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Research Article

Multi-Criteria Decision Analysis for Sustainable Crop Selection in Northeast Thailand: An Analytical Hierarchy Process Approach

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Abstract: This research presents a systematic framework for sustainable crop selection in Northeastern Thailand using the Analytical Hierarchy Process (AHP). It assesses six crop options—jasmine rice, shallots, cassava, chili pepper, rubber, and oil palm—against eight key criteria: climate suitability, water efficiency, soil adaptability, pest resistance, market demand, cultural acceptance, environmental impact, and crop rotation compatibility. Pairwise comparison surveys were conducted with seven expert stakeholder groups, including farmers, agricultural officials, scientists, economists, policymakers, suppliers, and cooperative representatives. The analysis achieved a consistency ratio of 5.16%, indicating reliable assessments (CR < 10%). Results show that climate suitability (33.32%) and cultural acceptance (23.47%) are the most critical factors. Jasmine rice emerged as the top choice with a proportion of 30.87%, followed by shallots at 21.06% and cassava at 18.20%. This AHP-based tool provides a robust quantitative approach to support sustainable crop selection in the region.

Keywords: Crop selection; Hierarchical analysis approach; Northeastern Thailand; Sustainable farming

1. Introduction

The agricultural sector in Thailand's Northeastern region is experiencing unprecedented challenges in sustainability and productivity. This region, which accounts for approximately one-third of Thailand's agricultural land, has historically been dominated by the cultivation of rice, cassava, sugarcane, and rubber. However, the increasing impacts of climate variability, coupled with socio-economic pressures, necessitate a systematic reevaluation of crop selection strategies (Yuanjit et al., 2023). Recent meteorological data indicate a 15.00% reduction in annual rainfall patterns and a 2.10°C increase in mean temperature over the past decade, significantly affecting traditional farming practices (Rachpibool and Kajornkasirat, 2022).

The complexities of sustainable agriculture in this region are manifold. First, the semi-arid climate and deteriorating soil conditions, characterized by low organic matter content (< 1.00%) and high salinity levels (EC > 4.00 dS/m), pose significant constraints on crop productivity (Ali, 2023). Second, the lack of comprehensive agricultural policies has resulted in suboptimal resource allocation, with 67.0% of farmers reporting difficulties in accessing water resources and 73.0% experiencing declining yields (Saikanth et al., 2023a). Third, socio-economic challenges, including high input costs and

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market volatility, have led to increasing rural-urban migration, with agricultural household debt averaging 78,512 baht per household in 2022 (Tammadid et al., 2023).

Although previous studies have examined various aspects of agricultural sustainability in Northeast Thailand, there is still a significant research gap in developing an integrated decision-making framework for crop selection. The Analytic Hierarchy Process (AHP), initially developed by Saaty (1980), offers a robust methodology for addressing such complex multi-criteria decisions. Recent applications of AHP in agricultural contexts have demonstrated its efficacy in balancing competing objectives (Rawat et al., 2022). However, these studies have primarily focused on developed agricultural systems, leaving a knowledge gap in their application to emerging agricultural economies with unique environmental and socio-economic constraints.

This study fills a significant research gap by developing a comprehensive AHP-based framework for crop selection in Ubon Ratchathani Province located in Northeast Thailand, addressing four critical dimensions: economic viability, environmental impact, climate resilience, and social acceptability. Unlike traditional AHP applications, this research incorporates region-specific parameters, such as local climate variability indices, soil quality indicators unique to Northeastern Thailand, market accessibility metrics, and the integration of traditional farming knowledge. The primary objectives are to construct a weighted criteria matrix for sustainable crop selection using expert opinions and stakeholder input, evaluate alternative crops relative to established regional staples, and create a flexible decision support framework applicable to similar agroecological zones.

This study aims to comprehensively apply AHP for crop selection, introducing an innovative framework that incorporates local environmental and socio-economic factors while establishing a methodological foundation for similar research in other developing agricultural regions. The findings have significant implications for government agricultural policy, extension services, and sustainable farming practices in Thailand and similar agroecological zones worldwide.

The paper is organized as follows: Section 2 reviews the literature on sustainable agriculture, Multi-Criteria Decision Analysis (MCDA), and the use of AHP in agricultural systems. Section 3 outlines the methodological framework, detailing expert selection, AHP implementation, and sensitivity analysis. Section 4 presents the findings and discusses their implications for regional agricultural policy and practice. Finally, Section 5 offers recommendations for implementation and suggests future research directions.

2. Literature Review

This section presents a systematic review of three key domains relevant to sustainable crop selection in Northeast Thailand: sustainable agriculture practices, multi-criteria decision analysis (MCDA), and the application of the Analytic Hierarchy Process (AHP) in agricultural decision-making. The review synthesizes current knowledge and identifies research gaps informing this study's objectives.

2.1. Sustainable Agriculture in Northeast Thailand

In-depth interviews and focus group discussions with farmers, local communities, and agricultural experts can provide valuable qualitative data on challenges and perspectives related to sustainable agriculture practices in the Northeastern region (Dahal et al., 2023; Saikanth et al., 2023a; Sukayat et al., 2023). These interactions offer insights into socio-cultural, economic, and environmental factors influencing crop selection decisions, aiding in a comprehensive understanding of barriers and drivers of sustainable farming adoption. Incorporating diverse stakeholders' qualitative data can help address limitations, enrich the analysis, and help develop targeted strategies to promote sustainable agriculture in the region (Dessart et al., 2019). The evolution of sustainable agriculture in Northeast Thailand reflects unique regional challenges and innovations as follows. Agronomic advancements and resource management systems are pivotal for sustainable agriculture. In terms of agronomic factors, advanced crop breeding programs, particularly for cassava, have led to genetic lines with improved stress tolerance and yield stability (Yuanjit et al., 2023). Precision farming techniques, such as laser land leveling and the use of biofertilizers, have shown substantial economic and environmental benefits (Pame et al., 2023).

