
The adoption of farm machinery among rice farmers: A pairwise correlation analysis of eight farm machinery

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Abstract Farmers' adoption of farm machinery is prioritized based on the perceived importance and profitability of each piece of equipment. Furthermore, farmers are more likely to use a variety of machinery rather than a single piece of equipment to complete jobs more efficiently. When establishing policy initiatives to promote diversified adoption, it is essential to consider the interrelationships among machinery to avoid biased findings or misinterpretations. Consequently, correlated adoption patterns of various machinery types – whether adopted together or separately – may be more relevant than simply modeling adoption intensity. This study investigated farm machinery adoption among 93 rice farmers in Nong Saeng district, Saraburi province, Thailand, using pairwise correlation analysis. The findings revealed pairwise correlations between the eight categories of farm machinery, with varying signs and levels of significance. Significant positive correlations were identified between knapsack sprayers and combine harvesters ($r_s = 0.4626$, $p < 0.01$), water pumps and lawnmowers ($r_s = 0.2604$, $p < 0.05$), and combine harvesters and truck carriers ($r_s = 0.2543$, $p < 0.05$). Conversely, significant negative correlations were found between wheel ploughs and tractors ($r_s = -0.2753$, $p < 0.01$) and wheel ploughs and lawnmowers ($r_s = -0.3083$, $p < 0.01$). From a policy standpoint, significant positive correlations suggest the potential effectiveness of bundled support. Significant negative correlations may indicate technological transitions, highlighting a need for targeted support for farmers using outdated equipment and incentives for modernization. Finally, weak or nonexistent correlations suggest unexploited synergies, which could be addressed through extension training programs focused on equipment complementarity to increase total farm efficiency.

Keywords: Policy support, Adoption pattern, Correlation analysis, Thailand

Introduction

The declining and aging agricultural workforce makes farm machinery increasingly essential for sustaining production levels. Mechanization directly contributes to heightened food output and improved operational efficiency. Furthermore, it is crucial for lowering overall production expenses and reducing the physical burden on farm workers (Rijk, 1986, 1989). Ultimately, enhancing

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agricultural efficiency and productivity strengthens the sector's economic viability, potentially attracting a new generation to agricultural careers (Daum, 2023).

The development and utilization of farm machinery diverges significantly across individual farms, countries, and regions (Rijk, 1986; Takeshima and Salau, 2010; Paman *et al.*, 2018). While mechanization is already prevalent in developed nations, many developing countries continue to strive toward comprehensive adoption (Rijk, 1986; Mongkoltanatas, 1998; Paman *et al.*, 2018). In Thailand, the agricultural sector has seen a notable increase in the quantity, size, and variety of machinery, alongside significant advancements in domestically produced equipment (Thepent and Chamsing, 2009; National Statistical Office, 2013, 2024; Cramb and Thepent, 2020).

However, many smallholder farmers in Thailand continue to face challenges in the optimal utilization of farm machinery (Thepent and Chamsing, 2009; Thailand Development Research Institute, 2020). A primary obstacle is the small size of plots allocated to crop production, which inhibits the efficient deployment of equipment. Indeed, this raises operational expenses due to high energy consumption per unit area, especially for larger equipment (Thailand Development Research Institute, 2020).

Furthermore, according to Rogers' conceptual model of the innovation-decision process, adopting particular technologies is a complex decision-making process (Rogers, 2003). From a policy standpoint, it is therefore critical to study adoption decisions for specific types of farm machinery to develop suitable strategies that support diversified adoption. Previous studies have investigated the factors influencing farmers' adoption of certain machinery (Carrer *et al.*, 2017; Fischer and Wollni, 2018; Fischer *et al.*, 2018; W. Li *et al.*, 2018; Quan and Doluschitz, 2021; H. Li *et al.*, 2023). These factors include, for instance, demographic traits, machinery costs and availability, market access, economic incentives, institutional impacts, and machinery effectiveness.

