

# Determinants of Climate-Smart Agriculture Adoption among Smallholder Dairy Farmers in Indonesia: Evidence from Malang Regency, East Java

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**Abstract.** Climate-Smart Agriculture (CSA) has emerged as a key strategy for enhancing climate resilience, productivity, and sustainability in livestock systems. However, empirical evidence on CSA adoption in Indonesia's dairy sector remains limited. This study investigates the adoption rate and determinants of CSA practices among smallholder dairy farmers in Ngantang and Pujon Districts, Malang Regency, East Java. A quantitative survey was conducted with 200 dairy farmers selected through purposive sampling between December 2024 and March 2025. Six CSA practices were examined: pasture nutrient management, agroforestry, improved waste management, enhanced feed conversion efficiency, livestock vaccination, and integrated crop–livestock systems. A multivariate probit model was applied to account for the simultaneous adoption of multiple practices and potential interdependencies among adoption decisions. The results reveal relatively high adoption rates across all CSA practices, exceeding 50% for each practice, with pasture nutrient management and feed conversion improvement showing the highest uptake. Access to extension services, membership in livestock farmer groups, access to credit, herd size, farming experience, education level, and access to CSA-related information significantly influence CSA adoption, though effects vary by practice. Herd size and credit access strongly promote improved waste management, while farming experience positively affects livestock vaccination but negatively influences agroforestry adoption. Older age reduces the likelihood of adopting improved feed conversion practices. In contrast, gender and household size do not significantly affect CSA adoption. The findings underscore the critical role of extension services, financial inclusion, and collective action in accelerating CSA adoption among smallholder dairy farmers. Strengthening institutional support, enhancing targeted extension programs, and improving access to credit can facilitate climate-resilient transformation in Indonesia's dairy sector and contribute to achieving Sustainable Development Goal 13 on climate action.

**Keywords:** Climate-Smart Agriculture, dairy farming, technology adoption, multivariate probit, smallholder farmers

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## 1 Introduction

A growing body of research has shown that Climate-Smart Agriculture (CSA) has a positive impact on climate change mitigation and adaptation. In African countries, CSA encompasses a range of practices, including sustainable agricultural management, restoration of degraded land, regenerative forestry and agricultural land practices, livestock sub-sector interventions, efficient water and energy resource management, and the use of weather and climate information services (Ariom *et al.*, 2022). CSA reduces the negative impacts of climate variability on agricultural production, enabling farmers to maintain productivity and strengthen food system resilience. Evidence from Southern Malawi shows that CSA also improves resource-use efficiency through more intensive and sustainable farming systems (Mnukwa *et al.*, 2025). In Ghana, farmers adopt CSA practices, such as improved crop management, new crop varieties, and climate change training to protect their livelihoods from climate-related risks. Beyond crop production, CSA plays an important role in the livestock sector, including dairy farming. In Tanzania, improved livestock management and the adoption of higher-yielding dairy cattle have increased household income, enhanced food security, and reduced greenhouse gas emissions (Shikuku *et al.*, 2017). Previous studies highlight the importance of technology implementation, farmers' perceptions, and decision-making processes in the adoption of agricultural innovations. Despite increasing efforts to promote Climate-Smart Agriculture (CSA), adoption remains limited in many countries due to socioeconomic and institutional constraints. Improving CSA adoption therefore remains a key challenge for policymakers and practitioners. The adoption of CSA innovations is shaped by individual, social, and organizational factors, with individual characteristics often playing a dominant role, alongside attributes of the innovations themselves (Mahama *et al.*, 2025).

Several breeder characteristics have been identified as important determinants of technology adoption, including age, education level, years of livestock-rearing experience, information-seeking activities, participation in livestock groups, and herd size in dairy farming systems. In this study, CSA adoption is examined across six practices: pasture nutrient management, agroforestry, improved waste management, enhanced feed conversion efficiency, livestock vaccination, and integrated crop–livestock systems. Pasture management practices focus on planting forage varieties that are resilient to extreme environmental conditions and reducing the use of chemical inputs during cultivation, thereby improving environmental sustainability and livestock productivity. Agroforestry adoption involves the planting of woody species, which in the study area has been implemented in Tulungrejo and Sumberagung villages through the cultivation of durian trees. Waste management practices, including the use of cattle manure for biogas and organic fertilizer, have been widely adopted and contribute to farm efficiency by reducing energy costs and supplying nutrients for forage production. Feed conversion efficiency is improved through appropriate feeding schedules and nutritionally balanced rations, which enhance feed digestibility and animal performance, resulting in higher milk yield or live weight gain (Sapkota *et al.*, 2021).

