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Land management and factors influencing agroforestry adoption on potato farmlands in the Dieng Plateau, Indonesia

ARI PUJIWINARKO[1,♥], TRI RETNANINGSIH SOEPROBOWATI[1,2,3], KISMARTINI[4]

[1]Graduate School of Environmental Science, Universitas Diponegoro. Jl. Imam Bardjo SH No. 3-5, Semarang 50241, Central Java, Indonesia. Tel: +62-24-8453635, ♥email: arcawinarko@gmail.com

[2]Department of Biology, Faculty of Science and Mathematics, Universitas Diponegoro. Jl. Prof. Sudarto, S.H., Tembalang, Semarang 50275, Central Java, Indonesia

[3]Cluster for Paleolimnology (CPalim), Universitas Diponegoro. Jl. Imam Bardjo SH No. 3-5, Semarang 50241, Central Java, Indonesia

[4]Department of Public Administration, Faculty of Social and Political Sciences, Universitas Diponegoro. Jl. Prof. Sudarto, S.H., Tembalang, Semarang 50275, Central Java, Indonesia

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Abstract. *Pujiwinarko A, Soeprobowati TR, Kismartini. 2024. Land management and factors influencing agroforestry adoption on potato farmlands in the Dieng Plateau, Indonesia. Biodiversitas 25: 2623-2641.* The Dieng area in Indonesia has long experienced agricultural land degradation, and intensive potato monoculture farming is one of the leading causes. Vegetative-based programs such as agroforestry have been implemented, but the level of adoption still needs to improve. This research aims to evaluate land management systems and analyze practices and the factors influencing agroforestry adoption of potato farming land in Dieng. We surveyed 260 potato farmers and interviewed 12 Key Informant Interviews (KII). Data were analyzed using binary logistic regression, descriptive statistics, and narrative approaches. Our research found changes in how potato farmers manage land regarding planting frequency and mulch use. The combination of potatoes and MPTS (Multi-Purpose Tree Species) is the plant composition most commonly found in agroforestry practices. Carrots (*Daucus carota* L.) are the vegetables that farmers most often plant when rotating potato crops. Mountain pine (*Casuarina junghuhniana* Miq.) and Carica (*Carica pubescens* (A.DC.) Lenne & K.Koch) are the species of trees and MPTS most commonly found in the fields of potato farmers who adopt agroforestry. Farmers maintain MPTS and trees on their land due to their suitability with main food crops and economic considerations. Several factors, including the species of energy source, use of mulch, frequency of potato planting, perception of disasters, farmer interest, prices, markets, the experience of vegetative activities, and government policy, significantly influence agroforestry adoption. Considering local agricultural systems, including the presence of principal crops and their management on the land, socio-economic and farmers' perspectives are essential to further increase agroforestry adoption in Dieng.

Keywords: Agroforestry adoption, crop combination, Dieng, land management, local food crops, potatoes

INTRODUCTION

In many regions of the world, the agricultural sector is essential to the subsistence system for farming households and the provision of fundamental needs for people. According to FAOSTAT data, of the 13.03 billion ha of land area globally, 4.75 billion ha, or 36.47%, is agricultural land (FAO 2022). The agricultural sector and agricultural land remain the most extensive land use in Asia and produce 90% of the world's total supply of rice, various subtropical and tropical fruits, as well as important plantation cash crops (Prabhakar 2021). Unfortunately, it is estimated that 40% of agricultural land globally, including in Asia, has been degraded, and some areas are even very damaged and no longer suitable for cultivation (Hooke et al. 2012). Degradation is also scientifically documented in highland agricultural land throughout the world, including in Africa (Berihun et al. 2019; Ebabu et al. 2019), Europe (Lizaga et al. 2020), America (Mattia et al. 2018; Stanek et al. 2019), and Asia (Yen et al. 2013; Choi et al. 2019). Likewise, in Indonesia, most of the highland areas, which are also upstream of watersheds and agriculturally productive regions, are currently in a degraded condition (Kementerian Pertanian 2015; Dassir et al. 2019; Danial et al. 2020; Narendra et al. 2021).

