ENHANCING RICE PRODUCTION EFFICIENCY THROUGH OPTIMIZED MACHINERY ALLOCATION IN KUBU RAYA, INDONESIA

Ekawati[1] R. Rizieq[1] A. Purwanto[2] Asti[1]
Assist. Prof. Prof. Assist. Prof. Lecturer
[1]Univ. Panca Bhakti, Pontianak, Indonesia
[2]PGRI Pontianak University, Pontianak Indonesia
e-Mail: ekawati@upb.ac.id

ABSTRACT

Optimizing the allocation of agricultural machinery is crucial for enhancing rice production efficiency, particularly in regions with uneven resource distribution. This study addresses the lack of localized, data-driven mechanization strategies in Kubu Raya Regency, bridging an important research gap in sustainable resource allocation. It focuses on Sungai Kakap and Kubu subdistricts in Kubu Raya Regency, West Kalimantan, to develop and **prioritize the distribution of hand tractors, cultivators, and power threshers based on land area, cropping index, and existing saturation levels. Primary data were collected through structured interviews with a representative sample of agricultural stakeholders, while secondary data included rice production levels, machinery availability, and land use statistics. The results identified Tanjung Saleh and Kampung Baru as high-priority villages due to extensive paddy field areas, high cropping intensities, and critically low machinery saturation levels. Addressing these shortages can significantly enhance land preparation, planting efficiency, and post-harvest processing, leading to increased productivity and reduced operational costs. A validated coefficient approach and stakeholder engagement were integrated into the prioritization framework to ensure robust decision-making and policy relevance. The proposed prioritization framework offers a data-driven approach for equitable machinery distribution, supporting sustainable agricultural development and regional food security. Beyond Kubu Raya, these findings provide actionable insights for policymakers and practitioners seeking to refine agricultural resource allocation strategies in similar contexts. This study** thus **proposes a foundation for future research on optimizing agricultural mechanization, highlighting potential benefits for policy and practice at both local and broader scales.**

Key words: agricultural mechanization, machinery allocation, rice production efficiency, cropping indeks, sustainable agriculture

تعزيز كفاءة إنتاج الأرز من خلال التوزيع الأمثل للآلات في كوبو رايا، إندونيسيا

إكاواتي [1] ر .ريزيق أ .بوروانتو[1] أستي[2][1]
أستاذ مساعد أستاذ أستاذ مساعد مُحاضِر
جامعة بانكا باكتي، بونتياناك، إندونيسيا [1]
جامعة بيرساتوان جورو جورو ريبوبليك إندونيسيا بونتياناك، بونتياناك، إندونيسيا [2]

المسلخص

يعد تحسين تخصيص الآلات الزراعية أمرا بالغ الأهمية لتعزيز كفاءة إنتاج الأرز، لاسيما في المناطق التي تشهد توزيعا غير متكافئ للموارد. تهدف هذه الدراسة إلى معالجة نقص الاستراتيجيات المحلية المستندة إلى البيانات فيما يتعلق بالميكنة الزراعية في محافظة كوبو رايا، مُسددة فجوة بحثية مهمة في تخصيص الموارد المستدام. وتركز الدراسة على منطقتي سونغاي كاكاب وكوبو في محافظة كوبو رايا، كاليمانتان الغربية، لتطوير وتحديد أولويات توزيع الجرارات اليدوية والمحاريث وآلات الحصاد الميكانيكية استنادًا إلى مساحة الأراضي، ومؤشر المحاصيل، ومستويات التشبع الحالية بالآلات. تم جمع البيانات الأولية من خلال مقابلات منظمة مع عينة تمثيلية من أصحاب المصلحة الزراعيين، بينما شملت البيانات الثانوية مستويات إنتاج الأرز، وتوافر الآلات، وإحصاءات استخدام الأراضي. وأظهرت النتائج أن قريتي تانجونغ ساليه وكامبونغ بارو تمثلان مناطق ذات أولوية عالية نظرا لمساحات حقول الأرز الشاسعة، وارتفاع كثافة المحاصيل، وانخفاض مستويات تشبع الآلات بشكل حاد. إن معالجة هذه النواقص يمكن أن تُحسن بشكل كبير من عمليات تجهيز الأراضي، وكفاءة الزراعة، والمعالجة بعد الحصاد، مما يؤدي إلى زيادة الإنتاجية وتقليل تكاليف التشغيل. تم دمج نهج المعاملات المصدق ومشاركة أصحاب المصلحة في إطار تحديد الأولويات لضمان اتخاذ قرارات قوية وذات صلة بالسياسات. ويقدم إطار تحديد الأولويات المقترح منهجية مستندة إلى البيانات لتوزيع الآلات بشكل عادل، داعما التنمية الزراعية المستدامة والأمن الغذائي الإقليمي. وإلى جانب محافظة كوبو رايا، توفر هذه النتائج رؤى قابلة للتطبيق لصانعي السياسات والممارسين الذين يسعون إلى تحسين استراتيجيات تخصيص الموارد الزراعية في سياقات مشابهة. وبالتالي، تقترح هذه الدراسة أساسا للبحوث المستقبلية حول تحسين الميكنة الزراعية، مسلطة الضوء على الفوائد المحتملة للسياسة والممارسة على المستويين المحلي والأوسع.