Livestock vaccination aims to protect animals from infectious diseases. During outbreaks of foot-and-mouth disease (FMD), livestock farmers in both sub-districts proactively vaccinated their animals to prevent disease transmission. Climate change further exacerbates livestock disease risks by expanding the geographical range of arthropod vectors and increasing the frequency of extreme climatic events, thereby necessitating effective mitigation and adaptation measures to reduce climate-related disease impacts on livestock. Integrated crop–livestock farming practices are also implemented by farmers in both sub-districts, particularly through the use of cattle manure as organic fertilizer. However, this practice faces challenges during the rainy season, when manure cannot be properly dried or fermented. Despite these constraints, crop–livestock integration has been shown to

sustainably increase agricultural productivity and farm income, as crop residues such as straw, bran, and plant waste are recycled into livestock feed, while cattle manure is converted into fertilizer for crop production.

Research on the adoption of Climate-Smart Agriculture (CSA) technologies in Indonesia's dairy farming sector remains very limited. Existing studies, however, suggest that CSA adoption is shaped by a range of socioeconomic and institutional factors, including farmers' age, formal education, years of farming experience, access to CSA-related information, type of occupation, household size, herd size, membership in livestock groups, access to extension services, and access to credit. Empirical evidence indicates that age can influence technology adoption, as older individuals often show lower propensity to adopt new technologies. Education is also a key determinant, with higher educational attainment significantly increasing farmers' likelihood of adopting agricultural technologies (Nyakudya *et al.*, 2024). Farming experience matters as well: farmers with more than five years of experience tend to adopt a wider range of dairy-farm technologies than those with less experience. In addition, information-seeking behaviour plays an important role, as technology adoption typically begins with active processes of information acquisition. Herd size is positively associated with adoption intensity, particularly in pasture-based dairy systems where larger herds are more likely to adopt precision and improved management practices (Selvaggi *et al.*, 2024). Finally, participation in farmer groups and agricultural associations is consistently linked to higher technology adoption in developing countries, as these organisations facilitate learning, information exchange, and collective access to support services.

This study contributes to the literature in several important ways. First, it expands existing research on climate change-related extension and advisory services for livestock farmers in developing countries. Second, it enhances understanding of livestock farmers' decision-making processes in adopting technologies to cope with climate change. Third, it provides empirical evidence on the impacts of Climate-Smart Agriculture (CSA) in the livestock sector. In addition, the study offers new insights into the factors influencing the adoption of CSA innovations in Indonesia, particularly in East Java. The findings also support the achievement of the Sustainable Development Goals (SDGs), especially SDG 13 (Climate Action), by informing strategies that promote timely and effective responses to climate change and its impacts.

## **2 Materials and methods**

### **2.1 Research location**

This study was conducted in dairy farming areas located in the Pujon and Ngantang Districts of Malang Regency, East Java, Indonesia. Specifically, the research sites included Sumberagung and Tulungrejo villages in Ngantang Sub-district, and Ngabab Village in Pujon Sub-district. The study was carried out between December 2024 - March 2025.

### **2.2 Research methods**

The study employed a descriptive quantitative survey design. A total of 200 respondents were included to ensure sufficient statistical power and facilitate robust data analysis. A larger sample size was used to enhance the reliability and validity of the findings. Respondents were selected using a purposive sampling method. The selection criteria included dairy farmers who had been operating a dairy farming business for at least one year and resided in the two study locations. Data were collected through a structured questionnaire. The questionnaire

captured socio-demographic and farm characteristics, including age, gender, formal education, household size, herd size, years of livestock farming experience, access to CSA-related information, type of occupation, membership in livestock farmer groups, access to extension services, and access to credit. In addition, information was collected on the adoption of six Climate-Smart Agriculture (CSA) practices: pasture nutrient management, agroforestry, improved waste management, enhanced feed conversion efficiency, livestock vaccination, and integrated crop–livestock systems.

