Rice farmers' participation in the use of improved technology and its impact on productivity and income

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Abstract. Technology and innovation are essential for agricultural development, which makes the production process more efficient. This study aims to examine rice farmers' participation in the use of high-yielding varieties and agricultural tools and machinery (ATAM) and its impacts on productivity and income. This study used primary data from the 2022 National Farmer Panel (PATANAS) study of five rice-based sample villages. The data were analysed descriptively and using R/C ratio calculations. The results showed that price, taste, and productivity influenced farmers' participation in the use of new high-yielding varieties. Meanwhile, the use of ATAMs was influenced by the type of agroecosystem. The difference in the productivity of new high-yielding varieties compared to local varieties was 60.4%. The profitability (R/C) of new high-yielding varieties was higher than local varieties, 3.28 *vs*. 3.09, respectively. Using ATAM at harvest time can reduce yield loss by 4.1–5.4% and harvest time by 71%. The use of combine harvesters results in a higher R/C ratio than without using them, 2.77 vs. 2.49, respectively. The recommendations from the results of this study are to expand the use of new technology, conduct multi-location tests, carry out socialisation, and pay attention to the socio-economic conditions of the community.

1 Introduction

The agricultural sector still plays an essential role in the Indonesian economy, especially for people who live in rural areas. Due to changes in the strategic environment, the agricultural sector faces more severe challenges in providing food and livelihood for the community. Climate change and limited natural and human resources demand urge the agricultural sector to use effective and efficient agricultural technology in cultivation, harvest, and post-harvest. The conversion rate of agricultural land to non-agricultural land is relatively unavoidable, indicating that increasing production through agricultural intensification should be prioritised in improving the performance of the agricultural sector.

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Technology and innovation have an essential role in agricultural development. New high-yielding varieties and new ways of cultivation, especially in food-crop commodities, encouraged the emergence of the green revolution in agriculture. Adopting seeds of high-yielding varieties is likely an appropriate strategy for climate change adaptation [1]. Technology in agriculture produces more effective and efficient output and improves product quality.

In the agricultural intensification process, the indicator is the farmer's behaviour in technological adoption. Increasing agricultural productivity by adopting better technologies can spur industrialisation and promote sustainable livelihoods [2]. Adopting technology is very diverse, such as using agricultural inputs (seeds, fertilisers, pesticides), cultivation methods, agricultural tools and machinery, and others.

This paper focuses on farmers' adoption of high-yielding rice varieties and the use of agricultural tools and machinery to increase the productivity of rice crops. The increase in production can ultimately increase farmers' income. Several studies on paddy farmer participation/adoption of high-yielding rice varieties have been conducted, such as in Lampung [3], Bengkulu [4], and Central Sulawesi [5]. However, it is still rare for studies on adopting rice varieties to be done simultaneously across agroecosystems, as will be explored in this paper.

In general, this paper aims to look at the behaviour of farmers at the research site in applying agricultural technology, especially the use of high-yielding varieties and agricultural tools and machinery for rice plants in several ecosystems. In particular, the analysis aims to (i) explore the application of high-yielding rice varieties at the farmer level; (ii) scrutinise the utilisation rate of agricultural tools and machinery before and after harvest; (iii) compare production, farm income from farmers based on the varieties used; (iv) evaluate production, farm income based on the intensity of use of agricultural tools and machinery; and (v) formulate alternative policies to encourage the application of agricultural technology at the farmer level.

2 Methodology

The primary data source was the results of the PATANAS† 2022 study in nine rice-based sample village locations in various agroecosystems, as described in Table 1. The method used in this paper was descriptive analysis. This method does not intend to make generally applicable conclusions or generalisations [6]. It aims to transform raw data into more understandable and more concise information [7].

Table 1. Location and number of PATANAS respondents, 2022.

Agroecosystem	Province	District	Village	Number of respondents
Irrigated	Central Java	Cilacap	Padangsari	40
Irrigated	East Java	Lamongan	Sungegeneng	40
Rainfed	Central Java	Grobogan	Jambon	40
Rainfed	South Sulawesi	Bone	Tungke	40
Tidal	South Sumatra	Banyuasin	Telang Rejo	40
Tidal	South Sumatra	Banyuasin	Upang Karya	40
Swamp	South Kalimantan	Tanah Laut	Sumber Makmur	40
Total				280

† PATANAS stands for National Farmer Panel. It is one of the activities in ICASEPS in order to capture the dynamics of agricultural and rural development. This activity has been carried out since 1983.

