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A Mixed-Methods Analysis of Systemic Factors Affecting the Integration into Rice Straw Supply Chains in Thailand

Adisai Watanaputi **,** ***Thammanoon Hengsadeekul*** *

Faculty of Logistics and Digital Supply Chain, Naresuan University, Phitsanulok 65000, Thailand

ABSTRACT

Rice straw, a by-product of rice cultivation, is commonly disposed of through open-field burning, which contributes to air pollution and environmental degradation. This study aims to identify the key factors influencing farmers' decisions on rice straw management and to develop policy recommendations that encourage the sustainable utilization of rice straw within the supply chain. A mixed-methods approach was adopted, combining qualitative interviews with nine key informants and a quantitative survey of 585 rice farmers across Thailand. Multinomial Logit Regression (MLR) was employed to analyze farmers' preferences among four management options: burning, composting, animal feeding, and selling. The results reveal that membership in farmer groups, ownership of livestock, access to baling machinery, knowledge, and skills related to straw utilization, ease of field access, availability of storage facilities, engagement in integrated farming, and year-round access to baling services significantly increased the likelihood of choosing sustainable alternatives over the burning straw. These findings underscore the importance of both capacity-building and infrastructure in enabling sustainable practices. Based on these insights, the study proposes a multi-level policy framework to enhance the value creation of rice straw. National policies should focus on expanding access to machinery and supporting innovation, while local governments should facilitate farmer training and improve straw logistics. Strengthening farmer organizations and market connections is also crucial for scaling adoption. Overall, structural integration and stakeholder coordination are key to reducing straw burning and promoting sustainable resource use in rice-producing regions.

Keywords: Rice Straw Management; Alternative Utilization; Burning; Multinomial Logit Regression; Agricultural Supply Chain

*CORRESPONDING AUTHOR:
Thammanoon Hengsadeekul, Faculty of Logistics and Digital Supply Chain, Naresuan University, Phitsanulok 65000, Thailand;
Email: thammanoonh@nu.ac.th

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1. Introduction

Rice is considered one of the most important economic crops in Thailand. It is grown in all regions of the country for both consumption and export, generating significant economic value for the country, particularly in irrigated areas where farmers can cultivate rice throughout the year. As a result, Thailand is ranked as the world's sixth-largest rice producer, with an annual production of approximately 31–33 million tons of paddy rice [1]. However, even though rice is the main crop that generates income, agricultural by-products are also produced during the harvesting process, such as rice husks, rice bran, broken rice [2], and notably, rice straw, which is generated during the separation process [3]. Rice straw is considered the most difficult by-product to manage. For every ton of rice harvested, approximately 0.7 to 1.4 tons of straw is produced [4], depending on cropping intensity, soil conditions, irrigation, and climate. While rice straw has the potential to be reused as compost, livestock feed, or raw material for bioenergy, it is often overlooked and disposed of through open-field burning**,** a common practice in many Asian rice-producing countries. In Thailand, an estimated 48% of rice straw is still burned [5].

This practice is not necessarily the result of limited environmental awareness but rather reflects the lack of access to feasible and effective management alternatives. Burning leads to decreased soil fertility, reduced crop yields, and missed economic opportunities. Additionally, it contributes significantly to air pollution, with PM2.5 concentrations in Thailand ranging from 4.8 to 218.6 micrograms per cubic meter during the post-harvest season. Alarmingly, 64 provinces report levels exceeding safety standards, and 44 face direct public health risks [6]. Moreover, straw burning is a major contributor to greenhouse gas emissions and climate change.

Previous studies on rice straw management have primarily focused on technical or economic aspects, such as the feasibility of converting straw into bioenergy, its potential to reduce fertilizer costs through composting, or its nutritional value as livestock feed. These studies tend to emphasize end-user outcomes rather than exploring the behavioral dimensions of farmers' decisions. Although the high prevalence of straw burning and its environmental consequences have been widely reported, what remains underexplored is the set of factors that shape farmers' decision-making in this context. Few studies have systematically explored why farmers persist in burning straw or what contextual factors enable or hinder the adoption of alternative practices, especially in a country as geographically and socioeconomically diverse as Thailand.

Given the nature of the decision-making process, where farmers must choose among multiple, non-ordered options, this study aims to identify the key factors influencing Thai farmers' decisions in selecting rice straw management strategies. To address this gap, the present study employs a Multinomial Logit Regression (MLR) model to examine the likelihood of farmers choosing among four straw management strategies: (1) burning, (2) composting, (3) using rice straw as animal feed, and (4) selling. The MLR model is suitable because it accommodates multiple categorical choices without assuming a natural order, and it enables the inclusion of diverse explanatory variables across economic, social, and operational dimensions. This analytical framework supports a more nuanced understanding of farmers' behavior and facilitates evidence-based, integrated policy recommendations to promote sustainable rice straw utilization at both the community and national levels.

2. Literature Review

Rice straw is a by-product of the rice production process. It is often left in large amounts after harvesting [7, 8]. In Thailand, 48% of rice straw is managed by burning because it is convenient, fast, and cost-saving [9]. However, burning causes environmental problems, especially air pollution, which directly affects human health [10, 11], as well as the loss of soil minerals due to heat, resulting in the death of soil microorganisms [12].

In order to reduce burning and increase the value of rice straw utilization, alternative management options have been proposed for its utilization in the supply chain in other industries, both on-site and off-site, such as composting, which is a recycling process of organic waste and helps improve soil and increase soil fertility as well as the use of rice straw as animal feed. However, the use of nutritious minerals requires treating rice straw with urea or ammonia to increase nitrogen content [13]. Farmers with livestock, therefore, tend to remove rice straw for animal feed more [14]. Promoting livestock for farmers to collect rice straw for animal feed during the dry season and selling [15]. The straw is compressed into a rectangle with dimensions of 32 x 80 x 42 cubic centimeters (CM^3) and weighs approximately 17-18 kilograms.

However, upon reviewing the knowledge of various management models in many countries, different supporting factors are identified. Composting requires knowledge, training, labor for management, government promotion, and management costs and time[16–18]. By contrast, the factors of using rice straw as animal feed include factors such as livestock numbers, experience, labor, storage locations, and accessibility [19]. Meanwhile, selling straw requires machinery, stable marketing, and sufficient capacity within the farming community [20, 21]. Farmers are willing to sell straw because they do not see any use for it [22]. Additionally, awareness of the benefits of rice straw has encouraged its increased utilization.

The Theory of Planned Behavior (TPB) [23] describes the attitude, subjective norms, and perceived behavioral control that influence rice straw utilization [24]. In this context, several studies have emphasized that awareness of the environmental and economic benefits of alternative practices is a key motivator for adoption [25].

When comparing each approach, it was found that making compost from rice straw requires knowledge, time, and machinery. For using rice straw as food, there must be cattle and buffalo in the area, a storage facility, and labor to manage it. Finally, the important factors for selling straw are machinery and connecting to supporting markets.

While many studies highlight the technical potential of composting, animal feeding, and selling rice straw, their conclusions are often context-specific and fragmented. Although composting is praised for its ecological value, its high labor requirements remain impractical in areas with declining agricultural labor. Likewise, while animal feeding is promoted, real-world adoption is hindered by unstable input costs, a lack of knowledge on straw treatment, and concerns over pesticide contamination, contradicting optimistic projections from earlier studies. Selling straw may ease labor demands, but it competes directly with composting, an underexamined trade-off. Ultimately, the viability of any strategy relies on local logistics and support services, aspects often neglected in method-specific analyses. These insights, though useful, have not been critically compared to assess whether such factors align or conflict across methods. A clearer synthesis is thus needed, especially in Thailand, where farming conditions vary widely, to identify which factors truly shape farmers' management decisions.

Although studies from countries such as China and India promote the use of rice straw in industrial energy applications, and those from Vietnam and the Philippines highlight its use in mushroom cultivation and livestock feed, rice straw utilization in Thailand remains primarily agricultural, mainly through composting and animal feeding. This reflects significant contextual differences, including demographic structure, labor availability, irrigation coverage, agricultural technology, access to machinery, infrastructure, economic systems, market dynamics, and government support.

This study addresses a significant research gap by systematically examining the factors influencing Thai farmers' decisions among four common rice straw management strategies: burning, composting, animal feeding, and selling across Thailand's diverse agricultural landscapes. To date, no existing nationwide study has integrated these options within a unified analytical framework tailored to Thai-specific contexts.

3. Materials and Methods

3.1. Profile of Study Area

This study encompasses farmers from all regions of Thailand, each with distinct cropping contexts. In the Northern region, most rice farmers cultivate in plains between mountains, where fields rely primarily on rainfall for irrigation. The Northeastern region features flat and dry land with low soil fertility, making rainfall the primary source of water for cultivation. The Central region is characterized by fertile lowlands and extensive irrigation systems, which support multiple rice-growing seasons per year. In the Southern region, rice farming is limited due to the coastal and mountainous terrain, which is characterized by high humidity and year-round rainfall, resulting in slower cropping cycles compared to other regions.

The quantity of rice straw generated was estimated using the Straw-to-Grain Ratio (SGR) method, which calculates straw volume based on rice yield [26]. Equation (1) is presented as follows.

$$Q_{rstw} = P_p \times SGR \quad (1)$$

Where Q_{rstw} was the amount of rice straw in the area, P_p was the rice yield and the rice straw occurrence rate. SGR was estimated with a coefficient of 0.75 [27, 28], which is the appropriate value derived from the factors of soil conditions, weather conditions, and moisture [29] multiplied by the rice yield. It was found that in the 2024 crop year, Thailand had a rice production of 33.85 million tons, with an amount of rice straw of approximately 25.38 million tons, which can be summarized in **Table 1.**

Table 1. Rice production and the amount of rice straw produced in each region of Thailand.