### 2.3 Data analysis

The data were analyzed using a multivariate probit model, with the assistance of Microsoft Excel and Stata version 17. This model was employed because farmers may adopt multiple Climate-Smart Agriculture (CSA) practices simultaneously, and the adoption decisions for different practices are likely to be interrelated. The multivariate probit framework allows for the joint estimation of multiple binary adoption decisions while accounting for potential correlations among the error terms across equations. By capturing these interdependencies, the model provides more efficient and unbiased estimates compared to separate univariate probit models. This approach is therefore appropriate for analyzing the determinants of CSA adoption across multiple practices within dairy farming systems

## 3 Results and discussion

### 3.1 Socio-Demographic characteristics in Pujon and Ngantang districts

Table 1 show that the farmers aged 36–50 years constitute the largest age group among respondents compared to other age categories. This pattern reflects the hereditary nature of dairy farming, where farm operations are commonly passed down within families. In many cases, farmers continue managing dairy farms until they experience declining physical capacity, after which responsibilities are gradually transferred to their children. As farmers age, their ability to access and process new information tends to decrease. Advancing age is also associated with a decline in physical strength, which can reduce farmers’ capacity to perform demanding farm activities and adapt to new practices.

**Table 1.** Age of Farmers.

Age ( Year )	Frequency (People)	Presentation (%)
20-35	14	7
36-50	103	51.50
51-65	81	40.50
>66	2	1
<b>Amount</b>	<b>200</b>	<b>100</b>

Furthermore, It is observed that dairy farming in Malang Regency is predominantly managed by men. Of the 200 respondents, 178 farmers (89%) were male, indicating that dairy farming in the region is largely male-dominated. This pattern may be attributed to men having greater access to production resources and institutional support, including information, training, and external assistance, which can facilitate the operation and development of dairy farming enterprises compared to women.

**Table 2.** Gender of the Farmers

Gender (Dummy)	Frequency (people)	Presentation (%)
Man	178	89
Woman	22	11
<b>Amount</b>	<b>200</b>	<b>100%</b>

Table 2 shows that the majority of farmers involved in dairy farming are men. Out of a total of 200 respondents, 178 farmers (89%) are male, while only 22 farmers (11%) are female. This distribution indicates that dairy farming in the study area is predominantly male-dominated, suggesting that men play a more significant role in farm management and decision-making. The low participation of women may be influenced by socio-cultural factors, division of labor, and limited access to resources and institutional support for female farmers.

**Table 3.** Formal Education

Formal Education ( years )	Frequency (people)	Presentation (%)
No school	6	3
Elementary school/ equivalent	91	45.5
Junior high school / equivalent	22	11
High School/Vocational School	79	39.5
Diploma-Bachelor	2	1
<b>Amount</b>	<b>200</b>	<b>100%</b>

Moreover, table 3 demonstrated that 45.5% or 91 breeders own level education last taken is an elementary school. In addition, there are 79 livestock breeders or 39.5% and 22 breeders or 11% of farmers who experience education last in high school and junior high school. The data show that level education breeders cow dairy in the Pujon and Ngantang District Still low . Breeders with level education more tall more Possible adopt technology feed improved livestock. Education helps breeders understand information and benefits from technology new, and increase participation they in training and access to service extension.

**Table 4.** Number of Household Members

Amount House ladder (person)	Frequency (people)	Presentation (%)
1-5 people	199	99.5
>5 people	1	0.5
<b>Amount</b>	<b>200</b>	<b>100</b>

A total of 99.5% (199 out of 200 respondents) reported having one to five household members, indicating that dairy farming households in the Pujon and Ngantang Districts are relatively small in size. Household size is an important factor influencing the availability of family labor, which plays a significant role in the adoption of agricultural and livestock management practices.

**Table 5.** Number of Household Members

<b>Amount Cattle ( tail )</b>	<b>Frequency (people)</b>	<b>Presentation(%)</b>
1-5 tails	95	47.5
6-10 tails	70	35
>10 tails	35	17.5
<b>Amount</b>	<b>200</b>	<b>100</b>

Most respondents were farmers owning 1–5 dairy cattle, totaling 95 farmers, followed by those with 6–10 cattle (medium scale), totaling 70 farmers. Only 35 farmers owned more than 10 cattle, representing large-scale operations. These findings indicate that dairy farming in Malang Regency is predominantly characterized by small- and medium-scale enterprises. Herd size significantly influences the adoption of livestock technologies. Small-scale farmers often face constraints in investing in technologies such as concentrate feed, pasture improvement, and housing facilities due to limited income and resource availability. In addition, herd size may also be affected by disease outbreaks, particularly foot-and-mouth disease (FMD), which has occurred in Malang Regency and negatively impacted cattle ownership levels.