Effective resource management strategies, including optimized cropping patterns and irrigation techniques, have increased net returns by 15-20% while simultaneously lowering water use (Jewpanya et al., 2022). Additionally, integrating pest management (IPM) with water conservation practices is essential for the sustainability of rice production (Mungkung et al., 2022). Socio-economic frameworks also play a crucial role. Farmer collectives and enhanced farm administration systems are strongly linked to the adoption of sustainable practices (Mungkung et al., 2022). Research conducted in Surin Province has highlighted the significant impact of farmers' knowledge, attitudes, and practices (KAP) on the effectiveness of sustainable farming initiatives (Liao et al., 2022). These findings emphasize the importance of community-driven approaches and educational programs in promoting agricultural sustainability.

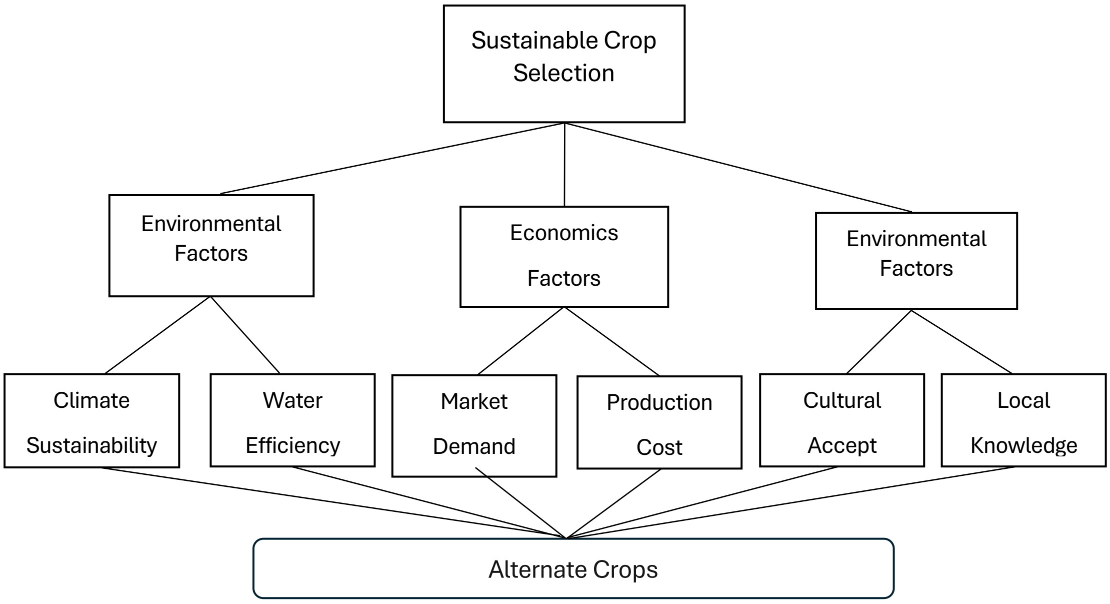
2.2. Multi-Criteria Decision Analysis (MCDA) in Agricultural Systems

MCDA methodologies, such as the Analytical Hierarchy Process (AHP), are useful tools for decision-makers to handle the intricate trade-offs involved in agricultural systems (Carlsen and Bruggemann, 2022). MCDA techniques provide a structured framework for evaluating and selecting the most optimum option from a wide range of alternatives, taking into account many criteria that may contradict each other (Rawat et al., 2022; Ziemba, 2022; Bandyopadhyay, 2021). These tactics help address the challenges of sustainable agriculture by providing a systematic approach to decision-making that considers the interconnectedness of criteria, alternatives, uncertainty, and entropy. Ultimately, this contributes to the selection of environmentally friendly solutions. By combining AHP with MCDA in a hybrid model, decision-makers can weigh criteria, normalize data, calculate criteria weights, and select the best agricultural solutions, especially in complex scenarios involving both qualitative and quantitative factors (Ravelo-Mendivelso et al., 2023; Stofkova et al., 2022). These methods enhance decision-making processes in agriculture by considering multiple conflicting criteria and ensuring the selection of environmentally sustainable solutions (Yuan et al., 2022). The necessity of considering a comprehensive set of sustainability indicators and decision support tools to capture the multidimensional nature of agricultural sustainability was emphasized (Hayati et al., 2010).

MCDA refers to a set of techniques and methodologies designed to assist decision-makers in evaluating and selecting the best alternative among multiple options, considering multiple and often conflicting criteria or objectives. MCDA methods are particularly useful in situations where decisions involve complex trade-offs between various factors, and there is no single optimal solution that satisfies all objectives simultaneously. The theoretical foundation of MCDA is rooted in decision theory, utility theory, and multi-objective optimization. The primary goal of MCDA is to provide a structured and transparent framework for incorporating multiple criteria, stakeholder preferences, and value judgments into the decision-making process. MCDA methods can be broadly categorized into two main approaches: multi-attribute utility theory (MAUT) and outranking methods. MAUT methods rely on the construction of a utility function that aggregates the performance of alternatives across multiple criteria, while outranking methods are based on pairwise comparisons and the concept of dominance between alternatives.