Region	Rice Production Volume (tons)	Straw Volume (tons)	Proportion
Northern	10,671,663	8,003,747	31.5%
Northeastern	14,474,405	10,855,804	42.75%
Central	8,383,708	6,287,781	24.75%
Southern	321,803	241,352	1%
Total	33,851,579	25,388,684	100%

Note: *SGR (Straw to Grain Ratio) = 0.75.

Source: Data from Office of Agricultural Economics, 2024 [30].

3.2. Sampling Design and Data Collection

This study employed a mixed-methods approach, combining both qualitative and quantitative research methods. Qualitative interviews were used to gain contextual insights into farmers' decision-making regarding rice straw utilization, while the quantitative survey provided broader, generalizable data on patterns and influencing factors.

Qualitative Component: In-depth interviews were conducted with nine key informants, each of whom had over ten years of experience in rice farming and had adopted various methods of rice straw management. Purposive sampling was applied to ensure diversity in practice and regional representation. The management practices included composting, animal feeding, baling, and open-field burning. Interviews were conducted using semi-structured guides, and the data were analyzed using thematic content analysis to identify key influencing factors.

Quantitative Component: The quantitative phase targeted rice farmers registered with the Department of Agricultural Extension across all four regions of Thailand. The sample size was calculated using Taro Yamane's formula at a 95% confidence level [31], based on the total population of 3,283,886 farming households [32], yielding a minimum required sample of 400 as shown in Equation (2).

$$n = \frac{N}{1 + N(e)^2} \quad (2)$$

To ensure adequate regional representation [33], stratified sampling was applied, followed by simple random sampling within each stratum. To increase statistical robustness, the sample was expanded to 585 households. The sample distribution is shown in **Table 2**.

Table 2. Population and sample size of rice farmers by region in Thailand.

Region	Number (households)	Percentage	Calculated Sample Count	Number of Actual Samples Collected
Northern	515,629	15.70	63	135
Northeastern	2,552,367	77.72	310	323
Central	209,365	6.38	26	116
Southern	6,525	0.20	1	11
Total	3,283,886	100	400	585

The questionnaire was collected from rice farmers in all regions of Thailand. The survey consisted of closed-ended questions, divided into 3 parts: Part 1: Socioeconomic characteristics, including gender, age, education level, rice cropping area, rice farming experience, number of household members engaged in farming, availability of baling machines, number of cows and buffaloes owned, membership of farmer groups, number of cropping per year, previous cropping season, and rice cropping area in the last season; Part 2: Rice straw management, including 4 post-harvest rice straw management; Part 3: Agricultural management capability and awareness, including skills and knowledge, accessibility to rice fields, rice straw storage locations, integrated rice farming, farmer groups, availability of baling machines, economic benefits, environmental benefits, and social benefits; Part 3 used a 5-level rating scale as shown in **Table 3**. The questionnaire passed the content validity test by experts, including reliability testing. With 30 sets of non-sample farmers, the reliability value (Cronbach's Alpha) was found to be between 0.704

and 936, greater than the 0.7 criterion and is considered acceptable [34]. This combination of qualitative and quantitative approaches enhances the depth and breadth of understanding of farmers' behavior and regional differences. The data collection period was from February 2025 to March 2025.

Table 3. Variables used in the empirical model.

Variable	Description/Measurement	Relevant Literature
Dependent Variable (Y) Rice Straw Management	Method of rice straw management 1. = Burning 2. = Composting 3. = Using as Animal Feed 4. = Selling	
Independent Variable (X) Socioeconomic characteristics		
1. Gender (X1)	1.= Male 2.= Female	[35]
2. Rice farming experience (X2)	1.= Less than 5 years 2.=Between 5-9 years 3.=Between 10-15 years 4.=Between 16-20 years 5.=More than 20 years	[16,36]
3. Number of cattle/buffaloes owned (X3)	1.= No cattle owned 2.= 1-2 cattle/buffalos owned 3.= 4-6 cattle/buffalos owned 4.= 7-9 cattle/buffalos owned 5. = 9 cattle/buffalos or more owned	[37]
4. Baler availability (X4)	1. = No rice straw baling machine 2. = Own baling machine	[38]
5. Membership of farmer groups (X5)	1. =Not being a member of a local farmer group 2. =Being a member of a local farmer group	[19,39]
6. Number of cropping rounds per year, cropping in the previous season (X6)	1. = 1 time/year of cropping 2. = 2 times/year of cropping	[40]
7. Rice cropping area (X7)	1. = 0-1.6 hectare 2. = 1.6-3.2 hectares 3. = 3.2-4.8 hectares 4. = 4.8 hectare or more	[17]
Agricultural Management Capability And Awareness		
8. You have the skills and knowledge to manage rice straw. (X8)	A five-point Likert scale answer: 5 = most, 4 = more, 3 = moderate, 2 = low, 1 = very low)	[41]
9. A route that provides easy and convenient access to rice fields. (X9)	The same as x8	[42]
10. A place to store rice straw that is sufficient for use (X10)	The same as x8	[43]
11. There is mixed farming, such as rice cropping, animal husbandry, and vegetable cultivation within the area. (X11)	The same as x8	[44]
12. The availability of a baler service provider all year round (X12)	The same as x8	[38,45]
13. Rice straw can generate income (X13)	The same as x8	[46]
14. Fermenting rice straw on-site can help reduce fertilizer costs (X14)	The same as x8	[47]
15. Utilization of rice straw helps reduce the generation of smoke and dust in the air (X15)	The same as x8	[48,49]
16. Utilization of rice straw helps prevent problems that bother others. (X16)	The same as x8	[24, 47]

3.3. Data Analysis

Qualitative data analysis was conducted using content analysis from in-depth interviews to identify factors affecting farmers' rice straw management. After collecting the questionnaires, the authors conducted quantitative data analysis in 2 steps: 1. Using descriptive statistics to summarize farmers' characteristics and rice straw management, 2. Using inferential statistics to analyze factors affecting rice straw management using the MNL model to analyze factors affecting the selection of rice straw management methods. The burning method was used as a reference category with SPSS version 26.0, which was employed to analyze the independent variables in the model.

The authors applied the MNL model to analyze the probability of choosing one rice straw management option compared to the reference of straw burning, which serves as the reference choice. The valuesobtained from the model, such as the coefficient (β) and the odds ratio, can reflect the level of influence and the direction of the relationship, which can serve as a basis for policy determination and guidelines to promote sustainable rice straw management. The mathematical Equation (3) is as follows.

$$In\left(\frac{P(Y=j)}{P(Y=1)}\right) = \beta_{0j} + \beta_{1j}X_1 + \beta_{2j}X_2 + \ldots.. + \beta_{pj}X_p,\ (j = 2,3,4) \quad (3)$$

Where $P(Y=j)$ represented the probability that farmers choose the j rice straw management approach, $P(Y=1)$ represented the probability of straw burning (reference), β_{0j} represented the constant of category j, and β_{0j} represented the coefficient of the independent variables that must be used to estimate X_p which represented the independent variables that affect farmers' choice of rice straw management approach. To calculate the absolute probability of choosing each rice straw management approach, Equation (4) can be used.

$$P(Y=j) = \frac{e^{\beta_{0j} + \Sigma\beta_{pj}X_p}}{1 + \Sigma^{j}_{k=2}\, e^{\beta_{0k} + \Sigma\beta_{pj}X_p}},\ (j = 2,3,4) \quad (4)$$

To calculate the reference category (straw burning), Equation (5) can be used.

$$P(Y=1) = \frac{1}{1 + \Sigma^{j}_{k=2}\, e^{\beta_{0k} + \Sigma\beta_{pj}X_p}} \quad (5)$$

Another important point is that this research only considered independent variables with a significance level of 0.05. If the probability (P-value) was less than the significance level, it was considered that the factor had an influence on the selection of rice straw management compared to the reference category.

3.4. Test of Independence of Irrelevant Alternatives (IIA)

To validate the use of the MNL model, we tested the Independence of Irrelevant Alternatives (IIA) assumption using the drop-one-alternative method. Each choice category ("selling," "composting," or "animal feeding") was removed in turn, and the model was re-estimated. The significance and direction of key variables—including Number of Cows, Machinery Available, Membership, and Crop Cycle—remained largely consistent.

Contextual and perception-based factors—including skills and knowledge to manage straw, easy access to rice fields, sufficient straw storage space, mixed farming practices, and year-round availability of baler services—also retained their significance across models. Similarly, perception variables such as the perceived economic benefit of rice straw utilization, perceived cost savings from on-site fermentation, perceived environmental benefits from reducing smoke and dust, and the belief that straw use prevents nuisance to others remained statistically significant.

Although a slight reduction in the significance of the Number of Cows was observed when "selling" was excluded, no substantial violations of the IIA assumption were found. These results confirm the robustness and appropriateness of the MNL model for analyzing farmers' choices regarding rice straw management.

Multicollinearity among the independent variables was evaluated using the Variance Inflation Factor (VIF). To assess this, a series of linear regressions were conducted, each time assigning a different independent variable as the dependent variable. The resulting VIF values ranged from 1.113 to 2.850, well below the commonly accepted threshold of 5, indicating no serious multicollinearity. These results support the reliability of the model estimates.

4. Results

4.1. Descriptive Analysis

Although the minimum sample size was set at 400 using Taro Yamane's formula, the final dataset consisted of 585 completed questionnaires. The increase in responses allowed for broader coverage across all regions and enhanced the representativeness of the findings, particularly in capturing the diversity of rice straw management practices among Thai farmers.