One of the recommendations suggested by landscape experts to reduce agricultural land degradation is agroforestry (Buck et al. 2020; Plieninger et al. 2020; Zinngrebe et al. 2020). Agroforestry systems have been shown to decrease the erosion rate and can be a way to restore degraded land in agricultural landscapes (Wilson and Lovell 2016; Gunawan et al. 2019), in addition to raising the water quality and fertility of the soil (Ebabu et al. 2019; Ngadisih et al. 2020). Regretfully, despite extensive promotion as a sustainable agricultural system capable of mitigating the adverse effects of intensive farming, farmers still need to adopt agroforestry at a high rate (Magugu et al. 2018; Tsonkova et al. 2018). Agroforestry promotion is often unsuccessful because farmers' perceptions, needs, and preferences in the designated areas are not considered (Jacobi et al. 2017) even though local communities' substantial involvement in environmental management in an area is one of the keys to the success of a program (Rudiarto and Doppler 2013; Gladkikh et al. 2020). As critical actors in agroforestry governance, small farmers are vital because the determination to adopt agroforestry on their agricultural land depends on them (Zinngrebe et al.

2020). The factors influencing farmers' decisions vary over time and space scales (Amare and Darr 2020). A combination of farmer households' socioeconomic characteristics, land, institutions, and biophysical characteristics determine these factors (Dinh et al. 2017; Sanou et al. 2019). Vegetation-based programs to reduce land degradation such as Forest and Land Rehabilitation (RHL, *Rehabilitasi Hutan dan Lahan*), Community Seed Gardens (KBR, *Kebun Bibit Rakyat*), Sustainable Farming Businesses (UTL, *Usaha Tani Lestari*) and Strengthening Community-Based Forest and Watershed Management (SCBFWM) have been widely implemented in Dieng. However, the success rate is still low (Pertiwi et al. 2017; Turasih 2019), as evidenced by the dominant monoculture system and the minimal land cover of trees and MPTS on potato farming land (Kartika et al. 2019). In Indonesia, research on adopting agroforestry is categorized as social dimension research, and the proportion is still the lowest compared to research on cultivation, environmental, or economic dimensions (Herawati et al. 2013). In addition, the existence of major food crops in a region is often overlooked in agroforestry research and promotion, even though it should be considered and designed to meet the needs of land-owning farmers to increase its adoption (Etshekape et al. 2018). Empirical evidence shows that several farmers continue adopting agroforestry practices in their potato fields. Studies on adopting agroforestry that focus on the main crops cultivated by local Dieng farmers have also yet to be widely studied. This research aims to evaluate land management in potato farming systems and existing agroforestry practices and analyze the many factors influencing agroforestry adoption on Dieng potato farming land.

MATERIALS AND METHODS

Research area

This research was conducted in the Dieng plateau area. Dieng is a plateau in Indonesia's Central Java Province, Indonesia (Figure 1), between 70 7' 4"-70 35' 2" and 1090 59' 53"-1100 04' 34", and has an altitude of more than 1,300-2,500 meters above sea level (masl). It has an area of 54,974.24 ha, covering six districts: Wonosobo, Banjarnegara, Temanggung, Pekalongan, Kendal, and Batang. This area is also upstream of seven large river basins, namely the upstream of the Serayu watershed (22,921 ha), Progo (2,672.13 ha), Bodri (3,646.62 ha), Lampir (5,967.56 ha), Sengkarang (16,857 .65 ha), Comal (380.48 ha) and Sragi watershed covering an area of 2,526.56 ha (BPDAS SOP 2007).

Dieng is one of the highest plateaus in the world, second only to Nepal. It has potential for forestry, agriculture, geology, and nature tourism. It is famous for its cultural heritage in the form of a Hindu temple complex (Bergen et al. 2000). Most land-owning farmers in Dieng derive their income from the horticulture-based agricultural sector, specifically industrial potato plants (Pradana et al. 2015; Turasih and Kolopaking 2016). Central Java potato production 2020 reached 269.476 thousand tons, 58% of which came from agriculture in Dieng (BPS Jawa Tengah 2021). Dieng's agricultural land has unfortunately been degraded due to intensive monoculture cultivation without the conservation awareness that potato farmers have long practiced, such as planting potatoes parallel to the slope, having poor terraces, not using annual plants, and using excessive amounts of chemical fertilizers (Pradana et al. 2015; Setiawan et al. 2018; Harjadi and Susanti 2019). Erosion levels have reached 121.434 to 166.350 t/ha/year (Christanto et al. 2018; Lesmana 2020).