**Table 6.** Experience in Livestock Farming

<b>Experience livestock ( year )</b>	<b>Frequency (people)</b>	<b>Presentation (%)</b>
0-5 years	2	1
6-10 years	4	2
>10 years	194	97
<b>Amount</b>	<b>200</b>	<b>100</b>

The majority of respondents have been engaged in livestock farming for more than ten years. Specifically, 97% (194 respondents) reported over ten years of farming experience, while only 4 respondents (2%) had 6–10 years of experience. The remaining 2 respondents had less than six years of farming experience. These results indicate that most respondents have long been involved in dairy farming activities. Longer farming experience is generally associated with higher levels of knowledge and skills in livestock management. In the Pujon and Ngantang Districts of Malang Regency, dairy farming is commonly practiced as a hereditary livelihood, passed down from one generation to the next.

**Table 7.** Acces To CSA Information

<b>Information (Dummy)</b>	<b>Frequency (people)</b>	<b>Percentage (%)</b>
Yes	93	46.5
No	107	53.5
<b>Amount</b>	<b>200</b>	<b>100</b>

Table 7 shows that out of 200 respondents, 93 farmers (46.5%) reported being aware of Climate-Smart Agriculture (CSA), while 107 farmers (53.5%) indicated that they were not aware of CSA. This finding suggests that access to CSA-related information remains relatively limited among dairy farmers in the study area. Limited access to information may be partly attributed to the relatively advanced age of many farmers, which can reduce their ability to absorb new information and consequently hinder the adoption of innovative CSA practices.

**Table 8.** Type Of Occupation

Type of Occupation (Dummy)	Frequency (people)	Presentation (%)
Main	137	68.5
Side job	63	31.5
<b>Amount</b>	<b>200</b>	<b>100</b>

Table 8 shows that of the 200 respondents interviewed, 137 farmers (68.5%) identified dairy farming as their primary occupation, while the remaining 63 farmers (31.5%) reported dairy farming as a secondary occupation. This indicates that dairy farming is the main livelihood for most households in the Pujon and Ngantang Districts. Favorable climatic conditions and the availability of forage resources make dairy farming a viable primary occupation in the area. Farmers who consider dairy farming as their main occupation also tend to have greater access to agricultural resources and are more likely to adopt dairy farming technologies compared to those for whom dairy farming is a secondary activity.

**Table 9.** Membership In Livestock Groups

Participation (Dummy)	Frequency (people)	Presentation (%)
Yes	170	85
No	30	15
<b>Amount</b>	<b>200</b>	<b>100</b>

Moreover, Table 9 shows that out of the 200 respondents interviewed, 170 farmers (85%) were members of a livestock farmer group, while 30 farmers (15%) were not. For most farmers in the Pujon and Ngantang Districts, participation in livestock groups facilitates the innovation adoption process by providing regular opportunities for knowledge sharing and information exchange related to farming challenges. Previous studies support this finding, showing that membership in farmer groups positively influences farmers' willingness to adopt innovations. For example, farmer group membership significantly increases the adoption of local feed innovations, as group members are more likely to receive training and institutional support that encourage technology uptake.

**Table 10.** Access to Extension Services

Access to Counseling (Dummy)	Frequency (people)	Percentage (%)
Yes	180	90
No	20	10
<b>Amount</b>	<b>200</b>	<b>100</b>

Then, table 10 shows that of the 200 respondents interviewed, 180 farmers (90%) had access to extension services, while 20 farmers (10%) did not. The lack of access among some farmers was mainly due to the absence of regular contact with extension officers and reluctance to attend extension meetings when they were conducted. Overall, these findings indicate that the majority of dairy farmers in the Pujon and Ngantang Districts have access to extension services.