4.1.1. Socioeconomic Characteristics

Table 4 shows the descriptive analysis of the Socioeconomic characteristics of households and individuals obtained from the sample. The total of 585 respondents was divided into males (52.8%) and females (47.2%). Most are farmers with over 20 years of experience in rice farming (66.7%). The remaining experience is similar. Most respondents are from the Northeast (55.2%), followed by the North (23.1%), the Central (19.8%), and the South (1.9%). About 63.8% do not own cattle and buffalos, while 36.2% own cattle and buffalos. Approximately 75.9% of them do not have machinery available in the area, while 24.1% do. Around 77.4% of them are members of the local farmer group, while 22.6% are not. The number of cropping rounds of farmers was equally distributed: 49.2% cultivated once per crop year, and 50.8% cultivated twice per crop year. The cultivated area is 1.6-3.2 hectares (32.6%). Next is 0.16-1.6 hectares at 30.6%, then 4.8 hectares and above at 17.9%, and 3.2-4.8 hectares at 18.8%.

The data on the behavior of farmers in Thailand's rice straw management found that most farmers use the method of burning rice straw, up to 34.7%, followed by selling at 25.5%, animal feeding at 21.4%, and finally composting at 18.5%.

Table 4. Socioeconomic characteristics of the sample**.**

Socioeconomic Characteristics	Variable	Frequency	Percentage
Gender	Male	309	52.8
	Female	276	47.2
	Total	585	100.0
Rice Farming Experience	Less than 5 years	44	7.5
	Between 6-9 years	33	5.6
	Between 10-15 years	64	10.9
	Between 16-20 years	54	9.2
	More than 20 years	390	66.7
	Total	585	100.0
Rice Cropping Region	Northern	135	23.1
	Northeastern	323	55.2
	Central	116	19.8
	Southern	11	1.9
	Total	585	100.0
Number of cattle/buffaloes owned	No cattle owned	373	63.8
	1-2 cattle/buffalos owned	77	13.2
	4-6 cattle/buffalos owned	65	11.1
	7-9 cattle/buffalos owned	35	6.0
	9 cattle/buffalos or more owned	35	6.0
	Total	585	100.0
Baler availability	no rice straw baling machine	444	75.9
	Own baling machine	141	24.1
	Total	585	100.0
Membership of farmer groups	Not being a member of a local farmer group	132	22.6
	Being a member of a local farmer group	453	77.4
	Total	585	100.0
Number of cropping rounds per year, cropping in the previous season	1. 1 time/year of cropping	288	49.2
	2. 2 times/year of cropping	297	50.8
	Total	585	100.0

Table 4. *Cont.*

Socioeconomic Characteristics	Variable	Frequency	Percentage
Rice cropping area in the previous season	0-1.6 hectare	179	30.6
	1.6-3.2 hectare	191	32.6
	3.2-4.8 hectare	105	17.9
	4.8 hectare or more	110	18.8
	Total	585	100.0
Rice straw management	1. Burning	203	34.7
	2. Composting	108	18.5
	3. Using as animal feed	125	21.4
	4. Selling rice straw	149	25.5
	Total	585	100.0

4.1.2. Agricultural Management Capability and Awareness

The last part is agricultural management capability and awareness, which consists of 9 items, using a Likert scale from 'most agree' to 'least'. In **Figure 1**, it was found that the respondents strongly agreed that the utilization of rice straw helps prevent problems that disturb others (53.3%), the utilization of rice straw helps reduce smoke and dust in the air (51.5), while the skills and knowledge in rice straw management, easy and convenient access routes to the rice fields, a place for storing rice straw sufficient for use, mixed farming such as rice planting, animal husbandry, and vegetable planting in the area, having rice straw baling service providers who are ready to provide services throughout the year, rice straw can generate income, and fermenting rice straw in the area helps reduce fertilizer costs, were at a fairly high and moderate level.

4.1.3. Regional Distribution of Rice Straw Management Practices

Rice straw management practices vary significantly across Thailand's regions, as illustrated in **Table 5**. In the Northern region, farmers primarily engage in composting (28.9%) and animal feeding (20.0%), reflecting a preference for on-farm utilization methods. The Northeastern region demonstrates a more balanced distribution, with comparable proportions of farmers practicing burning (31.0%), animal feeding (27.2%), and selling (27.9%). In the Central region, burning is the dominant practice (56.9%), suggesting limited adoption of alternative practices. Notably, in the Southern region, composting is the most prevalent method (54.5%), with no reports of burning. These regional patterns in **Table 5** highlight the need for location-specific policies and support mechanisms to promote sustainable rice straw utilization.

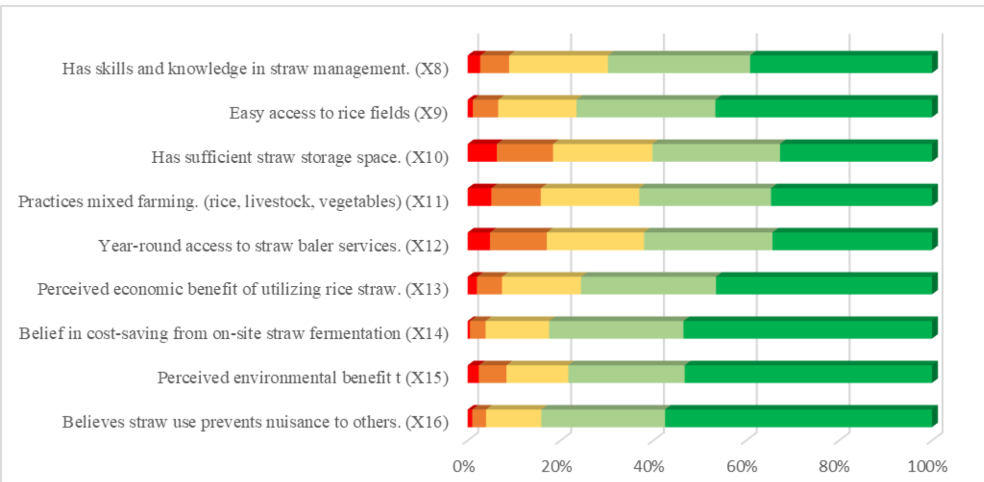

Figure 1. Agricultural management capability and awareness

Table 5. The proportion of farmers using each rice straw management method by region (% of respondents).

Region	Proportion of Utilization of Rice Straw in Each Region			
	Burning	Composting	Using as Animal Feed	Selling Straw
Northern (N = 135)	27.4	28.9	20.0	23.7
Northeastern (N = 323)	31.0	13.9	27.2	27.9
Central (N = 116)	56.9	15.5	6.9	20.7
Southern (N = 11)	0	54.5	18.2	27.3

4.2. Multinomial Logit Regression Analysis

Consideration of factors that have significant effects on the behavior of rice straw management of farmers in 4 groups: the group that burns rice straw, the group that makes compost, the group that uses rice straw as animal feed, and the group that sells rice straw, this research used the MNL method to analyze the important factors that affect rice straw management in various forms in Thailand. It is divided into socioeconomic characteristics**,** agricultural management capability, and awareness. The results of the analysis are shown in **Tables 6–8**.

To validate the model's robustness, we conducted a sensitivity analysis by removing two blocks of explanatory variables: (1) socioeconomic characteristics and (2) agricultural management capability and awareness. The results showed that removing management-related variables (e.g., machinery access and group membership) caused a more significant decline in model fit (Nagelkerke R^2). In contrast, the removal of demographic variables had a more minor impact. This suggests that farmers' capabilities and perceptions are more influential in determining straw management behavior. Moreover, a simplified model retaining only significant variables still maintained comparable explanatory power, confirming the model's stability and validity of predictor selection.

Table 6. Multinomial logit regression (MNL) parameter estimates for socioeconomic characteristics (baseline category: straw burning).

Parameter Estimates									
Variable	Composting			Using as Animal Feed			Selling Straw		
	Coeff	Odds Ratio	Sig	Coeff	Odds Ratio	Sig	Coeff	Odds Ratio	Sig
Intercept	0.386		0.704	-2.055		0.078	-1.491		0.113
Gender (X1)	0.081	1.084	0.764	-0.195	0.823	0.554	-0.341	0.711	0.187
Farming experience (X2)	0.087	1.091	0.400	-0.230	0.795	0.053	-0.094	0.910	0.340
Number of livestock (X3)	-0.080	1.083	0.716	1.637	5.142	0.000***	0.396	1.485	0.027*
Baler available (X4)	-0.657	0.518	0.170	0.307	1.359	0.454	1.326	3.767	0.000***
Farmer group member (X5)	1.166	3.208	0.000***	1.435	4.201	0.001**	1.359	3.892	0.000***
Cropping times per year (X6)	-1.348	0.260	0.000***	-1.739	0.176	0.000***	-1.949	0.142	0.000***
Farm size (X7)	-0.343	0.710	0.012*	-0.269	0.764	0.126	0.243	1.276	0.058

Note: Number of observations = 585; * Significant at 0.05, ** Significant at 0.01, *** Significant at 0.001; - 2 Log-likelihood = 771.629, Chi-Square = 417.072, Sig. = 0.000, Nagelkerke's R square = 0.546.

4.2.1. Socioeconomic Characteristics Factor Analysis

Results of MNL analysis as shown in **Table 6**, socioeconomic characteristics affecting farmers' rice straw management using burning as the reference category, found that the appropriateness of the model in the -2 Log-likelihood value was 771.629, the Chi-Square value was 417.027 with a significance level of 0.000, and the Nagelkerke's R Square value was 0.546, indicating that the model was significant and showed that the model could explain farmers' behavior approximately 54.6%.