However, when analyzing the adoption of a specific type of farm machinery, prior research often neglects the adoption decisions of other machinery, even when those decisions are made concurrently. Wu and Babcock (1998) and Donkoh *et al.* (2019) demonstrated that failing to consider interrelationships across agricultural technologies may result in misleading estimations of the factors influencing adoption. To that end, farm-level policies influencing the adoption of one machinery type may impact others. Consequently, understanding which correlated machinery types farmers are likely to adopt – whether together or separately – may be more crucial than simply modeling the factors influencing the adoption of a certain equipment or the overall adoption intensity.

Therefore, this study analyzed the pairwise correlations of farm machinery adoption among rice farmers in Nong Saeng district, Saraburi province, Thailand. The research identified eight types of farm machinery including the water pump, knapsack sprayer, wheel plough, combine harvester, tractor, lawnmower, planter, and truck carrier. It used data from a household survey of 93 rice farmers. In terms of policy implications, the findings can assist in establishing appropriate policies that support the adoption of various types of farm machinery.

Materials and methods

Study area

This study was conducted in Nong Saeng district, Saraburi province, in upper central Thailand. Nong Saeng is one of 13 districts in Saraburi. It encompasses approximately 87 km² and has the largest agricultural area in the province (Nong Saeng District Agricultural Extension Office, 2022; Saraburi Provincial Administration, 2024).

Nong Saeng district was chosen as the study area primarily because it is the province's largest agricultural area. Agriculture is the district's major economic sector and covers approximately 61.2% of the total land area (Nong Saeng District Agricultural Extension Office, 2022). The landscape is characterized by flat, low-lying clay soil and irrigation supports almost 90% of agricultural activity. The climate has an average annual rainfall of 1,133 mm. Most of this falls between July and September, and average temperatures range from 25°C to 30.5°C.

Nong Saeng district has 1,836 agricultural households. This accounts for 35.8% of the total households. Farmers make up the majority of the population and mostly cultivate paddy rice, vegetables, and fruits. About 87.98% of farmers in the district consider farming their major occupation, while 12.02% see agriculture as a supplementary source of income (Nong Saeng District Agricultural Extension Office, 2022). The average annual household income is approximately 267,747 Baht. Many households carry debt, largely to the Bank for Agriculture and Agricultural Cooperatives (Nong Saeng District Agricultural Extension Office, 2022).

Wet-season rice cultivation accounts for 98.3% of crop production in Nong Saeng district, which covers 52.36 km². The rice cultivation schedule includes planting from May to August and harvesting from August to December. June is the main planting month and November is the peak harvest season (Nong Saeng District Agricultural Extension Office, 2022). Nong Saeng district's rice yield in 2021 was 22,018.40 tons, with an average yield of 4.25 tons/ha. This is higher than

the central region and national averages (Nong Saeng District Agricultural Extension Office, 2022. Office of Agricultural Economics, 2023). The production cost of wet-season rice in irrigated areas is 26,788 Baht/ha, with sales income of 42,500 Baht/ha, yielding a profit of around 15,712 Baht/ha (Nong Saeng District Agricultural Extension Office, 2022).

In 2021, a large proportion (64%) of agricultural household heads in Nong Saeng district were over the age of 56 (Nong Saeng District Agricultural Extension Office, 2022). This demographic trend emphasizes the critical need for farm machinery to compensate for future labor shortages. Farm machinery usage in rice production includes (1) land preparation, planting, and irrigation, (2) maintenance, and (3) harvesting (Nong Saeng District Agricultural Extension Office, 2022).

Research design

This cross-sectional exploratory research was undertaken to investigate the correlated adoption of farm machinery among rice farmers in Nong Saeng district, Saraburi province, Thailand. It used a case study survey method. In this method, a survey is administered to a case – either a small sample or an entire population – in order to describe the characteristics of that population (Chmiliar, 2010). The total population consists of 1,836 agricultural households. The sample size was estimated using Yamane’s formula (Yamane, 1967). With 95% confidence, the sample size for a 10% margin of error is 92. The final sample size consisted of 93 rice farmers.