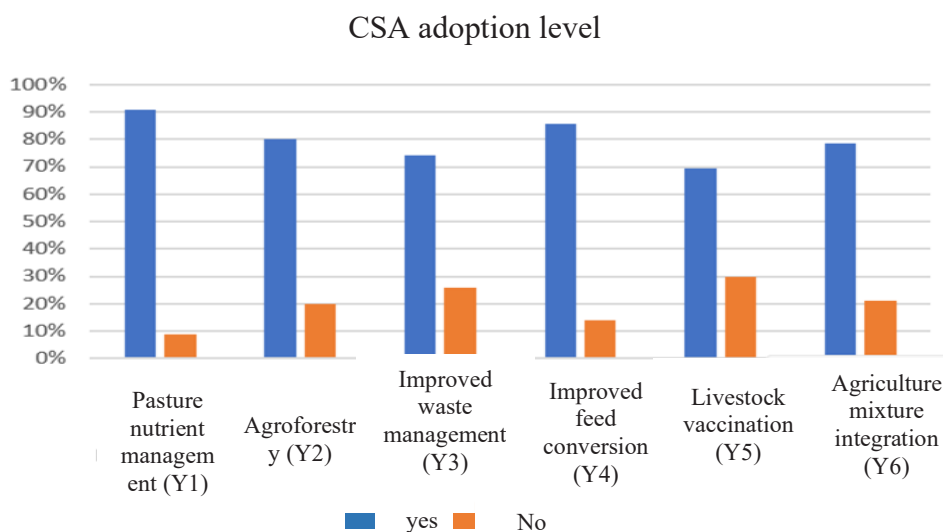
**Table 11.** Access To Credit

Credit Access (Dummy)	Frequency (people)	Percentation (%)
Yes	162	81
No	38	19
<b>Amount</b>	<b>200</b>	<b>100</b>

The final results on access to credit are presented in Table 11. Most dairy farmers in the Pujon and Ngantang Districts had access to credit, accounting for 81% (162 farmers) of the respondents. The majority of these farmers obtained credit through savings and loan cooperatives, including village unit cooperatives, sub-district cooperatives, and privately owned cooperatives. In contrast, 19% (38 farmers) did not have access to credit, primarily due to weak financial conditions and concerns about repaying existing debt. Access to credit plays a crucial role in facilitating the adoption of technological innovations, including livestock-related technologies. Farmers with access to credit are 1.23 times more likely to adopt new technologies compared to those without credit access, as credit helps overcome financial constraints associated with technology adoption.

### 3.2 Adoption rate of Climate-Smart Agriculture (CSA) innovations among livestock farmers

Figure 1 presents the adoption rates of six Climate-Smart Agriculture (CSA) practices among dairy farmers. Pasture nutrient management was adopted by 90% of respondents, followed by agroforestry (80%), integrated crop–livestock systems (79%), improved waste management (74%), enhanced feed conversion efficiency (86%), and livestock vaccination (70%). Farmers’ awareness of climate change and their understanding of the benefits of CSA practices play a critical role in shaping adoption decisions.



**Fig. 1.** CSA Adotlion Level by Farmers

**Table 12.** Multivariate Probit Test Using STATA.17

Variables	Forage Feed Management		Agroforestry		Waste Management Improvement		Feed Conversion Improvement		Giving vaccine cattle		Agriculture mixture integration crops and livestock	
	Coefficient	P> z	Coefficient	P> z	Coefficient	P> z	Coefficient	P> z	Coefficient	P> z	Coefficient	P> z
Farmer age	-0.007	0.969	0.024	0.150	-0.009	0.575	-0.039	<b>0.015*</b>	0.009	0.513	-0.022	0.128
Gender	-0.084	0.866	0.376	0.303	-0.542	0.239	-0.019	0.960	-0.071	0.842	-0.847	0.075
Formal education	0.022	0.599	0.070	0.071	0.071	0.089	0.042	0.271	0.009	0.778	0.071	<b>0.037*</b>
Amount house ladder	-0.059	0.696	-0.193	0.140	0.094	0.536	-0.033	0.800	0.013	0.913	-0.049	0.696
Amount dairy cows	-0.037	0.103	-0.005	0.797	0.239	<b>0.000**</b>	0.011	0.628	0.053	<b>0.018*</b>	0.039	0.215
Experience raising livestock	0.019	0.373	-0.033	<b>0.049*</b>	-0.001	0.935	0.017	0.310	0.047	<b>0.004**</b>	0.040	<b>0.012*</b>
Access to information about CSA	0.382	0.230	0.421	0.093	0.588	<b>0.041*</b>	0.407	0.090	0.645	<b>0.004**</b>	-0.352	0.125
Type of work	0.305	0.282	-0.353	0.177	0.211	0.456	0.505	<b>0.039*</b>	0.419	0.066	0.466	<b>0.041*</b>
Membership in a farmer group	-0.052	0.884	0.838	<b>0.004**</b>	-0.901	0.054	0.674	<b>0.023*</b>	-0.776	0.109	-0.182	0.558
Access to service counselling	0.811	<b>0.036*</b>	1.749	<b>0.000**</b>	0.337	0.419	-1.287	<b>0.024*</b>	0.746	<b>0.040*</b>	0.060	0.871
Access to credit	-0.148	0.723	0.201	0.504	2,307	<b>0.000**</b>	0.109	0.733	-0.518	0.083	0.321	0.253
Constant	4.243	0.705	-1.831	0.058	-2.240	0.043	2.490	0.025	-1.847	0.036	0.645	0.499
Log Likelihood												-429.91696
Number of obs						200						
Wald chi <sup>2</sup> (66)						210.04						
Prob > chi <sup>2</sup>						0.0000						
Likelihood ratio test						34.6161						

Source : Processed Primary Data , 2025; Description : \*\*\* show significant at the 5% and 1% levels.

