices (Munawar & Khalid, 2025). Through this balanced approach, the framework provides a pathway to achieve sustainable intensification of shallot production while preserving the cultural and environmental values that define the farming community in Larangan District.

Conclusion

Land suitability evaluation show a distribution of 16.04% or an area of 2,564.95 ha of the Moderately Suitable (S2) class with limiting factors of rainfall (wa), root medium (rc), nutrient retention (nr), and available nutrients (na), 44.65% or 7,140.05 ha of Marginally Suitable (S3) class with limiting factors of rainfall (wa), and 39.30% or 6,284.99 ha of Unsuitable (N) class with limiting factors of rainfall (wa) can be improved through repaired irrigation system, addition of organic matter, nitrogen fertilizer, soil conservation, and rooting media (rc), which cannot be improved. The local land management practices spanning are pre-planting (*nyuwat*, local land preparation), planting (*nyocrok, mupuk, nyulam*), and post-harvest phases (*mbedol, ngepe, nggedeng, narang*) that demonstrate sophisticated agricultural science principles within indigenous knowledge systems.

An integrated agricultural science technology approach to land management that combines land suitability evaluation with limiting factors and exploration of local knowledge is a key strategy for developing adaptive and contextual agricultural development to support the sustainability of the shallot farming system in Larangan District. The integration of agricultural science technology with local land management practices, such as *gilir giring* or water management and *mupuk* or organic fertilization, offers a sustainable pathway to address limiting factors. The implementation of GIS-based zoning programs combined with farmer field schools creates an effective framework for knowledge transfer that synthesizes scientific innovation with indigenous wisdom, without compromising local farming community values.

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Conflicts of Interest
The authors declare there is no conflict of interest.

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