As preliminary research, purposive and convenience sampling methods were employed to recruit participants for the survey. The inclusion criteria for samples were rice farmers in Nong Saeng district and those willing to participate in the research. Conversely, the exclusion criteria included farmers who were not rice growers and instead cultivated other crops or animal husbandry. It also excluded those unwilling to participate or unable to complete at least half of the questionnaire questions. While the samples may be biased and limit generalizability, they were carefully selected in cooperation with an agricultural extensionist from the Nong Saeng District Agricultural Extension Office. This officer was highly experienced and familiar with farmers in the study area. Furthermore, the sample farmers were at the targeted site. The Nong Saeng District Agricultural Extension Office had identified this site for a future project to strengthen and upgrade the capabilities of rice farmer groups with farm machinery and agricultural technology.

Ethical consideration

This study was conducted under international standards for the protection of human subjects, and the research protocols were reviewed and approved by the Institutional Review Board (IRB) of the Office of the Research Ethics Review Committee for Research Involving Human Subjects, Chulalongkorn University. The proposal of this research was reviewed by the Research Ethics Review Committee for Research Involving Human Subjects: The Second Allied Academic Group in Social Sciences, Humanities and Fine and Applied Arts under an expedited review category. It was approved on 2 January 2024 with the project reference code number 006/67.

Data collection

Primary data was collected through face-to-face interviews using a structured questionnaire from January to February 2024. The validity of the instrument was tested by three experts. The Index of Item-Objective Congruence (IOC) value was greater than 0.60 for each question. Reliability was tested using Cronbach's alpha coefficient, which yielded a value of 0.96. In addition, secondary data on the demographic and socioeconomic characteristics of the farmers in the district were provided by the Nong Saeng District Agricultural Extension Office.

The questionnaire consisted of two sections. The first section asked for background information about the respondent. This included gender, age, education level, farming experience, and the classification of farming activity as either full-time or part-time. The second section focused on farm machinery usage. In this part, the respondent was requested to identify farm machinery currently in operation. The types of farm machinery employed by the rice farmers were not pre-specified. This allowed for an examination of as many types as possible.

A total of 93 interviews were conducted. Each lasted 20-30 minutes. When a respondent did not comprehend a question, the author provided clarification. As a result, there was no missing data in the questionnaires.

Data analysis

Data collected from the 93 rice farmers were analyzed using descriptive statistics. These included frequencies, means, and standard deviations. In addition, Spearman's correlation coefficients (r_s) were calculated to examine the pairwise interrelationships between farmer adoptions of various types of farm machinery. The coefficient ranges between -1 and +1. A positive correlation coefficient indicates a relationship in the same direction between the adoptions

of the two types of farm machinery. A negative correlation coefficient signifies a relationship in the opposite direction. A coefficient value close to zero indicates a weak relationship. The analysis was carried out using Microsoft Excel.

The study employed a biplot analysis to visually present data within a two-dimensional framework. It enabled a comprehension of both the characteristics of the observations and the relative positions of the observed items. Points close together indicated similarity among observed objects. For variable vectors, short vectors near the origin represented low variability, whereas longer vectors indicated higher variability. Positive correlations appeared as vectors pointing in the same direction. Negatively correlated variables presented as vectors in opposite directions. Uncorrelated variables emerged as vectors forming approximately a right angle or 90°. Finally, the position of observed points relative to variable vectors indicated their scores on those variables. Points closer to the positive end of the vectors represented above-average scores. The variable vectors pointing toward a cluster of observations suggested that those variables are important in defining that group. The biplot graph was plotted using Microsoft Excel.

Results

Background of farmers

The background data of the 93 farmers were classified according to gender, age, education level, agricultural experience, and employment, as shown in Table 1. The results showed that 63.44% of respondents were female. Furthermore, the data showed that nearly half of the farmers (48.39%) were above the age of 60. Nearly another half (47.31%) fell between the ages of 40 and 60. Only 4.30% of respondents were under 40. This highlighted the predominantly aging farmer population.