Table 12 shows that age has a negative and statistically significant effect on the adoption of CSA innovations, particularly on improved feed conversion ( $p = 0.015 < 0.05$ ). This finding indicates that as farmers' age increases, their likelihood of adopting improved feed conversion practices decreases. Older farmers in both sub-districts tend to rely on existing feeding practices and are less willing to replace them with more efficient feed conversion methods. In addition, older farmers are often beyond their most productive working age, which may further limit their willingness to adopt new technologies.

Furthermore, gender does not significantly determine the adoption of CSA innovation practices among dairy farmers in the Pujon and Ngantang Districts of Malang Regency. This result may be explained by the large imbalance in the number of male and female farmers, as well as the relatively similar access to CSA-related practices among both groups in the study area. This finding is consistent with Purwanti et al. (2025), who reported that several econometric studies conclude gender is not a significant determinant of technology adoption, even though differences in access to resources and institutions may still influence adoption decisions between men and women. In contrast, formal education has a positive and statistically significant effect on the adoption of CSA innovations, particularly integrated crop–livestock systems (0.037). This indicates that higher levels of education increase the likelihood of adopting integrated farming practices. Farmers with higher educational attainment are more inclined to recycle dairy cattle manure into organic fertilizer for forage production. Similar findings were reported by Purwanti et al. (2023), who showed that farmers' education positively influences allocative efficiency in integrated crop–livestock systems. Better-educated farmers tend to allocate resources more efficiently, thereby reducing economic inefficiencies in mixed farming production systems.

Next, the other results presented in the table indicate that household size does not have a statistically significant effect on any of the six CSA innovation adoption practices. This suggests that the number of household members does not determine the adoption of adaptation strategies among dairy farmers in the Pujon and Ngantang Districts of Malang Regency. This may be attributed to the limited variation in household size, as most households consist of fewer than five members. In addition, adoption decisions related to CSA practices are typically made by the household head, and dairy farming activities generally require only one main labor input to manage daily operations. Similar findings were reported by Shibata et al. (2020), who observed that innovation-related decision-making is often dominated by men, with 69.7% making decisions independently, compared to 50.7% among married women, reflecting gendered decision-making dynamics within households. In contrast, herd size has a positive and highly significant effect on the adoption of improved waste management practices (0.000) at the 1% significance level. This result indicates that farmers with larger herds are more likely to adopt improved waste management practices. Dairy farmers in the Pujon and Ngantang Districts with larger herd sizes tend to have greater environmental awareness and stronger incentives to utilize livestock waste as organic fertilizer or biogas.

On the other hand, herd size has a positive and statistically significant effect on the adoption of livestock vaccination practices (0.018). This finding indicates that farmers owning a larger number of cattle are more likely to vaccinate their livestock. Herd size significantly influences farmers' vaccination decisions, as those with larger herds tend to be more proactive in protecting their investments through preventive health measures. In both sub-districts, farmers with larger herds demonstrate greater awareness of the importance of animal health, particularly following the foot-and-mouth disease (FMD) outbreak in 2020, which caused substantial livestock losses and increased farmers' incentives to adopt vaccination practices. Moreover, livestock farming experience has a negative and statistically significant effect on the adoption of agroforestry practices (0.049). This suggests that

farmers with longer experience are less likely to adopt agroforestry. In the Pujon and Ngantang Districts, agroforestry commonly involves the planting of woody species, particularly fruit trees such as durian, which are often established during the early stages of farm operation and then inherited by subsequent generations. As many experienced farmers already have long-established trees on their land, the marginal incentive to adopt additional agroforestry practices is reduced.

In contrast, farming experience has a positive and statistically significant effect on the adoption of livestock vaccination practices (0.004). This result highlights the role of experience in promoting preventive animal health management. Consistent with Ugochukwu and Phillips (2019), evidence from dairy and beef cattle farmers in Canada shows that prior experience with vaccination strongly shapes farmers' attitudes toward vaccine use. Farmers with longer involvement in the livestock sector tend to better understand the importance of vaccination for disease prevention and compliance with industry quality standards. Experiences of livestock losses due to FMD outbreaks have further reinforced preventive behavior, leading farmers to increasingly adopt vaccination as a risk-mitigation strategy.