الكلمات المفتاحية: الميكنة الزراعية، تخصيص الآلات، كفاءة إنتاج الأرز، مؤشرات المحاصيل، الزراعة المستدامة

Received:22 /8/2024, Accepted:12/1/2025, Published:December 2025

INTRODUCTION

Agricultural mechanization has emerged as a cornerstone of modern rice production, addressing critical global challenges related to food security, productivity, and sustainability. Mechanized systems are replacing traditional farming practices, driving enhanced operational efficiency, reduced labor dependency, and increased crop yields. These transformations are especially evident in developing countries, where rice remains a staple crop and a vital component of national food security strategies.The benefits of mechanization are well-documented in countries such as China, Vietnam, and Iraq, where advancements in agricultural technologies have significantly transformed productivity and resource management. In China, labor shortages driven by rural-to-urban migration have led to the adoption of mechanized tools like UAVs and optimized transplantation techniques, boosting productivity and improving resource efficiency (27). Similarly, Vietnam's Mekong Delta has embraced mechanization to enhance rice quality and market competitiveness, reinforcing its status as a leading rice exporter (20). These examples underscore the transformative impact of mechanization on agricultural systems.Despite its benefits, mechanization faces persistent challenges in achieving equitable implementation, particularly in resource-constrained regions. Smallholder farmers in developing countries often struggle with barriers such as limited access to machinery, misaligned equipment designs unsuitable for small-scale plots, and economic constraints, which perpetuate cycles of low productivity (18, 23, 25). In Indonesia, these challenges are evident in regions like Kubu Raya, West Kalimantan, where uneven distribution of agricultural machinery disrupts critical farming operations, thereby limiting productivity and threatening food security.

However, limited empirical studies have focused on Kubu Raya's unique constraints, highlighting a research gap in localized resource allocation strategies: Cropping intensity, defined by the frequency of planting and harvesting cycles, further complicates machinery allocation. High intensity cropping systems, such as double or triple cropping, demand efficient machinery for timely operations, especially in irrigated regions (11, 13). Conversely, lower cropping intensities reduce machinery investment incentives, perpetuating reliance on manual labor (33). These dynamics highlight the need for tailored mechanization strategies to address regional agricultural demands effectively. This study addresses these challenges by focusing on optimizing agricultural machinery allocation in Kubu Raya. By developing a localized, data-driven prioritization framework based on land area, cropping intensity, and machinery saturation levels, this research aims to enhance resource efficiency and support equitable agricultural development. Its objectives are twofold: (1) to identify high-priority areas for machinery allocation and (2) to provide actionable policy recommendations to address resource disparities. This study's contributions are both scientific and practical. By addressing machinery shortages in high-priority villages, it aims to improve resource utilization, reduce operational costs, and boost productivity. Additionally, the research offers a replicable framework adaptable to similar agricultural settings globally, ultimately supporting food security and sustainable farming practices.

MATERIALS AND METHODS

This study employed a systematic approach to assess and optimize agricultural machinery allocation in the Kubu Raya Regency, focusing on Sungai Kakap and Kubu subdistricts. The methodology integrated data-driven analysis, ß, and validated coefficients for machinery needs to develop a prioritization framework tailored to local conditions.

Study Area: The research was conducted in Sungai Kakap and Kubu subdistricts, covering 34 villages with varying levels of agricultural productivity. These areas were selected due to their strategic importance in rice production and their diverse cropping intensities.

Data Collection: Data collection in this study comprised both primary and secondary sources. Primary data were gathered through interviews with key stakeholders, including farmers, agricultural officers, and machinery operators. A representative sample of stakeholders was selected based on farm size, level of involvement in rice farming, and accessibility. This ensured diverse perspectives for more comprehensive data on machinery needs, cropping patterns, and operational challenges. Secondary data included land area calculations derived from GIS analysis using digital map data in the form of shapefiles, processed through ArcGIS software. Additional secondary data sources included cropping index statistics obtained from the Agricultural Office of Kubu Raya, agricultural machinery availability data provided by the Ministry of Agrarian Affairs, and subdistrict shapefiles used for spatial analysis.

Analytical Framework: The study applied a Multi-Criteria Decision Analysis (MCDA) approach, leveraging both quantitative and qualitative data to prioritize machinery allocation, with stakeholder feedback used to refine criteria weighting and ensure local relevance.

1. Calculation of Machinery Needs: The formula for determining machinery requirements incorporated coefficients such as work capacity and effective working hours. These coefficients were validated through field observations, consultations with local agricultural experts, and statistical calibration to ensure they accurately reflected field conditions (29).

Equation for Tractors and Cultivators:

$$KB=(LS \times CF)/(Ka \times tE \times E)$$

KB = Number of machinery units required.
LS = Land area (hectares).
CF = Coefficient factor.
Ka = Work capacity (hectares/hour).
tE = Effective working days.
E = Effective working hours per day.

Equation for Power Threshers (KB):

$$KB=(P \times CF)/(Ka \times tE \times E)$$

KB = Number of machinery units required.
P = Rice production (kg).
CF = Coefficient factor (assumed value: 1).
Ka = Work capacity (tons/hour).
tE = Effective working days (days).
E = Effective working hours (hours/day)

2. Saturation Level Analysis: Machinery saturation levels were calculated to identify overutilized and underutilized villages. Diagnostic tools and survey data provided real-time performance metrics, adapted to local contexts (10, 34).

Saturation Level Formula: $TK=K/KB \times 100$

TK = Saturation level (%).
KK = Current machinery availability.
KB = Machinery required.

3. Prioritization Framework: Villages were scored and ranked based on three criteria: Land Area: Larger areas received higher priority. Cropping Intensity (CI): Villages with higher cropping indices were prioritized. Machinery Saturation Levels: Lower saturation levels indicated higher needs. Scores from each criterion were combined to categorize villages into high, medium, or low priority. This framework was informed by best practices in MCDA and stakeholder-driven approaches (5). Stakeholder consultations were instrumental in determining threshold values and refining the weight for each criterion.