Farmer group membership significantly increases the likelihood of adopting all alternative rice straw management practices. Compared to burning, group members are 3.9 times more likely to sell straw (OR = 3.892), 3.2 times more likely to compost (OR = 3.208), and 4.2 times more likely to use straw as animal feed (OR = 4.201).

The number of livestock owned by farmers affects the decision to use rice straw as animal feed and sell it. The higher the number of cattle/buffaloes owned, the greater the impact on animal feeding (OR = 5.142) and the effect on selling rice straw (OR = 1.485). This indicated that farmers with many cows or buffaloes are 5.2 times more likely to use rice straw as feed than burn it, and have a 1.5 times higher chance of selling rice straw compared to burning it.

Access to a baler significantly increases the likelihood of selling rice straw, making farmers 3.8 times more likely to sell than burn it (OR = 3.767).

The number of cropping rounds, at 2 per year, reduces the likelihood of all rice straw management, with the most significant impact on composting (OR = 0.260), followed by a reduction in animal feeding (OR = 0.176) and selling rice straw (OR = 0.142).

Larger cropping areas are associated with a lower likelihood of composting rice straw, with farmers 29% less likely to compost than burn (OR = 0.710).

4.2.2. Agricultural Management Capability and Awareness Analysis

From **Table 7**, it was found that 8 factors in terms of agricultural management capability and awareness influenced the behavior in rice straw management. The -2 Log-likelihood value was 1113.146, the Chi-Square value was 430.347 with a significance level of 0.000, and Nagelkerke's R Square statistic was 0.558, indicating that the model was significant and showed that the model could explain farmers' behavior approximately 55.8%

Table 7. Multinomial logit regression (MNL) parameter estimates for agricultural management capability and awareness (baseline category: straw burning).

Parameter Estimates									
Variable	**Composting**			**Use as Animal Feed**			**Selling Straw**		
	Coeff.	**Odds Ratio**	**Sig.**	**Coeff.**	**Odds Ratio**	**Sig.**	**Coeff.**	**Odds Ratio**	**Sig.**
Intercept	-9.031		0.000***	-10.169		0.000***	-12.067		0.000***
Has skills and knowledge in straw management. (X8)	0.296	1.345	0.047*	0.415	1.498	0.022*	0.612	1.845	0.000***
Easy access to rice fields (X9)	0.336	1.400	0.012*	0.444	1.559	0.007**	0.787	2.197	0.000***
Has sufficient straw storage space. (X10)	-0.34	0.966	0.820	0.774	2.167	0.000***	0.385	1.470	0.013*
Practices mixed farming. (rice, livestock, vegetables) (X11)	0.523	1.687	0.000***	0.715	2.044	0.000***	0.533	1.704	0.001**
Year-round access to straw baler services. (X12)	0.338	1.402	0.018*	0.512	1.668	0.001**	0.812	2.253	0.000***
Perceived economic benefit of utilizing rice straw. (X13)	-0.059	0.943	0.635	-0.273	0.761	0.051	0.401	1.493	0.005**
Believes fermenting straw Perceived cost-saving benefit of fermenting rice straw on-site. (X14)	0.553	1.703	0.002**	0.006	1.006	0.971	-0.304	0.738	0.077
Environmental benefit perception: Reduction in smoke and dust (X15**)**	0.313	1.368	0.011*	0.340	1.405	0.12	0.270	1.310	0.460
Believes straw use prevents nuisance to others. (X16)	0.219	1.244	0.170	0.128	1.136	0.441	0.91	1.095	0.584

Note: Number of observations = 585; * Significant at 0.05, ** Significant at 0.01, *** Significant at 0.001; - 2 Log-likelihood = 1113.146, Chi-Square = 430.347, Sig. = 0.000, Nagelkerke's R square = 0.558.

Straw management skills and knowledge significantly influence all alternative straw management methods. Farmers with higher knowledge are more likely to adopt practices such as selling (OR = 1.845), animal feeding (OR = 1.498), and composting (OR = 1.345) compared to burning. In other words, those with relevant skills and understanding are nearly twice as likely to sell straw, about 1.5 times more likely to use it as animal feed, and around 1.3 times more likely to compost instead of burning.

Easy access to rice fields significantly enhances the adoption of sustainable rice straw management practices. Compared to burning, farmers with convenient access are 2.2 times more likely to sell straw (OR = 2.197), 1.6 times more likely to use it as animal feed (OR = 1.559), and 1.4 times more likely to compost it (OR = 1.400).

Adequate storage facilities play an important role in enabling sustainable straw utilization. Compared to burning, farmers with sufficient storage are 2.2 times more likely to use rice straw as animal feed (OR = 2.167) and 1.5 times more likely to sell it (OR = 1.470).

Integrated farming has a significant impact on all forms of rice straw management, with the greatest effect on animal feeding (OR = 2.044), followed by composting (OR = 1.687) and straw sales (OR = 1.704).

The year-round availability of straw baler services significantly promotes sustainable straw management across all practices. Compared to burning, farmers with access to baler services are 2.3 times more likely to sell straw (OR = 2.253), 1.7 times more likely to use it as animal feed (OR = 1.668), and 1.4 times more likely to compost it (OR = 1.402).

Perceived income potential from rice straw significantly influences selling behavior. Farmers who recognize the potential to generate income from rice straw are 1.5 times more likely to sell it rather than burn it (OR = 1.493).

The perceived cost-saving benefits of rice straw utilization significantly influence composting behavior. Farmers who believe that using rice straw can reduce agricultural expenses are 1.7 times more likely to compost rather than burn it (OR = 1.703).

Perceived environmental impacts, particularly the generation of smoke and dust, influence farmers' decisions regarding sustainable management of rice straw. The perception of air pollution risks has the strongest effect on composting, with farmers who are aware of these issues being 1.4 times more likely to compost their rice straw rather than burn it (OR = 1.368).

4.2.3. Regional Interaction Effects between Group Membership and Straw Management Choices

Interaction terms between region and group membership were tested to examine whether the influence of group membership varied by geographic location. The interaction term for the Northern Region × Group Membership was statistically significant in the animal feed category (OR = 1.772, p = 0.039), indicating that group membership in the Northern region enhances the likelihood of using rice straw as animal feed. This suggests that farmer groups in the North play a particularly strong role in facilitating internal straw utilization, likely due to the prevalence of integrated livestock systems and strong community ties.

In contrast, interaction terms for the Central region were not statistically significant in any category (e.g., animal feed OR = 1.315, p = 0.453), suggesting that group membership in this region does not significantly influence farmers' straw management decisions. For the Southern region, estimation errors occurred due to limited subgroup variation, particularly in the composting and selling categories, leading to computational overflow.

The Northeastern region was used as the reference group in the interaction model and was therefore not explicitly estimated. However, the consistent influence of group membership in the main model (**Table 6**) suggests moderate but stable group effects across the Northeast.

Based on these findings, only the Northern region exhibited a statistically meaningful interaction effect, highlighting a spatially contextualized role of farmer group membership in promoting animal feeding practices. These results underscore the importance of incorporating regional characteristics when designing policies to promote collective straw management strategies. The results are shown in **Table 8**.

The Southern region had only 11 respondents (1.9% of the total sample), with particularly low frequencies in the composting and selling categories. This resulted in estimation instability and computational overflow in the interaction terms involving this region. Therefore, while the Northern region yielded statistically interpretable interaction effects, the findings for the Southern region should be interpreted with caution due to the insufficient variation in the data.

Table 8. Multinomial logit regression (MNL) parameter estimates of regional interaction effects between farmer group membership and rice straw management choices.

Parameter Estimates									
Variable	Composting			Use as Animal Feed			Selling Straw		
	Coeff.	Odds Ratio	Sig.	Coeff.	Odds Ratio	Sig.	Coeff.	Odds Ratio	Sig.
Farmer group member	0.0919	2.506	0.040*	0.929	2.531	0.074	0.788	2.199	0.101
North Region × Group Membership	0.133	1.143	0.560	0.572	1.772	0.039*	0.080	1.083	0.739
Central Region × Group Membership	-0.158	0.854	0.508	0.274	1.315	0.453	-0.105	0.901	0.683
North eastern Region × Group Membership[b]	Ref. Group								

Note: b = Reference Group; Number of observations = 585; * Significant at 0.05, ** Significant at 0.01, *** Significant at 0.001; - 2 Log-likelihood = 896.603, Chi-Square = 680.465, Sig. = 0.000, Nagelkerke's R square = 0.736.

5. Discussion

This section examines how the key findings align with or challenge existing theoretical perspectives, as well as how various contextual factors influence rice straw management decisions among Thai farmers. The results highlight the crucial role of farmer group membership in enabling sustainable straw management practices. Group membership significantly increased the likelihood of adopting composting, animal feeding, and selling practices over burning. This strong influence may stem from the benefits of collective organization, such as knowledge exchange**,** shared access to machinery (e.g., straw balers), and cooperative action**.** Members may collaborate in straw collection, storage, and marketing or even develop community-based management plans. These findings are consistent with prior studies [50], which suggest that farmer organizations strengthen supply chain integration. Moreover, larger groups can access broader markets and achieve better prices through economies of scale [51].

The influence of livestock ownership reinforces the practical value of rice straw as a feed resource. This indicates that farmers with livestock tend to use rice straw as animal feed, and farmers' agricultural areas are more likely to utilize rice straw for animal feeding [52]. Additionally, Thailand often lacks crops for animal feed during the dry season due to a shortage of natural fresh grass. As a result, farmers who collect rice straw for animal feed sell some of it to generate income at a higher price during that season [53].