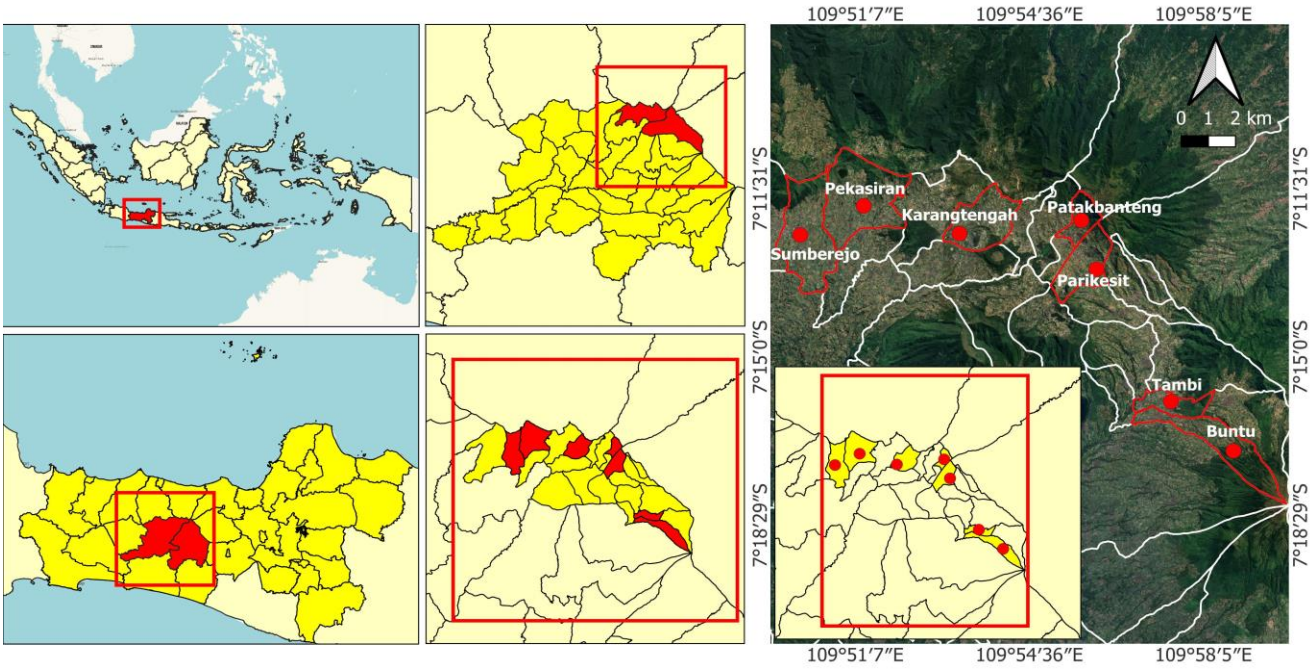

Figure 1. Research location in the Dieng Plateau Area, Central Java, Indonesia

Data collection

The research was conducted from January to April 2023. Quantitative data includes various characteristics of farming households, perceptions, socio-economics, and biophysical conditions/land management. Determination of location and sampling was carried out by multi-stage purposive sampling. Multi-stage purposive sampling is a sampling method conducted through 2 or more stages while ensuring that each stage reflects purposive and deliberate sampling according to the research objectives and limitations the researcher applies. Purposive sampling has the advantage of allowing the researcher to understand better the research problem and location (Rokonuzzaman et al. 2023). The multi-stage purposive sampling method is widely applied to select study locations and individual and group respondents. It is commonly carried out in complex research that uses a mixed methods approach (Collins et al. 2007; Ramanujan et al. 2022). As part of a multi-stage purposive sampling strategy, the first stage was to select the Batur sub-district and Kejajar sub-district as the research area. These two sub-districts are potato centres and face problems of land degradation and criticality due to massive and intensive potato cultivation compared to other areas in Dieng (Jariyah and Pramono 2013; Mukaromah and Handoyo 2019; Turasih 2019). Based on spatial critical land data released by CDK VII Jawa Tengah (2020), the total area of the Batur and Kejajar sub-districts is 12,592.99 Ha, and 7,825.87 Ha, or 61.67%, is in critical condition. The largest contribution to land criticality is estimated to come from land owned by 7,654.77 or 63.21% of the total area, most of which is based on potato crops. The second stage is selecting the villages that will be the sampling locations. Seven villages were selected from two sub-districts: four in the Kejajar sub-district (Patakbanteng, Buntu, Tambi, and Parikesit villages) and three in the Batur sub-district (Karang Tengah, Pekasiran, and Sumberejo villages). Apart from being a potato centre, these villages also received various vegetative activities from the government during 2010-2013. Even though it is still a highland agroclimate, the villages we chose are spread evenly at various altitudes with an altitude range of 1300-2100 masl. Amid the dominance of potato monoculture, we also ensure that on potato farming lands in these villages, there is an agroforestry pattern that the farmers are still adopting.