In terms of educational attainment, the majority of respondents (58.07%) had completed primary school. In addition, the majority of farmers (58.06%) had more than 20 years of experience, while less than one-fifth (18.28%) had less than 10 years of farming experience. Respondents were engaged in farming activities approximately equally between full-time (51.61%) and part-time (48.39%) employment.

Table 1. Background information of the farmers in the survey

Characteristics of farmers	Value	Frequencies	
		Count	Percentage
Gender	Male	34	36.56
	Female	59	63.44
Age	< 40	4	4.30
	40-60	44	47.31
	> 60	45	48.39
Education level	Primary	54	58.07
	Secondary	31	33.33
	Bachelor's	8	8.60
Farming experiences	1-5 years	9	9.68
	6-10 years	8	8.60
	11-20 years	22	23.66
	> 20 years	54	58.06
Classification of employment	Full-time	48	51.61
	Part-time	45	48.39

Source: Author's compilation based on the structured questionnaire

Adoption of farm machinery

According to the findings, the water pump was the most commonly adopted farm machinery, with 73 of 93 respondents (78.49%) using it. The knapsack sprayer was the second most widely used farm machinery, with 58 respondents adopting it, accounting for 62.37% of the sample farmers. The wheel plough was the third most adopted farm machinery, with 54 farmers (58.06%) adopting it. The rice combine harvester was the fourth most adopted farm machinery, with 50 respondents (53.76%). The tractor (33), lawnmower (22), planter (11), and truck carrier (6) were used by less than 50% of the sample farmers. The adoption of farm machinery by type among the 93 sample farmers is summarized in Table 2.

Table 2 Farmers' adoptions of farm machinery

Farm Machinery	Frequencies	
	Count	Percentage
Water pump	73	74.89
Knapsack sprayer	58	62.37
Wheel plough	54	58.06
Combine Harvester	50	53.76
Tractor	33	35.48
Lawnmower	22	23.66
Planter	11	11.83
Truck carrier	6	6.45

Source: Author's compilation based on the structured questionnaire

Interrelationship between adoptions of farm machiney – pairwise correlation

The correlation matrix of farm machinery adoption based on Spearman's correlation coefficients (r_s) is presented in Table 3. Across eight types of machinery, the findings revealed a statistically significant positive correlation between the adoption of a knapsack sprayer and a combine harvester ($r_s = 0.4626$, $p < 0.01$), a water pump and a lawnmower ($r_s = 0.2604$, $p < 0.05$), and a combine harvester and a truck carrier ($r_s = 0.2543$, $p < 0.05$). Furthermore, the findings indicated a statistically significant negative correlation between the adoption of a wheel plough and a tractor ($r_s = -0.2753$, $p < 0.01$), and a wheel plough and a lawnmower ($r_s = -0.3083$, $p < 0.01$).

Table 3. Correlation matrix of farmers' farm machinery adoptions

Farm machinery	Water pump	Knapsack sprayer	Wheel plough	Combine Harvester	Tractor	Lawnmower	Planter	Truck carrier
Water pump	1.0							
Knapsack sprayer	0.1564	1.0						
Wheel plough	0.0808	0.0845	1.0					
Combine Harvester	0.1432	0.4626 ^b	0.1158	1.0				
Tractor	0.1126	0.1450	-0.2753 ^b	-0.0464	1.0			
Lawnmower	0.2604 ^a	-0.0274	-0.3083 ^b	0.0833	-0.0427	1.0		
Planter	0.1328	0.0492	-0.0691	0.1547	-0.1325	0.0312	1.0	
Truck carrier	0.0491	-0.1255	0.1504	0.2543 ^a	-0.1948	0.1628	0.0393	1.0

^a/Values significant at $P < 0.05$

^b/Values significant at $P < 0.01$

The principal component analysis (PCA) biplot graph of eight variables within a two-dimensional framework is illustrated in Figure 1. These variables represented the adoption of certain types of farm machinery. The biplot vectors were dispersed in three quadrants. This indicated whether the variables were positively or negatively correlated. Positive correlations were found between the adoption of different types of machinery when the vectors pointed in the same direction. A smaller angle between the vectors indicated a higher correlation between the two variables. For instance, there were significant positive correlations between the adoption of a knapsack sprayer and a combine harvester

(0.4626), a water pump and a lawnmower (0.2604), and a combine harvester and a truck carrier (0.2543).