Access to a straw baler emerged as a critical enabler for commercialization. Farmers with access to balers were more likely to sell rice straw, suggesting that mechanization reduces the labor burden and increases economic viability. This finding aligns with Minas et al. [20], who found that farmers prefer market-linked straw management practices when infrastructure, such as buyers or baling services, is available. Cheewaphongphan et al. [54] Similarly, they noted that market conditions, labor costs, and technology costs influence selling decisions.

In contrast, cropping frequency (two rice cycles per year) had a negative effect on all sustainable alternatives, confirming the time constraint hypothesis**.** When replanting must occur rapidly, farmers are less likely to compost, feed animals, or sell straw due to the limited time between harvest and the next planting. The model shows that double-cropping farmers are 77% less likely to compost, 82.4% less likely to feed animals, and 85.8% less likely to sell straw than those cultivating once per year [18,55].

Farm size affects composting behavior due to scale-related management complexity. This may be because managing large volumes of straw requires more labor, storage space, and time. Similar findings were noted by Supaporn et al. [17], who emphasized labor as a significant constraint in composting. Likewise, larger farm sizes were found to hinder the use of rice straw for mushroom cultivation due to the high labor demands [56].

Knowledge and skills empower farmers to explore and adopt diverse straw utilization strategies. This aligns with findings from India and Vietnam, where access to knowledge encouraged transitions away from burning. These findings align with Kaur et al. [57], who reported that trained farmers in India are more likely to avoid burning and adopt sustainable straw management practices. Similarly, Dinh et al. [58] found that Vietnamese farmers are more willing to shift toward alternative methods when provided with accessible, low-cost knowledge and tools that suit their local contexts.

Field accessibility plays a logistical role: when roads are accessible, the cost and effort of transporting straw are lower, making alternative uses more feasible. This supports global evidence emphasizing the role of infrastructure in agricultural waste management. This is because road transport is the primary method for moving rice straw. When fields are located near accessible roads, transportation becomes more efficient, encouraging farmers to adopt alternative practices. Transport infrastructure, land accessibility, and road quality are critical enablers of sustainable agricultural waste management [59]. Poor access can drastically increase travel time and transport costs, especially in developing regions where roads are often winding or poorly maintained [60].

Storage capacity emerges as a hidden enabler. Farmers without proper storage tend to burn due to space constraints, while those with adequate storage are better equipped to delay usage or wait for market opportunities. Storage is a key component of infrastructure that adds value to rice straws by facilitating temporary storage before transportation or processing [61]. Without appropriate storage space—especially for loose, unbaled straw—farmers face logistical challenges that increase transport costs and reduce marketing opportunities [12]. As a result, some may opt for burning as a simpler but less sustainable option.

Integrated farming systems foster natural synergy by allowing rice straw to be repurposed internally, such as for animal feed or composting, thereby enhancing sustainability. This approach reduces dependence on external inputs and enables more efficient use of available on-farm resources. Similar findings were reported by Akter et al [62], who studied integrated farming systems in wetlands in Bangladesh and found that farmers using the Integrated Farming System increase their income and can fully utilize resources in the rice fields, such as mixing straw with animal manure to use as compost or as a raw material in other production systems instead of burning it, including reducing dependence on external factors by utilizing by-products or waste efficiently. An Integrated Farming System helps convert waste from one activity into a raw material for another, promoting the long-term sustainability of the agricultural system [63].

Access to baler service providers significantly facilitates the management of rice straw by lowering labor demands and reducing handling costs. Farmers linked to machinery services, such as baling and transportation, are therefore better equipped to transition from burning to more sustainable uses of rice straw [20].

Economic perception plays a crucial role in influencing farmers' decisions regarding the management of rice straw. When farmers perceive straw as a valuable resource, either as a source of income or as a cost-saving substitute for chemical fertilizers, they are more likely to adopt sustainable practices. This highlights the importance of economic framing in promoting behavioral change. In particular, when rice straw is viewed as a marketable commodity, farmers are more inclined to adopt selling practices, especially in areas with established market infrastructure, such as buyers and baler services. Prior research confirms that the decision to sell straws is closely tied to market access and the associated costs of labor and technology [54]. Additionally, farmers who aim to reduce production costs are more likely to convert straw into compost, viewing it as a feasible alternative to synthetic fertilizers. As noted by Khanam et al [64], rice straw can be effectively fermented with animal manure and bio-enzymes to produce high-quality organic fertilizer. This not only improves soil health and reduces dependence on chemical inputs but also enhances the long-term economic resilience of farming systems.

Environmental awareness also plays a pivotal role, particularly regarding concerns about air pollution. Farmers who are aware of the adverse effects of burning, such as smoke and dust, are more likely to adopt composting practices as an alternative. This behavioral tendency is consistent with the TPB, which posits that attitudes toward behavior and perceived behavioral control influence individual decision-making. In this context, farmers' environmental concerns foster a more favorable attitude toward sustainable straw management and strengthen their intention to avoid burning. As noted by Khanam et al. [65], increasing awareness of environmental protection, especially the need to reduce smoke and dust emissions, has become a key motivator for behavioral change. Moreover, prior studies have shown that such awareness promotes the adoption of eco-friendly technologies, including biogas systems, particularly in rural areas [48]. These findings underscore the importance of integrating environmental education and awareness campaigns into comprehensive strategies that foster pro-environmental behavior, aligning with the TPB framework.

In addition to individual-level factors, regional dynamics also shape farmers' behavioral responses toward straw management. The significant interaction between group membership and the Northern region in promoting the use of rice straw as animal feed suggests that social capital operates more effectively in areas with strong community cohesion. In Northern Thailand, where integrated crop-livestock systems are widely practiced, farmer groups serve not only as channels for information exchange but also as platforms for shared logistics and internal resource circulation. These dynamics reflect longstanding social structures and cultural practices that promote collective action and mutual support. Such conditions tend to reinforce both perceived social expectations and farmers' confidence in carrying out sustainable practices.

In the Northeastern region, although statistically used as the reference group, the moderate yet consistent influence of group membership also suggests a strong social foundation. Traditional cultural rituals such as Phi Ta Khon (a traditional rain-calling ceremony in Northeastern Thailand), an animistic rain-calling ceremony, illustrate the deep connection between agriculture and community life, supporting informal norms of cooperation and resource sharing. Even without statistically significant interaction effects, this cultural context likely supports the collective use of straw in practice.

By contrast, group membership had little influence in the Central region, possibly due to time constraints from double cropping, weaker reliance on peer networks, and a more urbanized, individualistic farming culture. In the Southern region, environmental barriers such as frequent rainfall and fragmented farmland further limited opportunities for group-based straw management. These findings suggest that even when farmers hold positive attitudes toward sustainable practices, constraints in time, infrastructure, or institutional support can hinder behavior, revealing a disconnect between intention and action.

Taken together, these findings highlight the need for spatially differentiated policies. In the North and Northeast, existing social capital can be leveraged to support feed-sharing networks and localized straw logistics. In contrast, the Central and Southern regions may first require investment in basic infrastructure such as storage, equipment access, and coordination mechanisms before collective strategies can be effectively adopted.

6. Conclusion

This study analyzed the factors influencing various rice straw management behaviors of farmers in Thailand based on different socioeconomic characteristics, agricultural management capability and awareness. The authors used MLR with 585 farmers and randomly selected the samples according to the proportion of farmers in each region. The survey results showed that most farmers have more than 20 years of rice cropping experience (more than 60%), do not own cattle/buffalos (63.8%), lack readiness in terms of management machinery (75.9%), even though they are members of local farmer groups (77.4%), have a similar number of cropping rounds, most cropping areas are about 1.6-3.2 hectares (32.6%). The behavior of burning rice straw was the most (34.7%), selling rice straw (25.5%), animal feeding (21.4%), and only 18.5% composting. The findings suggest that the sustainable management capability of rice straw utilization, most farmers strongly agreed that the use of rice straw helps prevent disturbing problems (53.3%). Using rice straws helps reduce the generation of smoke and dust in the air (51.5%).

The results of the MLR analysis indicated that socioeconomic characteristics that increased the likelihood of managing rice straw instead of burning included membership in the farmer group, the number of cattle or buffaloes owned, and the availability of baling machines. Meanwhile, the factors that decreased the chance of managing rice straw in other ways included the number of cropping rounds and the size of the cropping area. As for the agricultural management capability and awareness, the factors that increased the chance of managing rice straw instead of burning it included the knowledge and skills in managing rice straw, the accessibility of the rice fields to the fields conveniently, the storage area, mixed farming, the availability of rice straw baling service providers all year round, the perception of income and cost reduction in rice straw management, and the perception of dust dispersion from rice straw burning. The findings suggest that socioeconomic conditions, knowledge, resource availability, rice farming characteristics, and the perception of the economy and the environment significantly affected the straw management of farmers in different contexts.

Findings suggest four distinct farmer profiles based on rice straw management capacity, along with the quantitative analysis results from MLR as criteria for classification. There are four groups: 1. Vulnerable farmers in rice straw management; 2. Farmers who are ready to respond to opportunities for utilization; 3. Potential farmers are prepared for new opportunities, and 4. High-potential farmers for sustainable management. These groups are illustrated in **Figure 2** and offer a foundation for differentiated policy design. Targeted policies tailored to each profile can catalyze upstream improvements in the rice straw supply chain, thereby reducing reliance on open-field burning—a practice that poses significant risks to environmental quality, public health, and long-term agricultural resilience.