Limitations and Adaptations

The framework incorporated adaptive management principles to accommodate uncertainties such as climatic variability and evolving agricultural practices. Iterative adjustments based on stakeholder feedback ensured the model remained flexible and context-specific (1). In addition, regular meetings with local farming groups and extension officers helped address potential biases by validating initial assumptions regarding machinery allocation and usage patterns. This comprehensive methodology provides a replicable model for optimizing agricultural resource allocation, balancing efficiency, equity, and sustainability.

RESULTS AND DISCUSSION

This study reveals significant variations in agricultural machinery allocation priorities among the 34 villages in the Sungai Kakap and Kubu subdistricts. The analysis, detailed in Tables (1, 2, and 3) evaluates agricultural machinery availability, needs, and saturation levels, focusing on key factors such as land area, cropping intensity, and socio-economic conditions. These findings emphasize critical machinery shortages in high-priority areas, serving as a basis for strategic resource planning to improve rice farming systems in Kubu Raya Regency. While data were collected from a robust sample, variations in stakeholder responses and possible underreporting in certain villages highlight the need for caution when generalizing the results.

Land Area and Cropping Index

Villages with larger land areas and higher cropping indices demonstrate greater machinery needs due to the increased operational scale and intensity these factors entail. High-priority areas such as Tanjung Saleh (2,647.16 hectares; CI 1.50) and Kampung Baru (1,379.61 hectares; CI 0.96) exemplify this trend. Both villages require significant mechanization to manage land preparation, planting, and post-harvest operations. Despite this, their saturation levels for key machinery such as hand tractors and power threshers remain below 10%, highlighting unmet needs. These results align with similar findings in other Indonesian rice-producing regions, indicating that inadequate machinery access can substantially hinder multi-cropping practices (17).

Table 1. Availability, Needs, and Saturation Levels of Hand Tractors, Land Area, Cropping Index (CI), and Priority Scale for Additional Equipment in Each Village in Kecamatan Sungai Kakap and Kecamatan Kubu, Kubu Raya Regency

No	Village	Land Area (ha)	CI	Availability (unit)	Need (unit)	Saturation (%)	Total Skor	Priority Scale
				Kec. Sungai Kakap				
1	Jeruju Besar	199,5	0,69	0	7	0,00	8	Low Priority
2	Kalimas	521,18	0,52	3	18	16,44	8	Low Priority
3	Pal IX	419,61	1,23	1	15	6,81	7	Low Priority
4	Punggur Besar	1434,73	0,64	5	50	9,95	9	Low Priority
5	Punggur Kecil	797,6	1,00	9	28	32,23	6	Not a Priority
6	Sepuk Laut	22,03	0,00	0	1	0,00	9	Low Priority
7	Sungai Belidak	515,93	1,36	0	18	0,00	7	Low Priority
8	Sungai Itik	408,93	0,81	13	14	90,79	5	Not a Priority
9	Sungai Kupah	96,97	0,38	2	3	58,90	8	Low Priority
10	Sungai Kakakp	388,04	1,24	11	14	80,96	5	Not a Priority
11	Sungai Rengas	1014,79	0,94	21	36	59,10	8	Low Priority
12	Tanjung Saleh	2647,16	1,50	1	93	1,08	10	High Priority
13	Parit Keladi	478,9	0,56	6	17	35,78	7	Low Priority
14	punggur kapuas	267,29	0,38	1	9	10,69	9	Low Priority
15	Rengas Kapuas	170,18	3,78	0	6	0,00	7	Low Priority
				Kecamatan Kubu				
1	Air Putih	100,83	1,12	2	4	56,65	7	Low Priority
2	Ambawang	775,82	0,41	4	27	14,73	10	High Priority
3	Dabung	46,27	0,92	0	2	0,00	8	Low Priority
4	Jangkang I	385,88	1,35	2	14	14,80	7	Low Priority
5	Jangkang II	29,42	1,36	1	1	97,08	6	Not a Priority
6	Kampung Baru	1379,61	0,96	4	48	8,28	11	High Priority
7	Kubu	593,97	0,87	2	21	9,62	9	Low Priority
8	Mengkalan	429,87	0,76	3	15	19,93	8	Low Priority
9	Olak-Olak Kubu	1070,96	1,41	0	37	0,00	8	Low Priority
10	Pelita Jaya	37,25	1,42	3	1	230,01	3	Not a Priority
11	Pinang Dalam	129,71	1,03	1	5	22,02	7	Low Priority
12	Sungai Pinang Luar	195,02	0,97	0	7	0,00	8	Low Priority
13	Sungai Bembang	631,79	0,63	4	22	18,08	10	High Priority
14	Seruat III	299,07	0,92	1	10	9,55	8	Low Priority
15	Seruat II	110,87	0,87	0	4	0,00	8	Low Priority
16	Sepakat Baru	17,19	0,80	0	1	0,00	8	Low Priority
17	Sungai Selamat	121,2	0,90	0	4	0,00	8	Low Priority
18	Teluk Nangka	191,04	1,48	3	7	44,85	6	Not a Priority
19	Sungai Terus	321,04	1,05	4	11	35,58	7	Low Priority

Explanation: Not a Priority if Total Score < 6, Low Priority if Total Score 6 – 9, High Priority if Total Score >9

Table 2. Availability, Needs, and Saturation Levels of Cultivator, Land Area, Cropping Index (CI), and Priority Scale for Additional Equipment in Each Village in Kecamatan Sungai Kakap and Kecamatan Kubu, Kubu Raya Regency