In contrast, significant negative correlations between the adoptions of farm machinery were observed when the vectors pointed in opposite directions. A wider angle between the vectors indicated a higher negative correlation between the two variables. For example, the correlations between the adoption of a wheel plough and a tractor (-0.2753), and between a wheel plough and a lawnmower (-0.3083) were significantly negative.

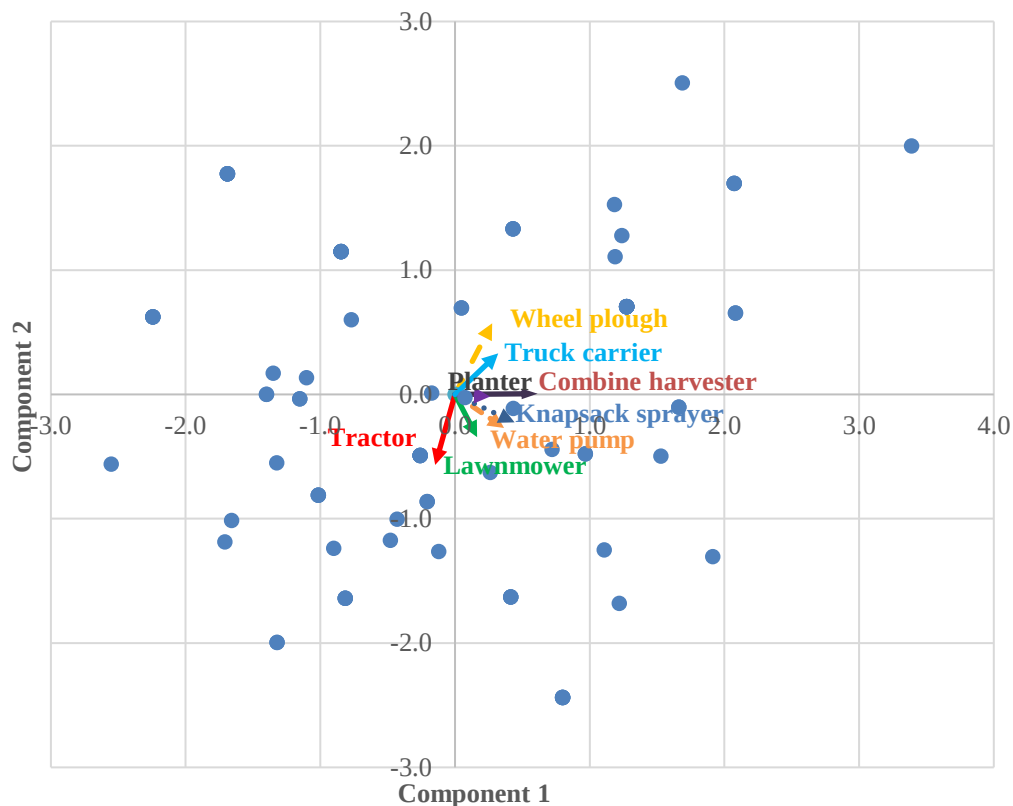


Figure 1: Principal Component Analysis (PCA) biplot graph of eight variables

According to the biplot graph, the ‘Combine harvester’, ‘Planter’, and ‘Knapsack sprayer’ variables were associated highly with Component 1, whereas the ‘Wheel plough’ variable was linked to Component 2. The position of observed points (blue dots) relative to the variable vectors indicated their scores on those variables. The variable vectors pointing toward a cluster of observations suggested that those variables were important in defining that group of observations. The biplot graph showed that ‘Knapsack sprayer’ and ‘Water pump’

were the two variables closest to the group of observations. This implied that both variables were important in defining the observed samples.