Furthermore, the classification and corresponding policy implications can be interpreted through the lens of the TPB, which highlights three key constructs that influence behavioral intention: Attitudes toward outcomes (e.g., perception of income generation or cost reduction), Subjective norms (e.g., influence of farmer groups and community norms) and Perceived behavioral control (e.g., access to storage, balers, and information). These psychological and structural determinants vary across the four farmer profiles. For instance, vulnerable farmers may face low behavioral control and limited supportive norms. In contrast, high-potential farmers possess strong internal motivation, enabling conditions, and peer support, enabling them to adopt sustainable practices. Recognizing these distinctions enables more precise and behaviorally informed policy interventions, thereby increasing the likelihood of successful transitions away from straw burning.

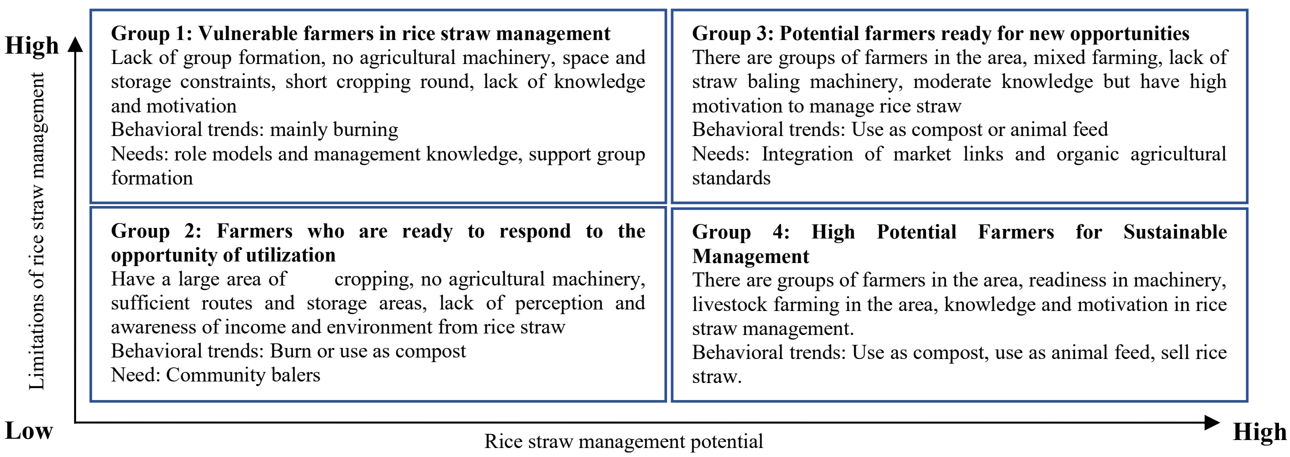

Figure 2. Types of farmers according to their potential and limitations in rice straw management.

6.1. Supply Chain Innovations for Rice Straw Utilization

The rice straw management in a circular system is not limited to the economic dimension but is also linked to the concept of the circular economy, which focuses on the efficient use of resources, reducing waste, and promoting sustainable production, especially when rice straw can be transformed to provide benefits in many ways, from reducing the cost of fertilizer and animal feed to reducing dependence on external factors.

The research results found that farmer grouping is a crucial mechanism for driving the utilization of rice straw in a comprehensive circulation system. The farmer groups promote on-site management, such as making compost, using it as animal feed, or mulching the soil in vegetable plots. They also help collect straw in large quantities, sufficient for resale to the private sector or the biomass energy industry, thereby increasing the economic value for farmers. Farmers who plan together, from planting and harvesting to post-harvest management, can utilize machinery such as balers more efficiently because they can operate simultaneously, reduce unit costs, and increase value at both the household and purchasing levels. It also facilitates straw sharing for community use, especially in areas with rotating or mixed farming systems.

Meanwhile, cooperation between farmer groups, local administrative organizations, and the private sector in providing community-level straw storage facilities will help create added value. Storage facilities can be used as a resting point for straw before transporting it to user groups. This can help reduce quality loss and transportation costs, as well as expand marketing opportunities for rice straw, both at the small-scale farmer level and in the industrial sector.

This suggests that sustainable rice straw management cannot be achieved solely through the efforts of individual farmers'. It requires a systematic cooperation mechanism, with farmer groups at the core and supported by local and government organizations, to promote the maximum benefit of rice straw utilization, reduce burning, and reduce PM2.5 dust, thereby supporting the country's sustainable agricultural development goals.

The interaction between regional and farmer characteristics, such as group membership or access to machinery, suggests that rice straw utilization strategies must be tailored to specific spatial contexts. For example, community-based baling services may be more effective in the central plains where collective harvesting is feasible, while localized composting may be more appropriate in high-rainfall southern areas.

6.2. Policy Recommendations

Reducing burning in agricultural areas and utilizing agricultural by-products for economic benefits are urgent policies that Thailand prioritizes. However, despite the government's past promotion, no concrete and spatially responsive measures have been effectively implemented. This study revealed that factors such as knowledge, group formation, convenience of transportation, storage availability, and access to straw baling machines are crucial for enhancing the utilization of rice straw. Sustainable rice straw management cannot rely solely on farmers' capacity. Systematic support from relevant stakeholders is necessary through policy design, practical implementation, and local-level promotion.

To promote integrated and sustainable rice straw management, this study proposes a multi-level policy framework that incorporates spatially differentiated strategies and defines stakeholder roles at the national, regional, and local levels as follows:

1. Spatially Differentiated Strategies by Region

The interaction effects between region and group membership reveal how social capital plays a differentiated role across geographic contexts.

- In the Northern region, membership in farmer groups significantly increased the likelihood of utilizing rice straw as animal feed. This suggests that community-based livestock systems and cohesive group structures in the North facilitate internal straw circulation, especially in mixed farming systems. Therefore, policy strategies for this region should emphasize strengthening group-based logistics and feed-sharing networks to maximize internal value loops.

- The Northeastern region was used as the reference group in the interaction model; it remains a crucial benchmark for understanding diversified straw management behaviors. With relatively even distributions among burning, animal feeding, and selling, this region reflects diverse but moderate group influence. Its high concentration of cattle farmers and large straw volume make it a key area for straw demand. Therefore, regional policies in the Northeast should emphasize market facilitation, straw transportation systems, and inter-regional straw exchange to match surplus from other regions with local demand.

- Central and Southern regions did not show a statistically significant effect, likely due to structural limitations such as time constraints (resulting from double cropping in the Central region) or geographic challenges (high rainfall in the South). Thus, in these regions, policy should focus on building enabling infrastructure, such as joint storage facilities and post-harvest coordination systems, before expecting farmer groups to perform effectively.

2. National-Level Policy Recommendations

a) National government agencies responsible for setting policies for using rice straw and reducing burning in agricultural areas include the Ministry of Agriculture and Cooperatives and the Ministry of Interior. They have the following duties:

- Create a strategic plan for rice straw management to promote the use of rice straw instead of burning, and integrate this approach into regional operations classified by spatial context to enable its utilization in various industries, such as organic farming, livestock, and energy, in the future.

- Develop knowledge of rice straw management for farmers to utilize through training and creating appropriate media, such as composting from rice straw, using rice straw for animal feed, preserving and processing rice straw, and promoting practical work through prototype learning plots.

- Support benefits and incentives for farmer groups by providing special privileges, including financial support measures such as transport subsidies, shared machinery, and access to specific markets and tax benefits, especially in agricultural areas where rice is grown twice a year.

- Develop marketing networks and link downstream industries that utilize rice straw, such as the livestock sector and organic farmers, or expand the market to the biomass energy industry; this will encourage farmers to enter the Carbon Credit system and receive rewards for reducing greenhouse gas emissions in the future.

b) Implementation agencies, whether sub-district administrative organizations or local administrative organizations, will be tasked with translating policies into practice to create appropriateness in utilization and reduce burning in the area. Have the following duties:

- Support the establishment of groups and the creation of participation mechanisms for planting and harvesting plans with farmers. Creating a mechanism for joint agricultural planning in the area, which involves planning and harvesting simultaneously, will help make more efficient use of machinery in managing rice straw, especially for vulnerable farmers and those ready to respond to opportunities for utilization. Group formation is considered the starting point for future utilization of rice straw.

- Develop infrastructure and places for straw collection. Develop road networks to provide easy access to remote areas. A centralized storage area will enable the distribution of utilization within the region or among agricultural groups in the area, as well as to other industries.

- Design creative campaigns and public relations initiatives to raise awareness of the economic benefits of rice straw and the environmental impacts associated with burning.

3) Farmer/cooperative/local wisdom member groups must be leaders in changing the community, which plays a vital role in driving sustainable rice straw management to perform the following duties:

- Manage the group and develop mechanisms as specified by government or local agencies, such as planning straw collection, prioritizing members' use of machinery, and distributing joint benefits.

- Establish a learning center for rice straw management, providing practical training and creating a model for agricultural communities to stop burning through community participation.

- Integrate and link the government sector and small farmers, both in terms of policy and practice linkages and coordinate integrated work with new markets in the future.

4) The last part is that farmers themselves will play a crucial role in rice straw utilization, as they are the primary stakeholders in its management. The suggestions are as follows:

- Develop knowledge and skills to adjust utilization behavior by being aware of the environmental impacts of burning.

- Design integrated farming to utilize rice straw, especially for raising cattle and buffalo. Additionally, there are indirect benefits from the sale of meat and cattle and buffalo in the future.