Then, livestock farming experience has a negative and statistically significant effect on the adoption of agroforestry practices (0.049). This finding indicates that farmers with longer experience in dairy farming are less likely to adopt agroforestry practices. In the Pujon and Ngantang Districts, agroforestry typically involves the planting of woody species, particularly fruit trees such as durian, which are often established at the early stages of farm operation and subsequently inherited by the next generation. As a result, experienced farmers who already have long-established trees on their land face lower incentives to adopt additional agroforestry practices. In contrast, livestock farming experience has a positive and statistically significant effect on the adoption of livestock vaccination practices (0.004). This result highlights the importance of experience in promoting preventive animal health management. Farmers with longer experience in livestock farming are more likely to recognize the importance of vaccination for disease prevention and compliance with industry quality standards. Consistent with Ugochukwu and Phillips (2019), evidence from dairy and beef cattle farmers in Canada shows that prior experience with vaccination strongly shapes farmers' attitudes toward vaccine adoption. Moreover, experiences of livestock losses during foot-and-mouth disease (FMD) outbreaks have reinforced preventive behavior, encouraging farmers to vaccinate their animals to reduce future risks.

Access to Climate-Smart Agriculture (CSA) information has a positive and statistically significant effect on the adoption of improved waste management practices (0.041). This finding indicates that greater access to CSA-related information increases the likelihood of adopting improved waste management practices. In the Pujon and Ngantang Districts, the most commonly adopted practices include the production of organic fertilizer from livestock manure and the use of biogas systems. Information support related to biogas technology and manure-based fertilizer production has been particularly helpful in enabling farmers in both sub-districts to construct and operate biodigesters. Similar results were reported by Ayal and Mamo (2024), who found that composting (85.41%) and manure management (70.39%) were the most widely adopted practices, while biogas production was less common (3.86%). A similar pattern is observed for livestock vaccination practices, where access to CSA information has a positive and statistically significant effect (0.004). This suggests that improved access to information encourages farmers to vaccinate their livestock. In both sub-districts, information is commonly disseminated through announcements regarding vaccination schedules. Vaccination directly reduces livestock mortality and disease risk, and access to CSA-related information helps farmers identify potential livestock diseases and adopt appropriate preventive measures.

Further, type of occupation has a positive and statistically significant effect on the adoption of improved feed conversion practices (0.039). This finding indicates that dairy

farming as a primary occupation increases the likelihood of adopting improved feed conversion practices. As the majority of farmers in both sub-districts consider dairy farming their main livelihood, they tend to focus more on feed efficiency to enhance productivity and profitability. Farmers whose primary occupation is dairy farming are more likely to adopt climate-smart livestock production practices, including improved feed conversion through better feed management and livestock performance optimization. A similar pattern is observed for the adoption of integrated crop–livestock systems, where type of occupation has a positive and statistically significant effect (0.041). This result suggests that farmers whose primary occupation is farming are more inclined to adopt integrated crop–livestock practices. Such farmers are more likely to cultivate legumes around forage areas, enhancing nutrient cycling and system efficiency.

Membership in livestock farmer groups also has a positive and statistically significant effect on the adoption of agroforestry practices at the 1% significance level (0.004). This indicates that farmers who are members of livestock groups are more likely to adopt agroforestry practices. In both sub-districts, agroforestry adoption is often implemented collectively, as many livestock groups are also affiliated with forestry or fruit tree producer groups, particularly for timber and durian cultivation. Similar finding showed that membership in farmer groups or local organizations significantly increases agroforestry adoption. Then, group membership facilitates knowledge sharing, peer learning, and access to training and resources that support agroforestry implementation.

The results presented in Table 12 also indicate that membership in a livestock farmer group has a positive and statistically significant effect on the adoption of improved feed conversion practices (0.023). This finding suggests that farmers who are members of livestock groups are more likely to adopt improved feed conversion practices. Access to information disseminated through livestock groups in both sub-districts facilitates the rapid spread and application of feed conversion improvements among farmers. Consistent with this result, Purwanti *et al.* (2023) reported that the adoption of improved cattle management practices, such as the use of concentrate feed, is more common among farmers with access to information and training. Although their study did not explicitly examine group membership, access to information is often facilitated through farmer groups or livestock associations.