Discussion

Sociodemographic characteristics toward the significance of farm machinery

According to the study's findings, sample farmers were predominantly aging. Only 4.30% were under the age of 40. Thus, farm machinery becomes critical in raising farm productivity and maintaining production levels (Rijk, 1986, 1989; Thailand Development Research Institute, 2020). It also helps to cut production costs and the physical demands placed on farm workers. Furthermore, farm machinery and mechanization have the potential to make the agricultural sector economically appealing. This could reignite the enthusiasm of young people in pursuing an agricultural profession (Daum, 2023).

Adoption of farm machinery and interrelationship between adoptions

The findings in this study that the majority of rice farmers used the knapsack sprayer (62%) and the wheel plough (58%) were similarly observed among 280 rice farmers in a recent study of farm mechanization in the Philippines. According to Bautista *et al.* (2017), the majority of those 280 rice farmers owned and used the knapsack sprayer (60%) as well as the hand-tractor or wheel plough (50%). However, this current study observed much higher levels of farmer adoption of the water pump (75%) and the combine harvester (54%) compared to the adoption in the Philippines. In that study, the adoption was just 14% and 15% respectively.

The findings of the interrelationship between the adoptions of various types of farm machinery revealed significant positive and negative correlations. There were statistically significant positive correlations between the adoption of a knapsack sprayer and a combine harvester, a water pump and a lawnmower, and a combine harvester and a truck carrier. This finding suggested that adopting a knapsack sprayer can promote the adoption of a combine harvester and vice versa. Similarly, the adoption of a water pump and a lawnmower, as well as the adoption of a combine harvester and a truck carrier, showed complementary usage patterns. In contrast, the findings demonstrated statistically significant negative correlations between the adoption of a wheel plough and a tractor, as well as a wheel plough and a lawnmower. These findings suggested that the use of a wheel plough may be replaced by the use of a tractor and vice versa. Likewise, the use of a wheel plough for mowing may be replaced by the use of a

lawnmower and vice versa. As a result, this negative correlation can suggest a technology transition from old to new or from low- to high-efficiency farm machinery.

A number of existing studies analyzed the adoption of a specific farm machinery, such as a rotary cultivator (Zhou *et al.*, 2020), or the total number of farm machinery used, ranging from one to twelve (Ma *et al.*, 2018). However, these studies ignored or failed to consider potential interrelationships between farm machinery adoptions. To account for these interrelations, Quan and Doluschitz (2021) investigated the factors that influenced maize farmers' adoption of four categories of machinery, which included plowing, planting, harvesting, and pesticide spraying. They also looked at the interrelation between these adoptions. Nonetheless, their findings only revealed that the adoptions of these four types of machinery were complementary and that adopting one category of machinery could encourage the adoption of others. Hence, this study advances the existing understanding of the interrelation between the adoptions of various types of farm machinery, whether in the same or separate categories, by employing Spearman's correlation coefficients and a biplot analysis.

To this end, the current study makes the following policy recommendations that address the implications of the interrelationships between the adoptions of various types of farm machinery. Firstly, for a strong positive correlation, policy could focus on bundled support for these types of machinery, such as a 'package deal' purchase or adoption. Secondly, in the case of a strong negative correlation, policy could focus on an incentive for adopting new machinery or technology, as well as support for those who rely on older ones. Thirdly, with a weak or no correlation, policy could focus on potential but still underutilized complements between different types of farm machinery. This could include demonstration or training programs of farm machinery for farmers. This agricultural extension work, including demonstration or training programs, would particularly address the required communication, which can lead farmers to continued adoption or the discontinuance of farm machinery (Rogers, 2003, Kamondetdacha, 2025). Overall, these measures can bring about increased farm efficiency and productivity, as well as improved living conditions for farmers and their families.

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Conflicts of interest

The authors declare no conflict of interest.

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