2.3. Analytical Hierarchy Process (AHP) in Agricultural Decision-Making

AHP is a widely used MCDA method developed by Thomas L. Saaty in the 1970s (Suksrimuang and Ongkunaruk, 2025). AHP is based on the principles of decomposition, comparative judgment, and synthesis of priorities. It involves structuring a decision problem into a hierarchical model, with the goal at the top level, criteria and sub-criteria at intermediate levels, and alternative options at the bottom level. This flow diagram as in Figure 1 illustrates the systematic and participatory approach taken in the research process, leveraging the AHP method and involving various stakeholders to provide well-informed recommendations for optimizing crop selection in the Northeastern region of Thailand, considering the complex interplay of environmental, economic, and social factors essential for sustainable agricultural practices.



Note: Adapted from Agarwal et al. (2014), this framework illustrates the integration of multiple criteria in agricultural decision-making processes

Figure 1 Conceptual Framework of Agricultural Decision-Making

Recent advancements in agricultural decision-making have integrated traditional practices with modern analytics. Key research from 2017 to 2024 highlights three main factors: sustainable agriculture in Northeast Thailand, MCDA, and AHP applications. In sustainable agriculture, major progress has been made in crop and resource management. Yuanjit et al. (2023) improved cassava breeding, while Jewpanya et al. (2022) optimized irrigation, boosting water efficiency and yielding 20% higher returns. These studies establish criteria for crop selection and resource use. The MCDA domain advanced with Ziemba (2022) sustainability indices and Benetto et al. (2008) fuzzy logic applications, refining agricultural decision tools. In parallel, Muslim et al. (2017) and Hazza et al. (2022) enhanced AHP frameworks, simplifying comparisons and strengthening planning methods. These integrated approaches mark a shift in agricultural strategies, blending empirical research with analytical rigor. The findings provide a foundation for sustainable practices in Northeast Thailand, suggesting a balanced future of traditional and modern methods.

2.4. Research Gaps

The systematic review identifies several significant gaps in current research that need to be addressed for more effective agricultural planning. First, from a methodological standpoint, there is a clear lack of integration between traditional agricultural knowledge and contemporary analytical frameworks. Additionally, there is a pressing need for simplified yet robust evaluation methods that can handle complex agricultural decisions, as well as dynamic assessment approaches capable of adapting to changing environmental conditions. Regionally, there is a notable scarcity of studies focused on Northeast Thailand, with research often overlooking the area's unique socio-economic landscape and the critical need to incorporate climate resilience metrics. In terms of implementation, significant challenges remain. Theoretical frameworks have not been sufficiently validated in real-world settings, there is a lack of user-friendly decision support tools for practical application, and existing mechanisms for stakeholder engagement are inadequate. Addressing these gaps, this study seeks to develop an integrated framework that is specifically tailored to the agricultural needs of Northeast Thailand. This approach combines traditional agricultural practices with modern analytical methods, ensuring that the framework is both scientifically rigorous and culturally relevant.

3. Research Methods

3.1. Expert Selection and Engagement

This step is crucial for selecting key agricultural stakeholders who have the deepest understanding of the study area. The Research in Nakhon Phanom Province highlighted the importance of co-investing with local governments and businesses to develop organic farming practices in smallholder chicken layer farms (Suwannasri and Promphakping, 2022). Similarly, a study in Ubon Ratchathani province emphasized the significance of stakeholder workshops and public consultations in the out-scaling implementation of the Sustainable Rice Platform (SRP) Standard, promoting behavior changes for sustainable rice cultivation (Faysse et al., 2022). Furthermore, discussions between actors in rural territories in Thailand identified innovative pathways to address challenges facing farms, emphasizing the readiness for farming system transformations and actions to enhance land tenure security and youth engagement in farming (Javari, 2023). By involving various stakeholders, including farmers, local administrations, and public agencies, a more comprehensive and effective approach can be adopted to ensure the sustainability of farming practices in Northeast Thailand. Then, seven experts were selected from a diverse range of key stakeholders as shown in Table 1.

By engaging with these diverse stakeholders, the data inputs and analysis can be enriched with local knowledge, practical experiences, and a comprehensive understanding of the economic, environmental, social, and cultural factors influencing sustainable farming practices in Northeast Thailand.

3.2. Criteria and Crop Alternatives Identification

Expert consultations and stakeholder workshops have identified relevant criteria for selecting crops for sustainable farming in Northeast Thailand. The evaluation criteria consider multiple factors that impact the sustainability and viability of agricultural practices (Yanai et al., 2020; Mishra et al., 2013). A hierarchical model was established, with optimal crop selection as the primary goal, followed by criteria and alternative crops at lower levels, illustrated in Figure 2. The identified criteria from expert brainstorming sessions include;

1. **Climate Suitability (CS):** Assess the crop's adaptability to the unique climatic conditions of the northeastern region, including temperature, rainfall patterns, and humidity levels.
2. **Water Use Efficiency (WUE):** Evaluate the crop's water requirements and its ability to thrive under limited water availability or drought conditions, considering the region's semi-arid climate.
3. **Soil Tolerance and Fertility (STF):** Consider the crop's tolerance to acidic soils and its ability to improve soil fertility and structure, as many areas in Northeastern Thailand have sandy or infertile soils.
4. **Pest and Disease Resistance (PDR):** Evaluate the crop's resistance to common pests and diseases prevalent in the region, aiming to minimize reliance on chemical pesticides.
5. **Market Demand and Economic Viability (MD):** Assess the crop's demand in local and regional markets, as well as its potential profitability for farmers, taking into account price fluctuations and market trends.
6. **Cultural Acceptance and Tradition (CAT):** Consider the crop's cultural significance and historical importance in the northeastern region, as well as its acceptance among local communities and traditional farming practices.
7. **Environmental Impact (EI):** Evaluate the crop's impact on the environment, including its carbon footprint, water usage, and potential for soil erosion or degradation, aiming to promote sustainable farming practices.
8. **Crop Rotation Compatibility (CRC):** Assess the compatibility of the crop with existing crop rotation schemes or intercropping systems commonly practiced in the region, aiming to improve soil health and pest management.