In the third stage, following consultation with the leader of the farmer collective and the village authorities, a local forestry expert joined us to collect a representative sample of 40 potatoes from each village. In addition, a total of 20 individuals who have adopted agroforestry practices and 20 individuals who have not adopted agroforestry practices were chosen from each village, based on the recommendations of the farmer group leader and the town authorities. The farmers surveyed, who produce potatoes on privately held ground or on rented land from farmers and other parties, are distinct from the state forest area maintained by Perhutani. According to the law, Perhutani is prohibited from cultivating seasonal crops. A semi-structured questionnaire was given to a total of 260 participants, with 130 being adopters and the other 130 being non-adopters. The task was executed by enumerators consisting of local students and representatives of farmer groups who had undergone prior recruitment and training. The lead investigator was present during the survey to verify the accuracy of the completed questionnaire. At the next stage, qualitative data was obtained through deep interviews with selected informant from the research location targeting main issues regarding external factors that influence the adoption of Agroforestry. These factors include market, price, experience with past planting activities, incentives, environmental service returns, government policy, and the current condition of the potato farming system in Dieng. There were 12 Key Informant Interviews (KII); most were heads of farmer groups, village heads, village officials, or community leaders. We confirmed that the selected sources were also involved in agroforestry activities from the government in the 2010-2013 period and were also active potato farmers until now.

Data analysis

External factor data from interviews is narrated qualitatively, briefly, and presented in the results and discussion section. These data are also used to support and clarify quantitative data obtained through previous surveys. The quantitative data from the survey was analyzed using descriptive statistics and logistic regression. Researchers in agriculture or agroforestry often choose binary logistic regression because of its non-linear nature, and with two classes of values—yes or no or 1 or 0—the dependent variable is a dichotomous choice (Jara-Rojas et al. 2020; Bandi et al. 2022). In this research, farmers are classified as adopters if, on their potato farming land, there is at least one tree plant or one fruit plant, shrub, bamboo, or forage grass, which we will henceforth refer to as Multi-Purpose Tree Species (MPTS). They are non-adopters if they do not have trees or MPTS in their potato fields. Agroforestry implementers get a score of 1, while non-agroforestry farmers get 0.

There are 17 independent variables representing three main factors, including socio-economic characteristics (age, education, family size, income from main crops, off-farm job, livestock ownership, species of energy source, land area and land ownership status), land management (use of plastic mulch, frequency of planting potatoes) and perception and interest factors (perceptions about potato productivity, influence of the presence of trees, rainfall, land fertility, occurrence of floods and landslides and farmers' interest in planting).

The model for estimating opportunities for agroforestry implementation that we propose is expressed as Logit (Y) = $\alpha + \Sigma\beta 1X1 \ldots + \Sigma\beta n\ Xn + \varepsilon i$, where the dependent variable (Y) indicates whether or not farmers have adopted agroforestry, 1 indicates an adopter, while 0 indicates a non-adopter. Intercept denoted by α, the independent variable's coefficients $\beta 1,\ldots,\beta n$ show how these factors affect the chance of adopting agroforestry, and X1,..., X17 are the independent variables. Additionally, the association between independent variables is investigated and checked for collinearity before doing logistic regression. We also estimated the appropriateness of our suggested regression model using the Hosmer-Lemeshow test.

RESULTS AND DISCUSSION

Socio-economic factors of potato farmers

The distribution of independent variables was examined by examining the frequency distributions and percentages of 260 respondents using descriptive statistics, and Table 1 presents the findings.