No	Village	Land Area (ha)	CI	Availa bility (unit)	Need (unit)	Satu-ra tion (%)	Total Skor	Priority Scale
				Kec. Sungai Kakap				
1	Jeruju Besar	199,5	0,69	0	8	0,00	8	Low Priority
2	Kalimas	521,18	0,52	2	20	10,13	8	Low Priority
3	Pal IX	419,61	1,23	2	16	12,58	7	Low Priority
4	Punggur Besar	1434,73	0,64	2	54	3,68	9	Low Priority
5	Punggur Kecil	797,6	1,00	2	30	6,62	7	Low Priority
6	Sepuk Laut	22,03	0,00	0	1	0,00	9	Low Priority
7	Sungai Belidak	515,93	1,36	1	20	5,12	7	Low Priority
8	Sungai Itik	408,93	0,81	1	15	6,46	8	Low Priority
9	Sungai Kupah	96,97	0,38	1	4	27,22	7	Low Priority
10	Sungai Kakakp	388,04	1,24	6	15	40,82	4	Not a Priority
11	Sungai Rengas	1014,79	0,94	1	38	2,60	9	Low Priority
12	Tanjung Saleh	2647,16	1,50	2	100	1,99	10	High Priority
13	Parit Keladi	478,9	0,56	3	18	16,54	7	Low Priority
14	punggur kapuas	267,29	0,38	0	10	0,00	9	Low Priority
15	Rengas Kapuas	170,18	3,78	0	6	0,00	7	Low Priority
				Kecamatan Kubu				
1	Air Putih	100,83	1,12	0	4	0,00	7	Low Priority
2	Ambawang	775,82	0,41	0	29	0,00	10	High Priority
3	Dabung	46,27	0,92	0	2	0,00	8	Low Priority
4	Jangkang I	385,88	1,35	2	15	13,68	4	Not a Priority
5	Jangkang II	29,42	1,36	0	1	0,00	7	Low Priority
6	Kampung Baru	1379,61	0,96	0	52	0,00	11	High Priority
7	Kubu	593,97	0,87	0	22	0,00	9	Low Priority
8	Mengkalan	429,87	0,76	0	16	0,00	8	Low Priority
9	Olak-Olak Kubu	1070,96	1,41	0	41	0,00	8	Low Priority
10	Pelita Jaya	37,25	1,42	0	1	0,00	6	Not a Priority
11	Pinang Dalam	129,71	1,03	0	5	0,00	7	Low Priority
12	Sungai Pinang Luar	195,02	0,97	0	7	0,00	8	Low Priority
13	Sungai Bembang	631,79	0,63	0	24	0,00	10	High Priority
14	Seruat III	299,07	0,92	0	11	0,00	8	Low Priority
15	Seruat II	110,87	0,87	0	4	0,00	8	Low Priority
16	Sepakat Baru	17,19	0,80	0	1	0,00	8	Low Priority
17	Sungai Selamat	121,2	0,90	0	5	0,00	8	Low Priority
18	Teluk Nangka	191,04	1,48	0	7	0,00	6	Not a Priority
19	Sungai Terus	321,04	1,05	0	12	0,00	7	Low Priority

Explanation: Not a Priority if Total Score < 6, Low Priority if Total Score 6 – 9, High Priority if Total Score >9

Table 3. Availability, Needs, and Saturation Levels of Power Thresher, Land Area, Cropping Index (CI), and Priority Scale for Additional Equipment in Each Village in Kecamatan Sungai Kakap and Kecamatan Kubu, Kubu Raya Regency

No	Village	Land Area (ha)	CI	Avai-la bility (unit)	Need (unit)	Satura tion (%)	Total Skor	Priority Scale
				Kec. Sungai Kakap				
1	Jeruju Besar	199,5	0,69	0	7	0,00	8	Low Priority
2	Kalimas	521,18	0,52	11	18	62,04	5	Not a Priority
3	Pal IX	419,61	1,23	4	14	28,02	6	Not a Priority
4	Punggur Besar	1434,73	0,64	8	49	16,39	9	Low Priority
5	Punggur Kecil	797,6	1,00	3	27	11,06	7	Low Priority
6	Sepuk Laut	22,03	0,00	0	1	0,00	9	Low Priority
7	Sungai Belidak	515,93	1,36	2	18	11,40	7	Low Priority
8	Sungai Itik	408,93	0,81	8	14	57,51	6	Not a Priority
9	Sungai Kupah	96,97	0,38	0	3	0,00	9	Low Priority
10	Sungai Kakakp	388,04	1,24	2	13	15,15	7	Low Priority
11	Sungai Rengas	1014,79	0,94	6	35	17,38	9	Low Priority
12	Tanjung Saleh	2647,16	1,50	9	90	9,99	10	High Priority
13	Parit Keladi	478,9	0,56	0	16	0,00	8	Low Priority
14	punggur kapuas	267,29	0,38	0	9	0,00	9	Low Priority
15	Rengas Kapuas	170,18	1	0	6	0,00	7	Low Priority
				Kecamatan Kubu				
1	Air Putih	100,83	1,12	1	3	29,15	7	Low Priority
2	Ambawang	775,82	0,41	0	26	0,00	10	High Priority
3	Dabung	46,27	0,92	0	2	0,00	8	Low Priority
4	Jangkang I	385,88	1,35	2	13	15,24	7	Low Priority
5	Jangkang II	29,42	1,36	2	1	199,84	4	Not a Priority
6	Kampung Baru	1379,61	0,96	0	47	0,00	11	High Priority
7	Kubu	593,97	0,87	0	20	0,00	9	Low Priority
8	Mengkalan	429,87	0,76	3	15	20,52	8	Low Priority
9	Olak-Olak Kubu	1070,96	1,41	2	36	5,49	8	Low Priority
10	Pelita Jaya	37,25	1,42	0	1	0,00	6	Not a Priority
11	Pinang Dalam	129,71	1,03	0	4	0,00	7	Low Priority
12	Sungai Pinang Luar	195,02	0,97	1	7	15,07	8	Low Priority
13	Sungai Bembang	631,79	0,63	1	21	4,65	10	High Priority
14	Seruat III	299,07	0,92	0	10	0,00	8	Low Priority
15	Seruat II	110,87	0,87	0	4	0,00	8	Low Priority
16	Sepakat Baru	17,19	0,80	0	1	0,00	8	Low Priority
17	Sungai Selamat	121,2	0,90	0	4	0,00	8	Low Priority
18	Teluk Nangka	191,04	1,48	3	6	46,16	6	Not a Priority
19	Sungai Terus	321,04	1,05	5	11	45,78	7	Low Priority