Table 1 Profile of target group

No.	Position/Role	Description
1.	Local farmers/agricultural community	A representative from various farming communities in the region, who can provide insights based on their practical experiences, traditional knowledge, and local preferences.
2.	Agricultural extension officer	A field expert from government agencies who works closely with farmers and has a deep understanding of local agricultural practices and challenges
3.	Plant breeder/geneticist	A researcher and scientist working on developing climate-resilient crop varieties and improving crop yields through genetic engineering or traditional breeding methods.
4.	Agricultural economists	An expert in market analysis, supply chain dynamics, and economic viability of different crop options and farming systems.
5.	Agricultural policy maker/government official	A representative from relevant government agencies or ministries responsible for agricultural policies, regulations, and support programs for sustainable farming.
6.	Agricultural input supplier	A representative from companies or organizations providing seeds, fertilizers, pesticides, or other agricultural inputs, can provide insights into product availability, pricing, and sustainability considerations.
7.	Agricultural cooperatives/farmer association	A representative from local agricultural cooperatives or farmer associations, who can provide collective inputs and perspectives from their members.

The criteria for assessing crop suitability in this region encompass various factors. Climate suitability, water use efficiency, soil tolerance, pest resistance, market demand, cultural acceptance, environmental impact, and crop rotation compatibility are crucial considerations. These factors help determine the adaptability of crops to unique climatic conditions, water availability, soil types, pest prevalence, market dynamics, cultural significance, environmental sustainability, and agricultural practices in the region. Evaluating these criteria aids in selecting crops that can thrive in the semi-arid climate, improve soil fertility, minimize pesticide use, meet market demands, align with cultural practices, reduce environmental harm, and enhance overall agricultural sustainability. Table 2 presents a summary of the references of selected criteria.

Table 2 Summary of references for the selected criteria

Authors/Criteria	Srisawat & Payakpate (2014)	Nualnoom (2018)	Karthikey et al. (2019)	Wannaviroj and Sriburi (2019)	Singha et al. (2020)	Shaloo et al. (2022)	Rahmawaty et al. (2022)	Nguyen et al. 2023	This Paper
Climate Suitability		x				x		x	x
Water Use Efficiency		x	x	x		x		x	x
Soil Tolerance and Fertility	x		x		x	x	x	x	x
Pest and Disease Resistance		x					x		x
Market Demand and Economic Viability	x	x		x				x	x
Cultural Acceptance and Tradition							x		x
Environmental Impact							x	x	x
Crop Rotation Compatibility				x	x	x			x

The selection of crop varieties well-adapted to the region's specific climatic conditions is crucial for ensuring optimal growth, yield, and resilience against climate-related stresses. Choosing crops with high water use efficiency can help conserve water in regions with limited resources while maintaining productivity, contributing to long-term sustainability. Selecting crops that can thrive in the region's soil conditions and contribute to soil fertility helps prevent degradation and maintain long-term productivity. Crops with natural resistance to pests and diseases reduce the need for chemical pesticides, promoting environmentally friendly farming practices and reducing health risks. Considering market demand and economic viability ensures the availability of a stable market and reliable income for farmers, contributing to the long-term sustainability of agricultural practices.

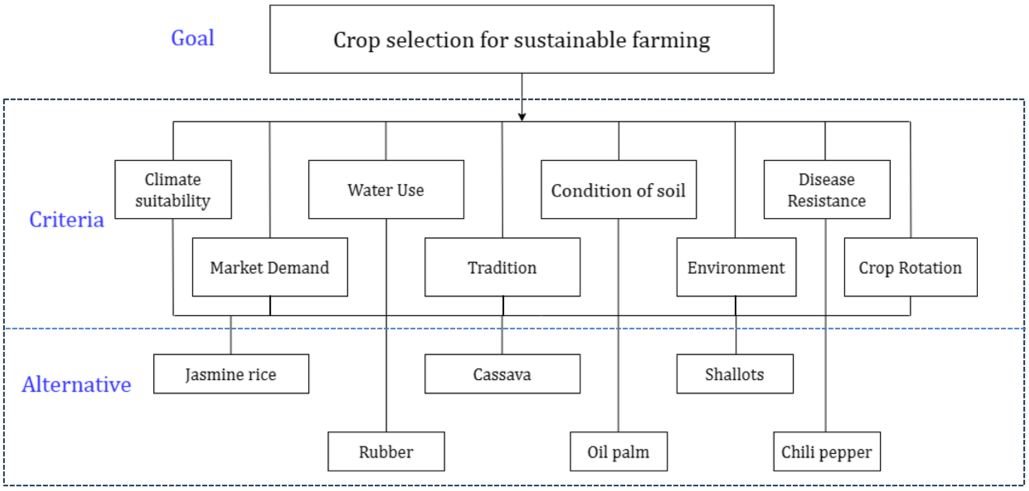


Figure 2 Hierarchical structure for crop selection

3.3. Data Collection

Questionnaires or pairwise comparison surveys are designed to elicit expert judgments on the relative importance of main and sub-criteria. A diverse group of experts, including agronomists, soil scientists, local farmers, and community representatives, are involved. Feedback on crop selection recommendations, potential obstacles, and concerns is gathered, and the analysis is refined as needed.