- Engage with farmer groups to stay informed about policies and harvesting plans, thereby systematically utilizing resources together and creating bargaining power to sell straws to other industries.

Policy integration for sustainability from national government agencies, operational agencies, farmer member groups, cooperatives, local scholars, and farmers will be a tool to enhance the potential of rice straw utilization and reduce burning, leading to tangible results such as reducing greenhouse gas emissions from burning in the agricultural sector, increasing income from using rice straw in a valuable way, and strengthening sustainable production systems at the community level in terms of the economy, environment, and society of Thailand.

6.3. Limitations of the Study and Future Research

The limitations of this research were as follows: First, although the variable design encompassed key socioeconomic characteristics and agricultural management capabilities, psychological factors such as farmers' attitudes, personal values, perceived behavioral control, and social conformity were not explicitly included in the empirical model. Incorporating these behavioral variables could enhance the explanatory power and inform more effective behavior-based policy interventions.

Second, the policy recommendations in this study were derived from analytical results and stakeholder perspectives but remained at the conceptual and strategic levels. They have not yet been tested or evaluated through real-world implementation. Further research should pursue policy experiments or pilot interventions to assess the effectiveness and feasibility of proposed measures under practical conditions.

Third, there were data limitations in the Southern region, where the number of respondents was minimal (only 11 observations, or 1.9% of the total sample). This resulted in estimation errors and hindered the interpretation of some interaction effects involving the South.

Future studies should aim to improve regional sample balance, particularly by increasing representation in areas with low response rates to enable more robust statistical modeling. Fourth, while this study explored a key interaction between region and group membership, other potential interaction effects, such as region × access to machinery or region × awareness variables, were not extensively examined. Future research should investigate a broader range of regional interactions to gain a deeper understanding of how contextual factors influence farmers' behavior differently across different locations.

Finally, future research should explore the potential of rice straw for energy production, particularly in the context of Thailand's long-term strategy for a circular bioeconomy. The energy sector offers high-capacity straw utilization potential. It could play a central role in transforming rice straw from an agricultural residue into a valuable industrial input, supporting both environmental and economic sustainability.

Author Contributions

Conceptualization, A.W. and T.H.; methodology; software; validation; formal analysis, A.W.; writing—original draft preparation, A.W.; writing—review and editing, T.H. All authors have read and agreed to the published version of the manuscript.

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Institutional Review Board Statement

The study was conducted according to the guidelines of the Declaration of Helsinki and approved by the Institutional Review Board of Technology and Social Sciences and Humanities, Naresuan University (NU-IRB) (COE. No. 023/2025, date of approval: 13 February 2025).

Informed Consent Statement

Not applicable.

Data Availability Statement

Not applicable.

Conflicts of Interest

The authors declare that they have no conflict of interest.

References

[1] Thai Rice Exporters Association, 2022. Rice production in Thailand. Available from: http://www.thairiceexporters.or.th/default_eng.htm (cited 20 December 2024).

[2] Nakhshiniev, B., Biddinika, M.K., Gonzales, H.B., et al., 2014. Evaluation of hydrothermal treatment in enhancing rice straw compost stability and maturity. Bioresource Technology. 151, 306–313. DOI: https://doi.org/10.1016/j.biortech.2013.10.083

[3] International Rice Research Institute, 2019. Rice knowledge bank, rice straw. Available from: http://www.knowledgebank.irri.org/step-by-step-

production/postharvest/rice-by-products/rice-straw (cited 20 December 2024).

[4] Dobermann, A., Fairhurst, T.H., 2002. Rice straw management. Better Crops International. 16(1), 7–11.

[5] Ren, J., Yu, P., Xu, X., 2019. Straw utilization in China—status and recommendations. Sustainability. 11(6), 1762. DOI: https://doi.org/10.3390/su11061762

[6] Ministry of Public Health, 2024. Summary report on the medical and public health operations regarding haze and PM2.5 in Thailand, 2024. Available from: https://hia.anamai.moph.go.th/web-upload/12xb1c83353535e43f224a05e184d8fd75a/filecenter/kpi/2567/5/09_Aug/3.30/3.30_kpi67_Aug_Report.pdf (cited 20 December 2024).

[7] Yang, Y., Wang, X., Zhang, T., et al., 2014. Utilization of crop straw resources in Anhui Province, Eastern China. Bulgarian Journal of Agricultural Science. 20, 1302–1310.

[8] Moraes, C.A., Fernandes, I., Calheiro, D., et al., 2014. Review of the rice production cycle: by-products and main applications, with a focus on rice husk combustion and ash recycling. Waste Management & Research. 32(11), 1034–1048. DOI: https://doi.org/10.1177/0734242X14557379

[9] Gadde, B., Menke, C., Wassmann, R., 2009. Rice straw as a renewable energy source in India, Thailand, and the Philippines: overall potential and limitations for energy contribution and greenhouse gas mitigation. Biomass and Bioenergy. 33, 1532–1546. DOI: https://doi.org/10.1016/j.biombioe.2009.07.018

[10] Kadam, K.L., Forrest, L.H., Jacobson, W.A., 2000. Rice straw as a lignocellulosic resource: collection, processing, transportation, and environmental aspects. Biomass and Bioenergy. 18, 369–389. DOI: https://doi.org/10.1016/S0961-9534(00)00005-2

[11] Korenaga, T., Liu, X., Huang, Z., 2001. The influence of moisture content on polycyclic aromatic hydrocarbons emission during rice straw burning. Chemosphere - Global Change Science. 3, 117–122. DOI: https://doi.org/10.1016/S1465-9972(00)00045-3

[12] Singh, R., Patel, M., 2022. Effective utilization of rice straw in value-added by-products: a systematic review of state of art and future perspectives. Biomass and Bioenergy. 159, 106411. DOI: https://doi.org/10.1016/j.biombioe.2022.106411

[13] Hussein, S., Sawan, O., 2010. The utilization of agricultural waste as one of the environmental issues in Egypt (a case study). Journal of Applied Sciences Research. 6, 1116–1124.

[14] Ahmed, T., Ahmad, W., 2020. Burning crop residue: farmers' choice among various practices. Pakistan Journal of Applied Economics. 29, 265–290.

[15] Watanaputi, A., Hengsadeekul, T., 2024. Guidelines for increasing farmers' income from rice straw management for stopping burning on agricultural fields in Thailand. Rajapark Journal. 18(59), 1–14.

[16] Chendrashekhara, S., Lokesh, G.B.., Patila, S., et al., 2018. Factors influencing the adoption of paddy straw management practices by farmers of Karnataka (India). Current Agriculture Research Journal. 6, 225–232. DOI: https://doi.org/10.12944/CARJ.6.2.13

[17] Supaporn, P., Kobayashi, T., Supawadee, C., 2013. Factors affecting farmers' decisions on utilization of rice straw compost in Northeastern Thailand. Journal of Agriculture and Rural Development in the Tropics and Subtropics. 114, 21–27.

[18] Haider, M.Z., 2013. Determinants of rice residue burning in the field. Journal of Environmental Management. 128, 15–21. DOI: https://doi.org/10.1016/j.jenvman.2013.04.046

[19] Widarni, N.A., Astuti, A., Andarwati, S., et al., 2021. Determinants of rice by-product utilization as a potential local feed for ruminants in Magelang Regency, Indonesia. Proceedings of The 2021 International Conference on Livestock in Tropical Environment; September 1–2, 2021, Surakarta, Indonesia. DOI: https://doi.org/10.1088/1755-1315/902/1/012049

[20] Minas, A.M., Mander, S., McLachlan, C., 2020. How can we engage farmers in bioenergy development? Building a social innovation strategy for rice straw bioenergy in the Philippines and Vietnam. Energy Research and Social Science. 70, 101717. DOI: https://doi.org/10.1016/j.erss.2020.101717

[21] Del Valle, T.M., Zhu, J., Jiang, P., 2022. Drivers of straw management in rural households: options for the development of the bioenergy sector in China. Energy for Sustainable Development. 71, 341–351. DOI: https://doi.org/10.1016/j.esd.2022.10.009

[22] Zuo, A., Hou, L., Huang, Z., 2020. How does farmers' current usage of crop straws influence the willingness-to-accept price to sell? Energy Economics. 86, 104639. DOI: https://doi.org/10.1016/j.eneco.2019.104639

[23] Ajzen, I., 1985. A Theory of Planned Behavior. Springer: Berlin, Germany. pp. 11–39.

[24] Guo, H., Xu, S., Wang, X., et al., 2021. Driving mechanism of farmers' utilization behaviors of straw resources—an empirical study in Jilin Province, the main grain producing region in the northeast part of China. Sustainability. 13(5), 2506. DOI: https://doi.org/10.3390/su13052506

[25] Sereenonchai, S., Arunrat, N., 2022. Farmers' perceptions, insight behavior and communication strategies for rice straw and stubble management in Thailand. Agronomy. 12(1), 200. DOI: https://doi.org/10.3390/agronomy12010200

[26] Delivand, M., Barz, M., Garivait, S., 2011. Overall analyses of using rice straw residues for power generation in Thailand—project feasibility and environ-

mental GHG impacts assessment. Journal of Sustainable Energy & Environment Special Issue. 39–46.

[27] Mahmood, A., Gheewala, S., 2020. A comparative assessment of rice straw management alternatives in Pakistan in a life cycle perspective. Journal of Sustainable Energy & Environment. 11, 21–29.

[28] Shafie, S., 2015. Paddy residue-based power generation in Malaysia: Environmental assessment using LCA approach. Journal of Engineering and Applied Sciences. 10(15), 6643–6648.