Explanation: Not a Priority if Total Score < 6, Low Priority if Total Score 6 – 9, High Priority if Total Score >9

Machinery Saturation Levels

Low machinery saturation levels in high-priority villages exacerbate operational delays during critical agricultural phases, reducing yields and increasing labor dependency. For instance, Tanjung Saleh requires 93 units of hand tractors, but its saturation level stands at a mere 1.08%. Kampung Baru also exhibits critically low machinery availability, including zero percent saturation for cultivators. Addressing these saturation gaps could significantly enhance labor efficiency and reduce operational costs, as supported by prior studies (8, 22). Nevertheless, alternative explanations, such as socio-economic barriers to machinery adoption or limited exposure to new technologies, could partially account for the observed low saturation levels and merit further investigation.

Economic Implications: Economic viability is a key factor in determining priorities for agricultural machinery allocation. Villages with consolidated landholdings and high cropping indices can justify investments in high-capacity machinery due to the potential for significant productivity gains. In contrast, areas with fragmented landholdings or low cropping intensities face challenges in adopting mechanization due to limited economies of scale. These findings align with research indicating that economic factors, such as income levels and access to credit, play a critical role in influencing machinery adoption (16). Moreover, adequate credit provisions and competitive pricing policies have been shown to enhance farmers' compliance with government agricultural plans and strengthen crop marketing systems (21). Therefore, investment decisions in mechanization should incorporate break-even analyses to ensure economic feasibility, particularly for smallholder farmers with limited landholdings. In parallel, farmers' perceptions of financial risk and potential benefits must be carefully evaluated to avoid underutilization of newly allocated machinery.

Socio-Economic and Geographic Contexts

Geographic diversity across Kubu Raya necessitates tailored machinery allocation strategies. Villages with unique topographical features or socio-economic constraints, such as limited market access, require customized solutions to overcome barriers to mechanization. For example, variable weather patterns and uneven terrains demand specialized equipment to optimize resource utilization. Previous research highlights the importance of aligning machinery choices with local contexts to enhance efficiency and adoption (35). Additionally, community-led cooperation can be pivotal in facilitating collective investment in machinery, mitigating individual costs, and promoting equitable access.

Policy and Support Mechanisms

Government policies and interventions play a vital role in bridging gaps in machinery access and utilization. High-priority villages like Tanjung Saleh and Kampung Baru would benefit from initiatives such as machinery-sharing programs, subsidized rental schemes, and targeted subsidies to reduce the financial burden on smallholder farmers. Aligning policy frameworks with regional agricultural needs could significantly improve machinery adoption and operational efficiency (7). The results of this study highlight the critical need for tailored strategies to address machinery shortages in high-priority villages such as Tanjung Saleh and Kampung Baru. Enhancing access to hand tractors, cultivators, and power threshers in these areas could significantly improve operational efficiency, increase crop yields, and contribute to sustainable agricultural development. These findings provide a foundation for evidence-based policymaking and further research on agricultural mechanization in Kubu Raya Regency. However, effective implementation will require consistent monitoring and evaluation to ensure that the newly allocated machinery effectively meets local needs and does not remain underutilized. The findings of this study highlight the transformative potential of an optimized machinery allocation framework tailored to the needs of rice-producing regions like Kubu Raya. The discussion delves into the implications of the framework by comparing it to existing strategies, examining alternative explanations for identified trends, addressing sustainability considerations, and exploring its scalability to other contexts.

Comparison with Existing Strategies

The proposed framework distinguishes itself by emphasizing local adaptability, stakeholder engagement, and sustainability. Unlike the one-size-fits-all approach often seen in conventional strategies (14), this framework tailors machinery allocation to the unique socio-economic and environmental conditions of specific villages. For example, by incorporating cropping intensity and land size into the prioritization process, the framework directly addresses local farming realities (6). Moreover, its focus on stakeholder engagement ensures alignment with community needs, bridging the gap between research and practice (3). Economic viability is another critical strength of the proposed framework. By assessing cost-effectiveness, the framework enables farmers to make informed decisions about machinery investments, avoiding underutilization or financial strain (30). Integrating technology and innovation, such as GPS-enabled tracking of machinery utilization, further enhances operational efficiency and aligns with the modern needs of smallholder farmers (15). Future studies might extend this approach by incorporating predictive analytics to anticipate shifting patterns in demand, climate conditions, and market forces.