3.4. AHP Calculations and Consistency Checks

Spreadsheet templates or AHP software (e.g., Expert Choice, Super Decisions) are used to construct pairwise comparison matrices, calculate priority weights for criteria and sub-criteria, and synthesize overall priorities for crop alternatives. Consistency checks are performed to ensure the reliability of expert judgments, and adjustments are made as necessary. The AHP process involves the following key steps:

3.4.1. Define the Problem and Establish the Decision Hierarcy

First, clearly define the goal or decision problem to be addressed. Second, identify the relevant criteria and sub-criteria that will influence the decision. Structure the problem as a hierarchy with the goal at the top, criteria, and sub-criteria at intermediate levels, and alternatives at the bottom level.

3.4.2. Construct Pairwise Comparison Matrices

For each level of the hierarchy, construct a pairwise comparison matrix by comparing the elements in pairs according to their relative importance or preference. Comparative judgments are established by creating pairwise comparisons between the n criteria, resulting in the formation of a matrix of order n based on these comparisons. This matrix is always positive reciprocal, meaning that all entries of the matrix are positive and each element a_{ij} is equal to the reciprocal of a_{ji}, where i and j range from 1 to n. Saaty proposed a scale (Table 3.) that establishes a one-to-one correlation between a set of options and a subset of rational numbers {1/9, 1/8, 1/7, 1/6, 1/5, 1/4, 1/3, 1/2, 1, 2, 3, 4, 5, 6, 7, 8, 9}. These numbers indicate the relative significance of the i^{th} alternative compared to the j^{th} alternative.

Table 3 Fundamental nine-point scale proposed by Saaty (1980)

Intensity of importance	Definition
1	Equal significance
3	Moderate importance of one over another
5	Relatively significant prioritization of one over another
7	Exceptionally critical
9	Absolute importance
2,4,6,8	Interpolated values between two consecutive assessments
Reciprocals of above	If factor *i* is given one of the values mentioned above, then factor *j* will have the reciprocal value in comparison to *i*.

Let's assume that we have n options that need to be compared in pairs. The variable a_{ij} represents the preference of the i^{th} choice over the j^{th} alternative, where i and j range from 1 to n. Pairwise comparisons are used to determine the relative significance of one choice compared to another with respect to each criterion. The relative preferences are used to create a positive reciprocal matrix $A = [a_{ij}]$ of order n. In this matrix, a_{ii} is equal to 1 for all $i = 1, 2, \ldots, n$, and a_{ij} is equal to 1 divided by a_{ji} for all $i, j = 1, 2, \ldots, n$. A pairwise comparison matrix of order n, denoted as a $n \times n$ matrix, may be expressed in Equation 1.

$$A = \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ a_{21} & a_{22} & \cdots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ a_{n1} & a_{n2} & \cdots & a_{nn} \end{bmatrix} = \begin{bmatrix} a_{11} & a_{12} & \cdots & a_{1n} \\ \frac{1}{a_{12}} & a_{22} & \cdots & a_{2n} \\ \vdots & \vdots & \ddots & \vdots \\ \frac{1}{a_{1n}} & \frac{1}{a_{n2}} & \cdots & a_{nn} \end{bmatrix} \tag{1}$$

The reciprocal values are used for the inverse comparisons as shown in Table 4 (e.g., if A is 5 times more important than B, then B is 1/5 times as important as A).

Table 4 Example pairwise comparison matrix for criteria

	A	B
A	1	3
B	1/3	1

3.4.3. Calculate priority weights

During the final stage, a series of calculations must be performed to assess the priority vector (weights) and the consistency of the judgments.

In practical situations, it is sometimes difficult to get ideal evaluations. Therefore, it is necessary to create a consistent pairwise comparison matrix after doing the paired comparisons. Hence, another crucial objective is to obtain a positive reciprocal matrix that closely resembles a consistent positive reciprocal matrix. If there are m criteria and $W = [w_1, w_2, \ldots, w_m]\ T$ is the weight vector corresponding to these criteria, then for a consistent pairwise comparison matrix A, Equation 2 must be satisfied.

$$A\,W = m \times W \tag{2}$$

This indicates that if m is an eigenvalue of A, then W is the corresponding eigenvector. Furthermore, it is worth noting that a pairwise comparison matrix that is consistent always has a rank of one. Therefore, the only eigenvalue of matrix A that is not equal to zero is m, and it is also the greatest eigenvalue. The Analytic Hierarchy Process (AHP) utilizes the eigenvector method to calculate the priority vector, which represents the weights of different criteria or alternatives (Saaty and Vargas, 2012; Ishizaka and Labib, 2011). This addition provides the necessary academic support for your methodological approach by citing both the foundational work by Saaty and Vargas (2012) and the comprehensive review by Ishizaka and Labib (2011), which covers the main developments in AHP. This addresses the reviewer's concern about proper citation for the selected methods. By using the eigenvector, the discrepancies are rectified by the computation of W and the accurate eigenvector of matrix A as Equation 3.

$$AW = \lambda_{max} \tag{3}$$

Equation 3 represents the maximum work done, denoted as AW, which is equal to the product of the wavelength λ and the maximum displacement W. Here, λmax represents the highest eigenvalue of the pairwise comparison matrix A.