[29] Dassanayake, M., Kumar, A., 2012. Techno-economic assessment of triticale straw for power generation. Applied Energy. 98, 236–245. DOI: https://doi.org/10.1016/j.apenergy.2012.03.030

[30] Office of Agricultural Economics, 2024. Agricultural economic information [in Thai]. Available from: https://farmerone.oae.go.th:5000/Plants/Detail?ID=697&year=2568 (cited 22 December 2024).

[31] Yamane, T., 1973. Statistics: An Introductory Analysis, 3rd ed. Harper and Row: New York, NY, USA. pp. 79–80.

[32] Office of Agricultural Economics, 2024. Farmer registration information and agricultural activities [in Thai]. Available from: https://farmerone.oae.go.th:5000 (cited 22 December 2024).

[33] Vanichbuncha, K., 2003. Statistical Analysis: Statistics for the Management, Administration and Research, 10th ed. Chulalongkorn University Press: Bangkok, Thailand. pp. 216–250.

[34] Hair, J., Black, W.C., Babin, B.J., et al., 2010. Multivariate Data Analysis. Pearson Education: Upper Saddle River, NJ, USA. pp. 1–785.

[35] Wang, L., Watanabe, T., 2016. Factors affecting farmers' risk perceptions regarding biomass supply: a case study of the national bioenergy industry in northeast China. Journal of Cleaner Production. 139, 517–526.

[36] Cuong, O.Q., Demont, M., Pabuayon, I.M., et al., 2024. What monetary incentives are rice farmers willing to accept to stop straw burning? Evidence from a choice experiment in the Mekong Delta, Vietnam. Environmental Challenges. 15, 100913. DOI: https://doi.org/10.1016/j.envc.2024.100913

[37] Roy, P., 2015. Status and problems of paddy straw management in West Bengal. International Journal of Advances in Agricultural & Environmental Engineering (IJAAEE). 2, 44–48. DOI: https://doi.org/10.15242/IJAAEE.ER1015204

[38] Lopes, A.A., Viriyavipart, A., Tasneem, D., 2020. The role of social influence in crop residue management: evidence from Northern India. Ecological Economics. 169, 106563. DOI: https://doi.org/10.1016/j.ecolecon.2019.106563

[39] Malik, K., Khan, M., Kumar, P., et al., 2023. Potential use of rice straw with sustainable technologies: knowledge and constraints. Environment and Ecology. 41, 2602–2608.

[40] Launio, C.C., Asis, C.A. Jr., Manalili, R.G., et al., 2014. What factors influence choice of waste management practice? Evidence from rice straw management in the Philippines. Waste Management Research. 32, 140–148.

[41] Nengah, M., 2019. A study on rice field farmer implementation of rice straw composting. Proceedings of The 1st International Conference of Interdisciplinary Research on Green Environmental Approach for Sustainable Development (ICROEST) 2019; August 3–4, 2019, Universitas Muhammadiyah Buton, Indonesia. pp. 1–7. DOI: https://doi.org/10.1088/1755-1315/343/1/012001

[42] Zainol, R.M., 2014. Farmers' participation in rice straw-utilisation in the MADA region of Kedah, Malaysia. Mediterranean Journal of Social Sciences. 5(23), 229. DOI: https://doi.org/10.5901/mjss.2014.v5n23p229

[43] Baba, S., Sohrah, S., 2019. Farmers perception of the utilization of agricultural waste as a feed in Maros Regency. Proceedings of The 1st International Conference of Animal Science and Technology (ICAST) 2018; November 6–7, 2018, Makassar, Indonesia. pp. 1–4. DOI: https://doi.org/10.1088/1755-1315/247/1/012062

[44] Kurniati, N., Sukiyono, K., Purmini, P., et al., 2021. Adoption level of integrated farming system based on rice–cattle and its determinants related to sustainable agriculture. Proceedings of The 1st International Conference on Bioenergy and Environmentally Sustainable Agriculture Technology (ICoN BEAT 2019); November 7–8, 2019; Malang, Indonesia. pp. 1–9. DOI: https://doi.org/10.1051/e3sconf/202122600034

[45] Ahmed, T., Ahmad, B., Ahmad, W., 2015. Why do farmers burn rice residue? Examining farmers' choices in Punjab, Pakistan. Land Use Policy. 47, 448–458. DOI: https://doi.org/10.1016/j.landusepol.2015.05.004

[46] Zeng, Y., Zhang, J., He, K., 2019. Effects of conformity tendencies on households' willingness to adopt energy utilization of crop straw: Evidence from biogas in rural China. Renewable Energy. 138, 573–584. DOI: https://doi.org/10.1016/j.renene.2019.02.003

[47] Jain, S., 2020. Paddy straw management: perception and challenges of paddy growing farmers. International Journal of Education & Management. 2020, 75–78.

[48] Qing, C., He, J., Guo, S., et al., 2022. Peer effects on the adoption of biogas in rural households of Sichuan Province, China. Environmental Science and Pollution Research. 29, 61488–61501. DOI: https://doi.org/10.1007/s11356-022-20232-y

[49] Hyink, J., Bresnahan, R., McFadden, B.R., et al., 2024. Agricultural producer and non-producer perceptions of crop residue burning: a focus on Arkansas. Discover Sustainability. 5, 95. DOI: https://doi.org/10.1007/s43621-024-00278-3

[50] Manyise, T., Dentoni, D., 2021. Value chain partnerships and farmer entrepreneurship as balancing ecosystem services: implications for agri-food systems resilience. Ecosystem Services. 49, 101279. DOI: https://doi.org/10.1016/j.ecoser.2021.101279

[51] Tao, J., Bai, W., Peng, R., et al., 2024. Sustainable regional straw utilization: collaborative approaches and network optimization. Sustainability. 16(4), 1557. DOI: https://doi.org/10.3390/su16041557

[52] Nath, B., Ahmmed, M.M., Paul, S., et al., 2025. Unlocking the potential of rice straw: sustainable utilization strategies for Bangladesh. Circular Economy. 4, 100126. DOI: https://doi.org/10.1016/j.cec.2025.100126

[53] Bureau of Animal Nutrition Development, 2024. To mitigate the shortage of forage crops, fermented rice straw can be produced during the dry season as an alternative feed resource. Available from: https://pvlo-pic.dld.go.th/webnew/index.php/th/service-menu/2023-02-18-09-04-26/302-1-2560 (cited 25 December 2024).

[54] Cheewaphongphan, P., Junpen, A., Kamnoet, O., et al., 2018. Study on the potential of rice straws as a supplementary fuel in very small power plants in Thailand. Energies. 11(2), 270. DOI: https://doi.org/10.3390/en11020270

[55] Arunrat, N., Sereenonchai, S., Sansupa, C., et al., 2023. Effect of rice straw and stubble burning on soil physicochemical properties and bacterial communities in Central Thailand. Biology. 12(4), 501. DOI: https://doi.org/10.3390/biology12040501

[56] Truc, N.T., Sumalde, Z., Espaldon, M.V., et al., 2012. Farmers' awareness and factors affecting adoption of rapid composting in Mekong Delta, Vietnam and Central Luzon, Philippines. Journal of Environmental Science and Management. 15, 59–73.

[57] Kaur, H., Iqbal, T., Dhiman, S., 2023. An assessment on the knowledge level of farmers regarding paddy straw management in Ludhiana, Punjab. AATCC Review. 11, 194–200. DOI: https://doi.org/10.58321/AATCCReview.2023.11.04.194

[58] Dinh, V.P., Duong, B.N., Nguyen, T.P.T., et al., 2024. Assessing people's awareness of environmental and health impacts of straw burning in Southeast Vietnam through factor analysis and proposing sustainable solutions. Environmental Health Insights. 18, 1–29. DOI: https://doi.org/10.1177/11786302241296692

[59] Donner, M., Verniquet, A., Broeze, J., et al., 2021. Critical success and risk factors for circular business models valorising agricultural waste and by-products. Resources, Conservation and Recycling. 165, 105236. DOI: https://doi.org/10.1016/j.resconrec.2020.105236

[60] Wang, S., Huang, X., Yin, C., et al., 2021. A critical review on the key issues and optimization of agricultural residue transportation. Biomass and Bioenergy. 146, 105979. DOI: https://doi.org/10.1016/j.biombioe.2021.105979

[61] Liu, H., Jiang, G.M., Zhuang, H.Y., et al., 2008. Distribution, utilization structure and potential of biomass resources in rural China: with special references of crop residues. Renewable and Sustainable Energy Reviews. 12, 1402–1418. https://doi.org/10.1016/j.rser.2007.01.011

[62] Akter, S., Ahmed, J.U., Begum, I.A., et al., 2025. Integrated farming system – a means of improving farmers' well-being in the wetland ecosystem of Bangladesh. Farming System. 3, 100127. https://doi.org/10.1016/j.farsys.2024.100127

[63] Kumar, M., Singh, A., Wamiq, M., et al., 2023. Integrated farming for long-term viability of agriculture: A review. The Pharma Innovation. 4771–4776.

[64] Khanam, S., Ray, S.K., Bhuiyan, R.H., et al., 2025. Advancing nutrient management in agriculture: rice straw to nitrogen, phosphorus and potassium-containing hydrogel as slow-release fertilizer. Industrial Crops and Products. 224, 120380. https://doi.org/10.1016/j.indcrop.2024.120380

[65] Connor, M., de Guia, A.H., Quilloy, R., et al., 2020. When climate change is not psychologically distant – factors influencing the acceptance of sustainable farming practices in the Mekong River Delta of Vietnam. World Development Perspectives. 18, 100204. https://doi.org/10.1016/j.wdp.2020.100204