The R/C ratio analysis was used to measure the profitability. Variables used were productivity and income. Information and primary data were enriched using relevant secondary data from the BPS-Statistics Indonesia and the Indonesian Ministry of Agriculture. Technology effectiveness was measured by comparing the productivity and income of two groups that intensively use agricultural technology (combine harvesters) and do not use combine harvesters.

3 Results and discussion

3.1 The use of rice varieties in agroecosystems

Agroecosystem conditions affect the level of adoption of technologies chosen by farmers. Technology choices will be significantly influenced by the family's resource potential, biophysical environment, and socio-economic environment. Technically viable varieties are not necessarily widely adopted because they may not be economically or socially feasible. A previous study showed that suitability, complexity, and observability affected the adoption rate of new high-yielding rice varieties [8].

Table 2 shows the proportion of rice varieties used by farmers in various agroecosystems. The most widely planted variety in irrigated and tidal rice agroecosystems is Inpari (the proportion of Inpari varieties ranges from 53% to 62%). Further, Inpari-42 dominates among the Inpari variety used in irrigated rice fields, while Inpari-32 dominates in tidal rice agroecosystems. In rainfed agroecosystems, the rice variety is still dominated by Ciherang, while local varieties dominate in *lebak* swamp agroecosystems.

Table 2. Rice varieties used according to agroecosystem and season in the sample location village, 2022 (%).

Varieties	Irrigation		Tidal		Rainfed			*Lebak* swamp
	Rainy season	Dry season-1	Rainy season	Dry season-1	Rainy season	Dry season-1	Dry season-2	Rainy season
Ciherang	3.57	1.85	11.11	11.32	36.17	66.67	50.00	-
Inpari	53.57	59.26	58.73	62.26	23.40	-	25.00	4.55
IR-64	10.71	11.11	-	-	6.38	-	-	-
Mekongga	1.79	-	-	-	2.13	-	-	-
Situbagendit	10.71	7.41	-	-	-	-	-	-
Local varieties	1.79	-	22.22	18.87	2.13	-	-	72.73
Other	16.07	20.37	7.94	7.55	29.79	33.33	25.00	22.73
Total	100.00	100.00	100.00	100.00	100.00	100.00	100.00	100.00

Valuable information was obtained from the diversity of rice varieties in the sample location. Firstly, the government's efforts to replace old high-yielding varieties with new ones have been quite successful, as evidenced in irrigated and tidal agroecosystems. The Inpari variety began to displace IR-64 and Ciherang or Situbagendit varieties that have previously been excellent for farmers. In rainfed and swamp agroecosystems, the Inpari variety is also found. However, it does not dominate, especially in places with sufficient water.

Secondly, The use of production is important for farmers when selecting varieties. In irrigated rice agroecosystems, which are the centres of rice production, farmers prioritise productivity, resistance to pests and diseases, and ease of selling. Farmers in irrigated rice fields widely choose Inpari-42 due to (i) its potential productivity can reach 10.58 tons/ha with an average of 7.11 tons/ha; (ii) its moderate resistance to brown leafhoppers, leaf blight, and blast; and (iii) fluffy rice texture. With these advantages, farmers believe planting Inpari-42 will increase production and make selling easier. In their study, Arianti et al. [9] concluded that using the Inpari-42 variety can increase rice productivity by up to 15–30%, which is higher than other varieties. Similarly, farmers highly demand the Inpari-32 variety due to its high productivity (average 8 tons/ha), and the taste is similar to Ciherang. In *lebak* swamp areas, where production is mostly to fulfil the needs of farmer households, the primary concern in choosing varieties is taste.

3.2 The level of participation in the use of agricultural tools and machinery

The role of agricultural tools and machinery in agricultural development is not only in the pre-harvest, harvest, and post-harvest processes but also includes efforts to downstream agricultural products. Agricultural tools and machinery's strategic role is to encourage faster processes, decrease labour costs, reduce yield losses, and increase the added value of the products. Appropriate agricultural tools and machinery will increase farmers' production, income, and welfare. However, the application of agricultural tools and machinery in the community must be careful, and technical specifications must be considered optimally. Thus, the use and placement of agricultural equipment and machinery technology must be appropriate for the location. The amount or ratio of agricultural tools and machinery should match the needs. Furthermore, farmers or operators of agricultural tools and machinery (human resources) and their management must be prepared to manage agricultural tools and machinery better, maintain it, and ensure it lasts longer.