To normalize the pairwise comparison matrix, each element is divided by the sum of its corresponding column. Once the matrix is normalized, the priority vector, or weights, is calculated by averaging the elements in each row of the normalized matrix. Additionally, methods such as the eigenvalue approach or other matrix operations can be used to derive these priority weights. An example calculation of the priority weights is illustrated in Table 5.

Table 5 Normalized matrix example

	X	Y
X	0.75	0.75
Y	0.25	0.25

Step 1: Normalize each column by dividing each element by the column sum. In this case, the column sums are:

Column sum for X = 0.75 + 0.25 = 1

Column sum for X = 0.75 + 0.25 = 1

Since each column already sums to 1, the normalized matrix remains the same.

Step 2: Compute the priority vector by averaging the rows of the normalized matrix:

Priority vector = $[(0.75 + 0.25)/2, (0.75 + 0.25)/2]$ = [0.5,0.5]

The priority vector for this example is [0.5, 0.5], indicating equal importance for both criteria (X and Y).

3.4.4. Check consistency

The eigenvector approach is valuable for determining the most reliable and ultimate weights of the alternatives evaluated at each level of the hierarchy. If matrix A is inconsistent, meaning that $\lambda_{max} > m$, and if $\lambda_{max} = m$, then matrix A must be consistent.

The consistency ratio (CR), which assesses the level of inconsistency in the judgments, is defined in Equation 4 and 5:

$$CR = \frac{CI}{RI} \tag{4}$$

$$CI = \frac{(\lambda_{max} - n)}{n-1} \tag{5}$$

Here, CI is the consistency index, which is used to assess the consistency of the matrix.

- RI is the random index, as defined by Saaty (1980).

The consistency index (CI) is used for evaluating the consistency of judgments. If the consistency index meets the required threshold, the choices may be accepted. Otherwise, the judgments should be revisited and revised until an acceptable level of consistency is achieved. Consistency ratios greater than 0.10 are generally considered acceptable. If the consistency ratio exceeds 0.10, the experts should reconsider their judgments and improve consistency.

3.4.5. Synthesize Priorities

Repeat 3.4.2 through 3.4.4 for each level of the hierarchy to obtain the priority weights for criteria, sub-criteria, and alternatives. Next, aggregate the priority weights across all levels using a weighted sum or other appropriate synthesis method to obtain the overall priority ranking of the alternatives. The methodology is summarized as shown in Figure 3.

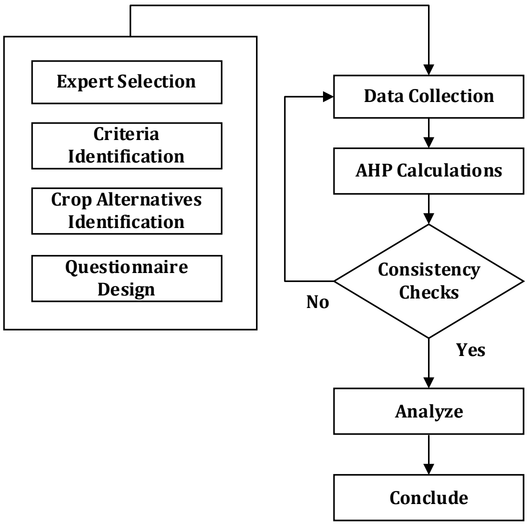


Figure 3 The AHP method for crop selection

4. Results and Discussion

4.1. Consistency Test

The consistency of expert judgments in the decision-making process, evaluated using the Consistency Index (CI), was 0.0728. This CI value was then compared to a Random Index (RI) of 1.41, resulting in a Consistency Ratio (CR) of 0.0516. As this CR is below the 0.1 threshold, it indicates a good level of consistency among the experts' assessments. Upon completing the development of the questionnaire, a comprehensive amount of data was gathered via conversations with agricultural specialists. Farmers in the area, agricultural policymakers, and other stakeholders are engaged in the process of selecting crops in the northeastern region of Thailand. The consistency ratio (CR) was determined as an assessment criterion via the use of a questionnaire. The content encompasses eight primary variables that influence the decision-making process. The CR values for each of the eight parameters assessed by experts were determined to be as follows: 0.0516, 0.0515, 0.0517, 0.0514, 0.0518, 0.0513, and 0.0519, respectively. All CR values adhere to the acceptable criterion (CR $\leq$ 0.1).

4.2. Criteria Ranking

The criteria for crop selection, as shown in Table 6, are ranked by importance. Climate suitability is the most important (33.32%), followed by cultural acceptance and tradition (23.47%), water use efficiency (14.69%), market demand and economic viability (11.14%), soil tolerance and fertility and crop rotation compatibility (both 5.94%), and finally, pest and disease resistance and environmental impact (both 2.75%). This ranking reflects the region's unique challenges and priorities, emphasizing the need for crops that can thrive in the local climate, align with cultural practices, and utilize water efficiently. While economic viability and long-term sustainability are also considered, they are ranked lower than the immediate concerns of climate adaptability and cultural relevance.

Climate suitability emerged as the most influential criterion, with a weight of 33.32%, underscoring its critical relevance in Northeastern Thailand. This region contends with considerable climate-related challenges, such as irregular rainfall, frequent droughts, and significant temperature fluctuations. Recent meteorological records indicate a 15.0% decline in annual rainfall and a 2.1°C increase in mean temperature over the past decade (Rachpibool and Kajornkasirat, 2022). The emphasis on climate suitability is consistent with research by Yuanjit et al. (2023), which highlights that climate adaptability is crucial for crop survival and yield stability in semi-arid tropical environments. Supporting this, Jewpanya et al. (2022) demonstrated that crops specifically adapted to local climate conditions can enhance yield stability by up to 40.00% and reduce water usage through optimized cropping strategies.