We studied 260 heads of potato farming households in the sample, and their ages ranged from 22 to 78 years. The farmer range of 25-44 years is the age with the most significant percentage, reaching 53.85%. Age is often one of the strongest predictors of agroforestry adoption potential (Stanek et al. 2019) and has a negative effect on adoption rates where the older conventional monoculture farmers are, the less interested they are in adopting new technologies such as agroforestry (Rois-Díaz et al. 2018). Even though it does not show significance in the level of AF adoption, the age of potato farmers, which is almost 97.31% of them at productive age (15-64 years), can undoubtedly be a consideration in planning further agroforestry promotion.

Most potato farmers have low education, or junior high school or below, as many as 212 people (81.54%), with farmers with elementary school education numbering 129 people (49.62%). In this research, farmers' education did not influence their decision to adopt Agroforestry. The results differ from studies showing that higher-educated farmers are more inclined to use new technology; they maintain the existence of trees on their agricultural land due to their capacity to comprehend and analyze a variety of knowledge, better understand conservation and the importance of adopting Agroforestry on agricultural land (Etshekape et al. 2018; Magugu et al. 2018; Kaba et al. 2020). A different opinion was expressed by Buyinza et al. (2020) and Bandi et al. (2022) who stated that the level of education does not necessarily influence the adoption of agroforestry. However, new knowledge or perceptions obtained not through formal education may further influence farmers' beliefs and intentions to be involved in tree planting activities. Dieng farmers' knowledge of the various benefits and impacts of planting trees or MPTS on their land should be equal and evenly distributed among all potato farmers in Dieng regardless of their level of education. The Dieng area is still a priority target for handling land degradation by various related parties, one of which is through various vegetative-based programs. In the process, all these programs are aimed at all farmers without considering their level of education and other social status. The program is accompanied by adequate socialization, mentoring, training and technical guidance. Extension officers and related technical agencies also conduct counselling and disseminate information individually and collectively through farmer groups. However, the perception formed by new knowledge or various increases in understanding depends entirely on each farmer and is influenced by many factors. These factors include the primary job type and land ownership size. The limited area of land ownership and the main livelihood as a land-based farmer, with potatoes as the primary commodity, causes a very high dependence on land. In addition, the still high negative perception of the existence of trees, low prices and unclear markets for agroforestry products could cause farmers to be reluctant to take the risk of adopting new technologies such as agroforestry, which they consider could threaten their daily livelihood system from the land they cultivate with potato plants.

According to Iiyama et al. (2017), household size is often used as an indicator of the availability of agricultural labor and has a positive effect on adopting agroforestry. However, the opposite opinion states that a large household size can hinder agroforestry adoption because it will increase the need for food and other subsistence activities (Sanou et al. 2019; Beshir et al. 2022). Potato farmers in Dieng are dominated by farmers with 3-4 family members totaling 182 people (70.00%). Table 1 shows that family size did not influence the decision to adopt agroforestry. Even though labor costs in Dieng are higher than in lower areas, it is currently difficult to find agricultural laborers. Apart from that, there is a decline in young people's interest in becoming farmers. During the potato planting or harvest season, which requires more labor, potato farmers with capital and significant land ownership hire workers from outside the area. However, the limited land owner usually does it alone or involves their family members.

Table 1 showed that 65.38%, or 170 farmers, had an income of 1-3 million rupiah/month, 15.00%, or 39 farmers, had an income of 3-4 million rupiah/month, and only 13.08%, or 34 farmers, had an income of more than 4 million rupiah/month of their potato farm. Income from potato farming does not influence agroforestry adoption. This is positive for increasing adoption in the future as much evidence suggests increasing income from primary crops/agricultural income could also cause reduced intention in adopting agroforestry (Dinh et al. 2017; Pello et al. 2021). Several adoption studies in Indonesia show that farmers who have jobs outside their main agriculture tend to have lower levels of agroforestry adoption (Murniati et al. 2022; Wijayanto et al. 2022). However, this did not significantly affect agroforestry adoption in the Dieng Plateau, even though of the 260 farmers surveyed, 57.69%, or 150 farmers, said they had other jobs outside of potato farming. This is because the contribution of potatoes to farmers' household income is still substantial, reaching 69.70% of total family income (Pratiwi and Hardyastuti 2018).