Sustainability Considerations

Mechanization's impact on sustainability is multifaceted, encompassing environmental, economic, and social dimensions. The study demonstrates how increased mechanization can enhance productivity and resource efficiency while posing potential risks to soil health and biodiversity. The use of heavy machinery can result in soil compaction and a decrease in organic matter, posing a threat to long-term sustainability (12). To mitigate these risks, the framework emphasizes adopting sustainable practices, such as water-saving technologies and precision agriculture tools, to balance productivity with environmental conservation (36). Economically, mechanization boosts farm profitability by reducing labor costs and increasing yields. However, the framework acknowledges the need for long-term economic resilience, emphasizing that farmers must adapt to market fluctuations and rising maintenance costs (26). Socially, mechanization's impact on labor dynamics is significant. While it reduces manual labor demand, potentially displacing workers, it also creates opportunities for jobs in machinery operation and maintenance, contributing to rural livelihood diversification (2). To ensure equitable outcomes, collaboration between government agencies, farmer groups, and private sector entities is vital.

Implications for Rural Development

Optimizing machinery allocation has profound implications for rural development, particularly in labor-intensive sectors like rice farming. By enhancing labor efficiency, the framework allows farmers to achieve higher yields with fewer resources, addressing challenges posed by urban migration and labor shortages (16). The economic benefits of mechanization, such as increased incomes and operational cost savings, empower farmers to invest in education and diversify their income sources (4). The framework's emphasis on equitable access to machinery also promotes social equity. Through collaborative models like cooperatives, smallholder farmers can overcome financial barriers and access the benefits of mechanization (25). This inclusivity is crucial for reducing poverty and fostering sustainable rural development. Nonetheless, further research should examine how socio-cultural factors may influence cooperative success and machinery-sharing arrangements.

Scalability and Broader Applications

Scaling the framework to other regions or crop types presents both opportunities and challenges. Geographically, diverse environmental conditions, such as soil types and climatic variability, necessitate context-specific adaptations to ensure machinery solutions remain effective (19). Socio-economic diversity, including income levels and access to credit, must also be addressed to facilitate widespread adoption (28). For crops beyond rice, the framework must account for differences in planting, cultivation, and harvesting methods (31). For example, mechanization needs for root crops or fruit orchards differ significantly from those of rice paddies. Policymakers must therefore incorporate crop-specific considerations into machinery allocation strategies to maximize effectiveness and sustainability. Infrastructure and policy support are critical enablers for scaling. Investments in roads, storage facilities, and training programs can improve access to machinery and enhance its utilization in remote or underserved areas (24). Strategic policies, such as subsidies and low-interest credit schemes, further ensure that smallholders can participate in mechanization efforts without facing financial strain (9). Studies from other regions indicate that collective ownership or pooled financing for machinery can also reduce entry barriers, suggesting a potential model for future adaptation in Kubu Raya.

Long-Term Vision

The proposed framework aligns with global efforts to achieve sustainable agricultural development. By integrating technology, sustainability principles, and stakeholder involvement, it addresses short-term productivity needs while laying the foundation for long-term resilience. Future research should focus on refining the framework to incorporate climate resilience measures, such as greenhouse gas reduction strategies and ecosystem-based farming practices (32). In conclusion, the optimized machinery allocation framework offers a comprehensive, adaptable, and sustainable approach to addressing disparities in agricultural mechanization. By prioritizing local context, fostering stakeholder engagement, and emphasizing long-term sustainability, it provides a replicable model for enhancing productivity and resilience in rice farming and beyond. Crucially, acknowledging potential biases in data and exploring alternative explanations for low machinery saturation underscore the importance of further empirical validation.

CONCLUSION

This study presents a comprehensive framework for optimizing agricultural machinery allocation to address disparities in resource distribution and enhance rice production efficiency in Kubu Raya. The findings underscore the critical role of tailored, data-driven strategies that consider local agricultural conditions, cropping index, and land size. High-priority villages such as Tanjung Saleh and Kampung Baru were identified as key beneficiaries of additional machinery allocation. These regions, characterized by extensive land areas, high cropping indices, and low machinery saturation levels, demonstrated significant potential for productivity gains through improved mechanization. By addressing machinery shortages, the framework offers actionable solutions for improving land preparation, planting schedules, and post-harvest efficiency, which are essential for boosting rice yields and reducing operational costs.The proposed framework also emphasizes the importance of sustainability, integrating principles of resource efficiency and environmental stewardship. Mechanization, when implemented with sustainable practices such as precision agriculture and water-saving technologies, can minimize negative environmental impacts while supporting long-term agricultural resilience. Moreover, the framework highlights the value of stakeholder engagement and policy support in facilitating the adoption of mechanization. By involving farmers, local communities, and policymakers, the framework ensures that solutions align with regional needs and priorities. Subsidy programs, training initiatives, and infrastructure development are identified as critical enablers for equitable and effective machinery distribution. The implications of this research extend beyond Kubu Raya. The framework's adaptability allows it to be scaled to other regions and crop types, provided that local conditions are carefully considered. Future research should further examine alternative explanations for low machinery saturation, integrate climate resilience measures, and evaluate long-term economic impacts in various socio-economic contexts. In conclusion, the proposed framework offers a replicable model for improving agricultural mechanization. By addressing disparities, fostering sustainability, and promoting inclusive development, it contributes to the broader goals of food security, rural development, and sustainable agriculture. Policymakers and agricultural stakeholders across diverse regions are encouraged to adopt and refine this framework, facilitating cross-contextual comparisons and informing best practices for equitable resource allocation

ACKNOWLEDGEMENTS

I would like to extend my deepest gratitude to the Ministry of Education, Culture, Research, and Technology of the Republic of Indonesia for their financial support for the research titled *"Geographic Information System-Based Spatial Information Distribution and Demand Analysis of Agricultural Tools and Machinery in Kubu Raya Regency."* This research would not have been possible without their funding and commitment to advancing agricultural development through research and innovation. I also extend my thanks to all stakeholders, collaborators, and agricultural agencies in Kubu Raya Regency who contributed to the data collection and analysis process. Their support and cooperation were crucial to the success of this research.