Table 6 Scores indicating the importance of criteria in the selection of alternatives

Criteria	Proportion (%)	Rank
Climate Suitability (CS)	33.32	1
Cultural Acceptance and Tradition (CAT)	23.47	2
Water Use Efficiency (WUE)	14.69	3
Market Demand and Economic Viability (MD)	11.14	4
Soil Tolerance and Fertility (STF)	5.94	5
Crop Rotation Compatibility (CRC)	5.94	5
Pest and Disease Resistance (PDR)	2.75	7
Environmental Impact (EI)	2.75	7

The equal weightings of 5.94% between soil tolerance and fertility and crop rotation compatibility, as well as 2.75% between pest and disease resistance and environmental impact, underscore the interconnected nature of these criteria in sustainable farming. The link between soil health and crop rotation shows that effective rotation enhances soil fertility, while healthy soil improves rotation outcomes. Similarly, the equal weighting between pest resistance and environmental impact reflects their shared influence on ecosystem balance and sustainable pest management. These connections highlight the importance of viewing agricultural criteria as integrated systems rather than isolated factors. Further research using sensitivity analysis and fuzzy Analytical Hierarchy Process methods could provide deeper insights into these relationships.

4.3. Crop Ranking

Table 7 and Figure 5 present the overall evaluation results for crop selection, considering all criteria. Jasmine rice ranks first with a proportion of 30.87%, making it the most suitable crop overall based on factors such as climate suitability, water use efficiency, soil tolerance, pest resistance, market demand, cultural acceptance, environmental impact, and crop rotation compatibility. Shallots and cassava are tied for second place with proportions of 21.06% and 18.20%, respectively. Shallots perform well in climate suitability, water efficiency, soil tolerance, and pest resistance, while cassava stands out in soil tolerance and fertility. Chili pepper follows in fourth place with 11.28%, and rubber ranks fifth with 11.23%, notable for pest resistance but weaker in other areas. Oil palm ranks last with 7.36%, performing well in market demand and economic viability but scoring lower in most other criteria. These rankings provide a comprehensive assessment of crop suitability for sustainable farming in Northeastern Thailand, reflecting the combined impact of all evaluated criteria.

In summary, jasmine rice emerges as the most suitable option, followed by cassava and shallots. Rubber and chili pepper have moderate suitability, while oil palm is the least suitable alternative based on the given criteria. The results presented above provide valuable insights and a comprehensive evaluation of various crop alternatives for sustainable farming in the Northeastern region of Thailand. However, it is important to recognize that these findings are intended to serve as a guide or reference, rather than a definitive prescription.

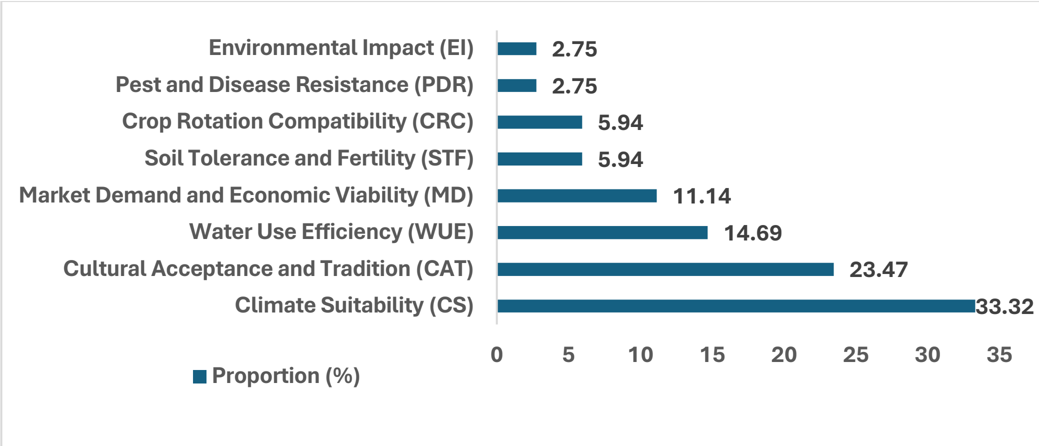


Figure 4 Criteria importance distribution (%)

Table 7 Proportion of crop alternatives based on eight criteria

Alternatives	Weight of Criteria								Proportion (%)	Rank
	CS	WUE	STF	PDR	MD	CAT	EI	CRC		
Jasmine rice	0.333	0.328	0.098	0.111	0.269	0.373	0.229	0.273	30.87	1
Shallots	0.197	0.207	0.188	0.159	0.148	0.256	0.229	0.264	21.06	2
Cassava	0.197	0.207	0.326	0.176	0.081	0.147	0.229	0.190	18.20	3
Chili Pepper	0.111	0.109	0.098	0.176	0.081	0.120	0.120	0.133	11.28	4
Rubber	0.111	0.098	0.188	0.315	0.148	0.066	0.120	0.089	11.23	5
Oil Palm	0.047	0.047	0.098	0.060	0.269	0.036	0.070	0.047	7.36	6

While the analysis suggests that jasmine rice, cassava, and shallots may be the most suitable options based on the specified criteria, it is ultimately up to each farmer to make the final decision regarding which crops to cultivate. Farmers possess unique knowledge and understanding of their specific local conditions, resources, and preferences, which may influence their choice of crops. Farmers may choose to prioritize certain criteria over others based on their specific needs, goals, and constraints. For instance, some farmers may place a higher emphasis on cultural acceptance and tradition, while others may prioritize market demand and economic viability. The decision-making process should remain flexible and tailored to individual farmers' situations.