The application of agricultural tools and machinery requires technological and management accuracy so that they can be developed and provide benefits as the goal of agricultural modernisation [10]. Otherwise, assisting with or providing agricultural tools and machinery potentially leads to a crowding-out effect on mechanisation businesses owned by individuals or private entities. Moreover, it increases farmers' dependence on government assistance. In many cases, the provision of agricultural tools and machinery by the government discourages individual or private agricultural tools and machinery service businesses that already exist in the community. New technology introduction in the farm requires four factors to be taken into account, namely (1) technically feasible, (2) economically profitable, (3) socially acceptable, and (4) regulatory that aligns with government regulations [11].

The discussion of the behaviour of applying rice agricultural tools and machinery is focused on land processing (tractor *vs*. non-tractor), harvesting (combine harvester *vs*. non-combine harvester), dryer (dryer *vs*. non-dryer), milling (static *vs*. mobile RMU) as shown in Table 3. The five groups of agricultural tools and machinery are essential because they provide an overview of production, agricultural human resource, and rice post-harvest performances in a region.

Table 3 shows that farmers' participation in using agricultural tools and machinery for pre-, harvest, and post-harvest is quite diverse and influenced by agroecosystems. It shows that the use of tractors is very high (more than 96%) in almost all agroecosystems (except swamp agroecosystems). In swamp agroecosystems, farmers' participation in using tractors is approximately 75%, and it is strongly influenced by the topographic conditions. With the dominance of *lebak* swampland, the operationalisation of tractors and other heavy equipment becomes inefficient. The high participation of farmers in the use of tractors, especially for land processing activities, is generally caused by farmers chasing time so that they can plant simultaneously and are considered more efficient than using agricultural labour. Farmers' participation in tractor use on irrigated land is lower than on tidal and rainfed land. This is because some farmers cultivate on narrow irrigated land, so they can still work manually without using a tractor. Meanwhile, in tidal and rainfed agroecosystems, it will be more efficiently done with tractors.

Table 3. The participation rate of the use of agricultural tools and machinery according to the agroecosystem, 2022 (%).

Agroecosystems	Tractor	Combine harvester	Dryer	RMU	
				Static RMU	Mobile RMU
Irrigation	96.40	47.75	0.00	98.20	1.80
Tidal	97.39	100.00	0.00	100.00	0.00
Rainfed	98.04	40.43	2.38	65.98	34.04
Lebak swamp	75.00	4.17	0.00	100.00	0.00
Total	95.35	63.30	0.39	93.94	6.06

There was a yield loss in each harvest and post-harvest activity due to inappropriate harvesting up to 20.51% [12]. The combine harvester technology applied is one of the breakthroughs in harvesting activities, mainly to reduce rice yield loss. Combine harvesters can harvest, thresh, and pack grain products in various activities. Before this innovation, farmers needed a lot of labour and waited for queues of harvest labourers, making it difficult to catch up with processing and planting schedules. As an illustration, the use of a combine harvester for 2 hours is equivalent to 6 farm workers working for 7 hours, so for a rice field of 1 ha, it only takes 1–2 hours. Another advantage of a combined harvester is that it can reduce yield losses, especially in threshing activities. When manual human labour is used for harvesting, yield loss can reach up to 16%. However, if a combine harvester is used, the yield loss reduces to only about 4.1–5.4%. Another benefit is the production of clean grain, not mixed with dirt that usually exists if harvested manually.

Among the four agroecosystems, the largest participation combine harvesters is in tidal agroecosystems. In such an agroecosystem, paddy cultivation is wide, and harvest time is relatively short. With these conditions, farmers are more efficient in terms of time and cost because they can carry out harvesting, threshing, and packaging activities several times. On irrigated and rainfed land, some land is considered inefficient in using combine harvesters because of the scattered topography of the land and the relatively narrow arable area of each farmer.

One of the post-harvest handling activities for rice is drying to reduce the grain moisture content. Thus, the risk of damage to materials due to enzyme and biological activities can be reduced so that the quality of products can be maintained during storage. In sample villages, rice dryers are only found in rainfed agroecosystems, with a usage rate of only 2.38%. Most farmers still dry rice manually with sunlight. This phenomenon is also influenced by the grain sales system practised by farmers. Rice is usually sold directly after harvest as wet unhusked grain (GKP), without any drying process, such as in the *tebasan* system.

The role of rice milling units, both static and mobile RMUs, is significant in rice milling technology. It means that in all agroecosystems, there is no manual rice milling. In rainfed agroecosystems, the use of mobile RMUs is quite high. The RMU mobile is more convenient for farmers than a static RMU due to the small volume to be milled, the dispersed location, and the gradual milling activity as needed.