Access to extension services also has a positive and statistically significant effect on the adoption of pasture nutrient management practices at the 5% significance level (0.036). This result indicates that better access to extension services increases the likelihood that farmers will adopt pasture nutrient management practices. Farmers in both sub-districts who have access to extension services benefit from knowledge sharing and skill development, which positively influence technology adoption. Group-based, consistent, and practical training approaches are particularly effective in promoting the adoption of recommended pasture management practices.

Further show that access to extension services has a positive and statistically significant effect on the adoption of agroforestry practices (0.000). This finding indicates that farmers with access to extension services are more likely to adopt agroforestry practices. Extension services enhance farmers' knowledge of the importance and benefits of agroforestry. In the Ngantang Sub-district, particularly in Tulungrejo Village, many livestock farmers were previously engaged in forestry and plantation farming before transitioning into dairy farming, which may further facilitate agroforestry adoption. However, previous research by Hounkpati *et al.* (2024) reported that approximately 54.5% of respondents had no contact with extension services, reflecting a low extension agent–to–farmer ratio. Nevertheless, small-group, consistent, and practice-oriented training approaches have been shown to improve the implementation of recommended land and forage management practices.

In contrast, the adoption of improved feed conversion practices is negatively and significantly affected by access to extension services at the 5% level (0.024). This result suggests that farmers with access to extension services are less likely to adopt improved feed conversion practices, possibly because many farmers particularly older ones continue to rely on traditional feeding methods and are reluctant to change established practices. In both sub-districts, feed management and feed conversion practices are not solely managed independently by farmers but are also influenced by local cooperatives and partnerships with private companies, such as Nestlé. These institutional arrangements may limit the effectiveness of extension services in promoting improved feed conversion practices. In contrast, Tedeschi *et al.* (2024) found that effective extension services can enhance farmers' understanding of efficient feeding practices, which in turn improves feed conversion ratios (FCR), highlighting the importance of extension quality and contextual relevance.

A similar pattern is observed for the adoption of livestock vaccination practices, where access to extension services has a positive and statistically significant effect (0.040). This finding indicates that greater access to extension services increases the likelihood of livestock vaccination adoption. Recent extension activities in both sub-districts of Malang Regency have focused on foot-and-mouth disease (FMD) prevention and vaccination programs to reduce disease transmission. Effective extension services help farmers understand the benefits of vaccination and address implementation barriers. Limited information and inadequate access to extension services have been identified as major constraints to livestock vaccination adoption (Williams *et al.*, 2022). Access to credit also has a positive and highly significant effect on the adoption of improved waste management practices at the 1% significance level (0.000). This result suggests that farmers with access to credit are more likely to adopt improved waste management practices. In the Pujon and Ngantang Districts, access to credit supports investments in biogas and biodigester systems. Since the construction of biogas units requires substantial upfront capital, credit availability plays a critical role in enabling farmers to convert livestock waste into biogas. Consistent with this finding, Berhe *et al.* (2017); (Williams *et al.*, 2022) reported that access to credit significantly increases the adoption of biogas energy systems, as it allows adopters to finance installation, maintenance, and operational costs.

## 4 Conclusion

Based on respondents' characteristics, the study finds that dairy farmers in the study area are predominantly male, with an average age of approximately 50 years and relatively low educational attainment, mainly at the elementary and secondary school levels. Most respondents have more than ten years of livestock farming experience and manage an average herd size of 5.6 animal units. The majority of farmers did not receive extension services during the previous year, had an average household size of three members, considered dairy farming as their primary occupation, were members of livestock farmer groups, and had access to credit through cooperatives. Regarding CSA practices, all six practices exhibited adoption rates exceeding 50%, indicating a relatively high level of CSA adoption among dairy farmers in the Pujon and Ngantang Districts. The analysis further reveals that CSA adoption in the study area is influenced by several factors, including age, education, herd size, farming experience, access to CSA information, type of occupation, membership in livestock groups, access to extension services, and access to credit. Among these factors, only gender and household size do not show a statistically significant effect on CSA adoption.

Notably, the findings indicate that age, livestock farming experience, and access to extension services have negative effects on the adoption of certain CSA practices. These results highlight important areas for further investigation, particularly regarding how institutional arrangements, information delivery mechanisms, and farmer characteristics

interact to shape adoption behavior. Given that empirical research on Climate-Smart Agriculture remains limited in Indonesia especially in East Java, future studies should focus on the technical and institutional dimensions of CSA implementation. Strengthening the roles of government institutions and universities in supporting technology dissemination and farmer capacity building is essential to accelerate CSA adoption and promote sustainable livestock development in Indonesia.

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