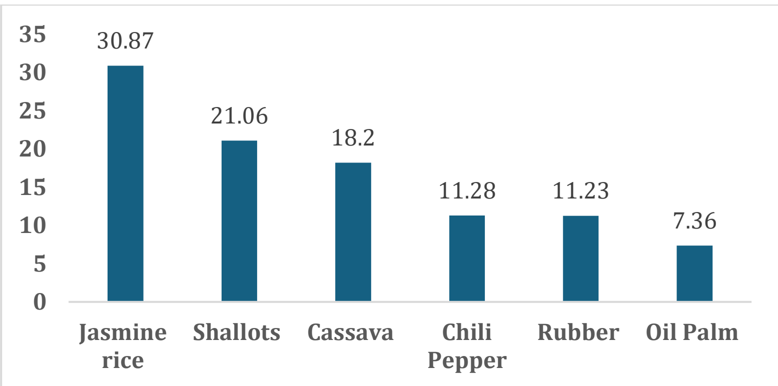


Figure 5 The weight of crops from AHP analysis

4.4. Research Findings and Implications

The application of the AHP methodology in this study offered valuable insights into sustainable crop selection for Northeastern Thailand. By effectively addressing the complex multi-criteria nature of agricultural decision-making, the framework enabled a quantitative assessment of qualitative judgments while maintaining high consistency. This research extends previous work, such as that of Muslim et al. (2017), by incorporating region-specific criteria and engaging seven diverse stakeholder groups to ensure practical, locally relevant outcomes. The decision support framework produced clear criteria weightings, metrics, and visualizations, enhancing communication and applicability for various stakeholders.

Climate suitability emerged as the most influential factor (33.32%), reflecting pressing regional challenges like irregular rainfall and temperature fluctuations. This emphasis aligns with documented climate trends in Northeastern Thailand (Rachpibool and Kajornkasirat, 2022) and underscores the need for selecting climate-resilient crops. Cultural acceptance, the second most important criterion at 23.47%, highlights the necessity of balancing traditional practices with agricultural innovation. Water use efficiency ranked third (14.69%), emphasizing the importance of aligning crop choices with existing irrigation infrastructure and soil management practices.

The region-specific focus of this framework underscores its adaptability and relevance. Climate considerations dominated the analysis, with climate suitability receiving the highest weighting due to the area's significant challenges related to rainfall variability and temperature extremes. Cultural integration was also a key factor, ensuring that crop recommendations respected local traditions while fostering innovation. Meanwhile, the emphasis on water use efficiency reflects the need to optimize available resources within existing agricultural systems. Additionally, the focus on current climate conditions points to the necessity of developing dynamic frameworks that account for future climate scenarios. Finally, this study reinforces the importance of integrating local knowledge and participatory approaches in agricultural decision-making. By involving diverse stakeholders, the research captured valuable insights and expertise, leading to context-specific and relevant recommendations, as emphasized by Tzeng and Huang (2011).

This research has far-reaching implications. For policymakers, it offers evidence-based crop selection guidelines, supports agricultural extension services, and provides a robust framework for policy development. Practically, the decision support tools can assist farmers, enhance agricultural planning, and optimize resource allocation. Overall, the study highlights the promise of structured decision-making frameworks in agriculture, with the AHP methodology proving adaptable to other regions facing similar challenges, though ongoing refinement will be necessary to address evolving environmental and socio-economic conditions.

5. Conclusions

This research developed an effective AHP-based framework for sustainable crop selection in Northeastern Thailand. The analysis showed that climate suitability (33.32%) and cultural acceptance (23.47%) were the most influential factors, highlighting the region's specific environmental and socio-cultural challenges. The framework assessed six crop alternatives, with jasmine rice ranking highest at 30.87%, followed by shallots at 21.06% and cassava at 18.20%. The reliability of the framework was confirmed through a consistency ratio of 0.0516, indicating strong expert agreement. The participatory approach, involving seven diverse stakeholder groups, ensured that economic, environmental, and socio-cultural factors unique to this region were comprehensively addressed. These findings provide valuable guidance for agricultural policy development and sustainable farming practices in Northeast Thailand. The methodology demonstrates the effectiveness of AHP in addressing complex agricultural decision-making and can be adapted for similar agroecological regions facing comparable challenges. Future research should focus on incorporating climate change scenarios, expanding the analysis to include emerging crop varieties, and developing user-friendly decision support tools for practical implementation. This analysis was conducted based on current climate conditions and did not account for potential future climate change scenarios. Additionally, while expert judgments were used to inform the criteria weights and rankings, these assessments may still contain inherent biases, even though acceptable consistency levels were achieved. Lastly, the framework's regional specificity could restrict its direct applicability to other areas. This necessitates modifications to adapt to different environmental and socio-economic contexts.

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Author Contributions

Klorklear contributed to the conception and design of the study, literature review, data collection, and manuscript drafting. Kanokkarn performed the data analysis and interpretation and contributed to manuscript drafting. Pornthipa initiated the research topic, literature review, supervised the research project, provided critical revisions, and approved the final version of the manuscript.

Conflict of Interest

The authors declare that there is no conflict of interest regarding the publication of this article.

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