CONFLICT OF INTEREST

The authors declare that they have no conflicts of interest.

DECLARATION OF FUND

The authors declare that they have not received a fund.

REFERENCES

1. Andrieu, Nadine, Bougouna Sogoba, Robert B Zougmoré, Fanny Howland, Oumar Samaké, Osana Bonilla-Findji, Miguel Lizarazo, Andreea Nowak, Catherine Dembele, and Caitlin Corner-Dolloff. 2017. “Prioritizing investments for climate-smart agriculture: lessons learned from mali.” Agricultural Systems 154:13–24. https://doi.org/10.1016/j.agsy.2017.02.008.

2. Berg, Håkan, Thai H. P. Lan, Nguyễn T. Tâm, Duong H. Trang, Pham H. T. Van,

Huynh N. Duc, and Chau T. Da. 2023. "An ecological economic comparison between integrated rice-fish farming and rice monocultures with low and high dikes in the Mekong Delta, Vietnam." Ambio 52 (9): 1462–74. https://doi.org/10.1007/s13280-023-01864-x.

3. Brown, Brendan, Gokul P. Paudel, and Timothy J. Krupnik. 2021. "Visualising adoption processes through a stepwise framework: a case study of mechanisation on the Nepal Terai." Agricultural Systems 192 (August):103200. https://doi.org/10.1016/j.agsy.2021.103200

4. Das, Dwarika Mohan, S. K. Swain, S. Paramaguru, S. K. Mohanty, M. Mohapatra, R. Toppo, and S. Mandi. 2020. "Small farm mechanization in rice for doubling the income of small and marginal farmers in Gajapati district, Odisha: a case study." International Journal of Current Microbiology and Applied Sciences 9 (8): 3873–86. https://doi.org/10.20546/ijcmas.2020.908.446.

5. Elbarkouky, Mohamed M G. 2012. "A multi-criteria prioritization framework (MCPF) to assess infrastructure sustainability objectives." Journal of Sustainable Development 5 (9): 1–13. https://doi.org/10.5539/jsd.v5n9p1.

6. Emami, Mohammad H, Morteza Almassi, Hossein Bakhoda, and Issa kalantari. 2018. "Agricultural mechanization, a key to food security in developing countries: strategy formulating for Iran." Agriculture & Food Security 7 (1). https://doi.org/10.1186/s40066-018-0176-2.

7. Huo, Yuewen, Songlin Ye, Zhou Wu, Fusuo Zhang, and Guohua Mi. 2022. "Barriers to the development of agricultural mechanization in the north and northeast China plains: a farmer survey." Agriculture 12 (2): 287. https://doi.org/10.3390/agriculture12020287.

8. Islam, Akms. 2021. "Mechanized cultivation increases labour efficiency." Bangladesh Rice Journal 24 (2): 49–66. https://doi.org/10.3329/brj.v24i2.53448.

9. Kirui, Oliver K. 2019. "The agricultural mechanization in africa: micro-level analysis of state drivers and effects." SSRN Electronic Journal. https://doi.org/10.2139/ssrn.3368103.

10. Kostomakhin, Mikhail. 2024. "Information and diagnostic tools for monitoring units of agricultural machinery." E3s Web of Conferences 515:04011. https://doi.org/10.1051/e3sconf/202451504011

11. Kumar, M. S, K. R. Ashok, M. Prahadeeswaran, and R. P. Vasanthi. 2021. "The impact of groundwater irrigation development on cropping intensity and crop productivity in Krishnagiri district." Asian Journal of Agricultural Extension Economics & Sociology, 110–21. https://doi.org/10.9734/ajaees/2021/v39i730615.

12. Ladha, J. K, Ando M. Radanielson, Jessica Rutkoski, R. J. Buresh, A. Dobermann, Olivyn Angeles, Irish L. B. Pabuayon, et al. 2021. "Steady agronomic and genetic interventions are essential for sustaining productivity in intensive rice cropping." Proceedings of the National Academy of Sciences 118 (45). https://doi.org/10.1073/pnas.2110807118.

13. Le, Li, Zurui Ao, Yaolong Zhao, and Xulong Liu. 2019. "Impacts of rapid socioeconomic development on cropping intensity dynamics in China during 2001–2016." Isprs International Journal of Geo-Information 8 (11): 519. https://doi.org/10.3390/ijgi8110519.

14. Li, Wei, Xipan Wei, Rong Zhu, and Ke Guo. 2018. "Study on factors affecting the agricultural mechanization level in China based on structural equation modeling." Sustainability 11 (1): 51. https://doi.org/10.3390/su11010051.

15. Liao, Wangda, Zeng Fu-sheng, and Meseret Chanieabate. 2022. "Mechanization of small-scale agriculture in china: lessons for enhancing smallholder access to agricultural machinery." Sustainability 14 (13): 7964. https://doi.org/10.3390/su14137964.

16. Liu, Xiangjuan, and Xibing Li. 2023. "The influence of agricultural production mechanization on grain production capacity and efficiency." Processes 11 (2): 487. https://doi.org/10.3390/pr11020487.