3.3 The use of rice variety and their implications on the productivity and income

Increasing access to and utilisation of seeds of high-yielding varieties is essential for agricultural production. However, studies on food security and household security are more likely to focus on increasing crop productivity as a pathway from seeds to food availability, income, and food security [13]. The use of high-yielding varieties is one factor determining rice productivity. Another study found that new high-yielding rice varieties contribute significantly to national rice production, accounting to around 56% [14].

Table 4 shows the productivity, income, and profitability level of rice farming from various varieties grown in PATANAS village sites. It can be seen that the Inpari variety has the highest average productivity (6,437 kg/ha), followed by IR-64 (5,280 kg/ha) and Situbagendit (4,937 kg/ha). At the same time, the lowest productivity is achieved by local varieties (3,500 kg/ha). New high-yielding varieties have higher productivity than local varieties because they are cultivated more intensively.

Table 4. Productivity level, income, and R/C ratio in rice farming in irrigated rice agroecosystems by rice variety, 2022.

Varieties	Productivity (kg/ha)			Income (IDR 000/ha)			R/C ratio		
	RS	DS-1	Avg	RS	DS-1	Avg	RS	DS-1	Avg
Ciherang	5,024	4,728	4,925	18,252	17,014	17,840	3.14	3.57	3.28
Inpari	6,546	6,334	6,437	16,738	18,542	17,668	2.96	2.42	2.68
IR-64	5,123	5,438	5,280	15,481	16,826	16,153	3.02	1.80	2.41
Mekongga	4,019		4,019	10,108		10,108	2.69		2.69
Situbagendit	5,046	4,774	4,937	14,915	17,981	16,141	2.95	1.83	2.50
Local	3,500		3,500	12,906		12,906	3.09		3.09

Note: Avg (average), RS (rainy season), DS-1 (dry season-1)

The productivity of Inpari variety is higher than that of other varieties. It was also found that the productivity of the IR-64 variety outperformed that of other high-yielding varieties such as Ciherang, Mekongga, and Situbagendit. The growth and production of rice in irrigated agroecosystems can be influenced by various factors, including the treatment of the cultivation system, which has a significant effect [15]. The variety has a significant impact on rice growth, but it has no impact on production. The rice cultivation system produces higher productivity than the dry rice cultivation system, which reaches up to three times higher.

Plant performance will improve when environmental conditions meet their needs [16]. Low temperatures will affect the physiological processes of the plant. Low-temperature conditions in the highlands affect the life of plants, which become longer when compared to rice varieties in the lowlands. Even the alternating planting pattern (*jajar legowo*), which is considered to increase rice production yields, apparently also has specific conditions. The *jajar legowo* planting system only significantly reduces the number of saplings per clump. However, it did not significantly affect other yield components such as filling, the number of grains per panicle or weight per 1,000 grains [14]. Applying the *jajar legowo* planting system is more suitable when combined with varieties with many tillers but less suitable for a few types. Therefore, if the application is inappropriate, it cannot support the increase in results.

Farm profits obtained are not always linear with the level of productivity. Although Inpari variety has the highest productivity, income obtained by Ciherang variety is slightly greater (Table 4). It can happen because of differences in grain prices at harvest time and costs incurred in rice farming. Generally, the profit of rice farming in the dry season is greater than in the rainy season.

The profitability calculation shows that rice farming in irrigated fields is economically feasible, as indicated by an R/C value greater than 1. The highest profitability level was obtained by the Ciherang variety, with an average value of 3.28, followed by the local variety, which ranked second with a value of 3.09. Based on the growing season, the highest profitability was achieved by the Ciherang variety in the first dry season with a value of 3.57. In general, the profitability of new and local high-yielding varieties of rice farming is still profitable.

3.4 The use of agricultural tools and machinery and its implications on the productivity and income

The intensity of agricultural tools and machinery use is approached by the use of combine harvesters at the harvesting time. The use of combine harvester can be used as an indicator because this technology is considered the most advanced and has been widely applied in rice fields, especially for harvesting activities. Although many new technologies and innovations have been developed in agriculture, their adoption at the farmer level is still low. If a combine harvester is used in harvesting activities, the intensity of using agricultural tools and machinery in farming is considered intensive; otherwise, it is categorised as less intensive.

Based on agroecosystems and the intensity of use of agricultural tools and machinery, the highest productivity is obtained on irrigated land with an average of 6,999 kg/ha (intensive) and 4,835 kg/ha (less intensive) (Table 5). There is a considerable difference in productivity between villages that use combine harvesters and other harvesters. The results show that combine harvesters can reduce yield loss by 200.39 kg per ha or about 3.52% of the total yield [17]. The difference in productivity is not solely due to the use of more sophisticated harvesting equipment but also other factors such as land fertility, input use, and irrigation quality.