17. Liu, Zhenhuan, Peng Yang, Huajun Tang, Wenbin Wu, Li Zhang, Qiangyi Yu, and Zhengguo Li. 2014. "Shifts in the extent and location of rice cropping areas match the climate change pattern in China during 1980–2010." Regional Environmental Change 15

(5): 919–29. https://doi.org/10.1007/s10113-014-0677-x.
18. Meng, Meng. 2024. "Machinery structure, machinery subsidies, and agricultural productivity: evidence from China." Agricultural Economics 55 (2): 223–46. https://doi.org/10.1111/agec.12820.
19. Mottaleb, Khondoker A, Timothy J. Krupnik, and Olaf Erenstein. 2016. "Factors associated with small-scale agricultural machinery adoption in Bangladesh: census findings." Journal of Rural Studies 46:155–68. https://doi.org/10.1016/j.jrurstud.2016.06.012
20. Nguyen, Huy B, and Nguyen T. Nghi. 2023. "A study on greenhouse gas emissions of paddy cultivation mechanization in Mekong delta, Vietnam." International Journal on Advanced Science Engineering and Information Technology 13 (3): 809–15. https://doi.org/10.18517/ijaseit.13.3.18839.
21. Noor, A. A., A.D.K. Al-Hiyali, and KH. M Muhammed. 2023. "An analysis of the impact of some socio-economic variables in regulating the cultivation and marketing of the rice crop in Iraq." Iraqi Journal of Agricultural Sciences. 54 (1): 317–29. https://doi.org/https://doi.org/10.36103/ijas.v54i1.1704
22. Paman, Ujang. 2023. "Rice food security on small farmer households under current mechanization level in Kampar region, Indonesia." International Journal on Advanced Science Engineering and Information Technology 13 (5): 1805–12. https://doi.org/10.18517/ijaseit.13.5.18475.
23. Paudel, Gokul P, Dilli B. Kc, Dil B. Rahut, Scott Justice, and Andrew J. McDonald. 2019. "Scale-appropriate mechanization impacts on productivity among smallholders: evidence from rice systems in the mid-hills of Nepal." Land Use Policy 85:104–13. https://doi.org/10.1016/j.landusepol.2019.03.030.
24. Qiu, Hailan. 2023. "Agricultural machinery socialization service adoption, risks, and relative poverty of farmers." Agriculture 13 (9): 1787. https://doi.org/10.3390/agriculture13091787.
25. Quan, Xiuhao, and Reiner Doluschitz. 2021. "Factors influencing the adoption of agricultural machinery by Chinese maize farmers." Agriculture 11 (11): 1090. https://doi.org/10.3390/agriculture11111090.
26. Rusmayadi, Gusti. 2024. "Strategic agricultural policies and fertilizer subsidies: driving business success in Cianjur's rice sector." International Journal of Business Law and Education 5 (2): 1667–77. https://doi.org/10.56442/ijble.v5i2.676.
27. Shen, Xue. 2023. "Off-farm employment, outsourced machinery services, and farmers' ratoon rice production behavior: evidence from rice farmers in central China." Agriculture 13 (10): 1881. https://doi.org/10.3390/agriculture13101881.
28. Shi, Yishao, Qianqian Yang, Liangliang Zhou, and Shuyuan Shi. 2022. "Can moderate agricultural scale operations be developed against the background of plot fragmentation and land dispersion? evidence from the suburbs of Shanghai." Sustainability 14 (14): 8697. https://doi.org/10.3390/su14148697.
29. Thapa, Raju, Julius Codjoe, and Amanua Osafo. 2021. "Survey of work zone practices and validation of highway capacity manual work zone capacity model." Transportation Research Record Journal of the Transportation Research Board 2675 (10): 1083–91. https://doi.org/10.1177/03611981211014524.
30. Tong, Wenxia, Guangke Qin, Yong Xu, and Yong Q Fu. 2023. "Sustainable growth, input factors, and technological progress in agriculture: evidence from 1990 to 2020 in China." Frontiers in Environmental Science 10. https://doi.org/10.3389/fenvs.2022.1040356.
31. Wang, Xiaobing, Futoshi Yamauchi, and Jikun Huang. 2016. "Rising wages, mechanization, and the substitution between capital and labor: evidence from small scale farm system in China." Agricultural Economics 47 (3): 309–17. https://doi.org/10.1111/agec.12231.
32. Wang, Yakun, Jinlong Jiang, Dongqing Wang, and Xinshang You. 2022. "Can mechanization promote green agricultural production? an empirical analysis of maize production in China." Sustainability 15 (1): 1. https://doi.org/10.3390/su15010001.
33. Wittwer, Raphaël, Brigitte Dorn, W Jossi, and Marcel G A van der Heijden. 2017. "Cover crops support ecological intensification of

arable cropping systems." Scientific Reports 7 (1). https://doi.org/10.1038/srep41911.
34. Yagi, Hironori, and Tsuneo Hayashi. 2020. "Machinery utilization and management organization in japanese rice farms: comparison of single-family, multifamily, and community farms." Agribusiness 37 (2): 393–408. https://doi.org/10.1002/agr.21656.
35. Zhang, Juan, and Qin Chen. 2022. "The impact of farmland tenure security on China's agricultural production efficiency: a perspective of agricultural production factors." Sustainability 14 (23): 16266. https://doi.org/10.3390/su142316266.
36. Zhang, Weipeng, Bo Zhao, Guangrui LI, Liming Zhou, Kang Niu, and Shang Gao. 2023. "Configuration optimization method of agricultural machinery cluster operation maintenance service vehicle." Inmateh Agricultural Engineering, 537–48. https://doi.org/10.35633/inmateh-69-51.