In terms of productivity, tidal land ranks second (4,789 kg/ha), followed by rainfed and swamp land, which yield 4,786 kg/ha and 4,482 kg/ha, respectively, in the rainy season. However, on average, the productivity of rainfed land is higher than tidal (4,352 kg/ha *vs*. 3,471 kg/ha). In tidal villages, crop failure occurred during the first dry season (MK-1) due to massive rat pest attacks, resulting in decreased productivity. Productivity in *lebak* swampland (local variety) is the lowest, yielding 2,560 kg/ha. In aggregate, across agroecosystems, productivity on fields with intensive use of agricultural tools and machinery is higher than on less intensive ones. It can also be seen in Table 3 that in tidal fields harvesting only uses combine harvesters.

It has implications for the benefits obtained and high productivity in irrigated rice fields. Farming on irrigated land provides an average profit of IDR 18,051,000 (intensive) and IDR 15,517,000 (less intensive). The average profit from rice farming is IDR 12,476,000/season (intensive) and IDR 11,877,000 (less). The relatively low level of productivity and profit cannot be separated from the influence of productivity and profit levels in tidal agroecosystems during the very low dry season. If rice farming in tidal agroecosystems is not calculated, the total productivity level will be 6,431 kg/ha, and the total income rate will be IDR 17,572 thousand/ha.

Meanwhile, regarding profitability (R/C ratio) per agroecosystem, data shows a difference between productivity and income. The profitability level in tidal agroecosystems ranked highest (4.27), followed by rainfed (4.25) and irrigation (2.77) for intensive harvesting systems. In aggregate, profitability in all agroecosystems was 3.83 (intensive) and 2.43 (less intensive).

Table 5. Rice productivity, income, and R/C ratio by the intensification level of agricultural tools and machinery use, 2022[1)].

Agroeco-systems	Season[2)]	Productivity (kg/ha)		Income (IDR 000/ha)		R/C ratio	
		Intensive	Less	Intensive	Less	Intensive	Less
Irrigation	Rainy season	7,194	4,642	17,533	13,813	2.97	2.89
	Dry season-1	6,812	5,041	18,551	17,342	2.58	2.06
	Average	6,999	4,835	18,051	15,517	2.77	2.49
Tidal	Rainy season	4,786		15,557		5.71	
	Dry season-1	1,877		3,826		2.51	
	Average	3,471		10,253		4.27	
Rainfed	Rainy season	4,482	4,322	10,637	9,978	4.33	2.70
	Dry season-1	3,865	2,400	10,967	6,298	3.93	2.91
	Average	4,352	4,237	10,707	9,620	4.25	2.63
Lebak swamp	Rainy season	2,560	2,155	6,297	5,455	2.35	2.04
	Dry season-1						
	Average	2,560	2,260	6,297	5,443	2.35	2.01

[1)]Intensity level of agricultural tools and machinery: intensive = using combine harvester; less = not using.
[2)]In the dry season-2, rice is only planted in rainfed agroecosystems, and there is no use of combine harvesters.

4 Conclusions and policy recommendations

High farmer participation in the adoption of new high-yielding varieties in sample villages in irrigated and tidal rice agroecosystems has replaced the dominance of old high-yielding varieties. The government's efforts to introduce many new high-yielding varieties in other agroecosystems have also been successful. However, farmers' participation in adopting a variety is not only determined by productivity but also by other factors such as price, taste, and the purpose of the output produced.

Farmer participation in harvesting and post-harvest agricultural tools and machinery is quite diverse and influenced by the type of agroecosystem. Tractors are used extensively in almost all agroecosystems. Combine harvesters have become widely used by farmers. These machines have the advantages of being faster, cleaner, and cheaper. Combine harvesters are most widely used in tidal rice field agroecosystems.

Using agricultural tools and machinery (technology-intensive) in the case of combine harvesters positively affects rice productivity in all agroecosystems. An increase in rice production has a positive impact on profitability and improves farmers' income levels.

Farmers responded positively to new varieties, agricultural tools and machinery technologies. This can be a good lesson learned for creating technology that provides economic benefits and is socially acceptable to farmers. The resulting technology needs to be carefully tested before release so that farmers feel the benefits of the technology introduced.

Modernisation of agriculture has become a necessity in the future so that agricultural businesses can be effective and efficient. However, to a certain extent and under certain conditions, attention must also be paid to the socio-economic conditions of the community. All stakeholders related to technology dissemination must understand the socio-economic dynamics that occur in society.

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