Households farming that have livestock have a greater chance to employ agroforestry because livestock feed can be obtained from plants on their land or from the forest (Jara-Rojas et al. 2020; Sharmin et al. 2021), but it can also hinder adoption when labor resources and costs are more allocated to this livestock than to tree planting/MPTS activities (Beshir et al. 2022). Table 1 shows low levels of livestock ownership in Dieng, with only 23 potato farmers keeping livestock out of 260 farmers. They allocated more time and costs focused on potato farming. Most potato agricultural land is sprayed with pesticides, which are dangerous for livestock, so farmers are unwilling to use grass from potato fields. Apart from that, the fertilizer suitable for potatoes is chicken manure, which must be bought from outside the area, not sheep manure, usually kept by breeders in Dieng.

Table 1. Socio-economic characteristics of the respondents

Socio-economic characteristics		Freq.	Percent (%)
Age	15-24	10	3,85
	25-44	140	53,85
	45-64	103	39,62
	>64	7	2,69
Education level	Not completed in primary school	35	13.46
	Elementary sch.	129	49.62
	Junior high sch.	48	18.46
	Senior high sch.	42	16.15
	Diploma	2	0.77
	Univ. degree or above	4	1.54
Household/Family size	1-2	32	12.31
	3-4	182	70.00
	5-6	42	16.15
	> 6	4	1.54
Income from potatoes	< 500,000 IDR	4	1.54
	IDR 500,000-1,000,000	13	5.00
	IDR 1,000,000-2,000,000	85	32.69
	IDR 2,000,000-3,000,000	85	32.69
	IDR 3,000,000-4,000,000	39	15.00
	> 4,000,000 IDR	34	13.08
Of farm Job	No	110	42.31
	Yes	150	57.69
Livestock	No	237	91.15
	Yes	23	8.85
Type of energy source	Electricity, LPG	144	55.38
	Electricity, LPG, Firewood	64	24.62
	Electricity, LPG, Charcoal	52	20.00
Land holding	< 500 m^2	14	5.38
	500 to 1,000 m^2	39	15.00
	1,000 to 2,500 m^2	50	19.23
	2,500 to 5,000 m^2	72	27.69
	5,000 to 10,000 m^2	55	21.15
	> 10,000 m^2	30	11.54
Land ownership status	Owned land	109	41.92
	Rental land	49	18.85
	Sharing land	20	7.69
	Owned/village land + rental/sharing land	67	25.77
	Owned/village land + renting out land/sharing land results	15	5.77

Most farmers possess small land for intensive potato-based farming, namely 67.31% or 175 people for land ownership under 0.5 hectares. Potato farmers who own more than 1 hectare of land are only around 11.54% or 30 farmers. Land is a farmer's main asset and an essential resource for every agricultural economic activity, and the factor that most generally influences farmers' decisions to apply agroforestry (Ashraf et al. 2015; Nyaga et al. 2015). According to Magugu et al. (2018), farmers who have more agricultural land are more likely to embrace agroforestry technology to a greater extent. In contrast, when the land is too small, farmers are unlikely to adopt agricultural technology beyond the conventional system, which they are familiar with and perceive as more financially advantageous (Rois-Díaz et al. 2018). Most of the land owned is acquired by inheritance, and its agricultural area is shrinking due to population growth. Many farmers also sell their land to other parties outside the region, as is often true in Tambi Village, Kejajar Sub-district. In Karang Tengah Village, Batur Sub-district, some potato farmers rent land from state-owned companies (BUMN, *Badan Usaha Milik Negara*) or private parties for their potato farming business. There are five categories of farmers based on land ownership that we found in the potato farming system in Dieng, namely 109 land-owning farmers (41.92%), 49 land renters (18.85%), 20 sharecroppers (7.69%), farmers who own land and also rent land are 67 people (25.77%) and finally there are farmers who own land and also rent/share the produce of their land with other farmers, totaling 15 people (5.77%). Potato farmers' land ownership status did not influence agroforestry implementation in Dieng. Land ownership status in practice is often a limitation in adopting agroforestry because farmers who rent land cannot cultivate trees/MPTS because the land owner is not permitting (Martin et al. 2016; Rois-Díaz et al. 2018). On the other hand, farmers who receive clarity on land status from the government or own land and cultivate it themselves have more potential to adopt agroforestry than rented land or land whose ownership is unguaranteed (Dinh et al. 2017; Jha et al. 2021). In Xinjiang, China, farmers who have contracted land and land tenure guarantees from the government were found to adopt more intercropping with trees than farmers who manage vacant land where there is no guarantee of ownership (Rao et al. 2016).

Land management and crop composition of agroforestry practices on potato farming land

The potato growing system traditionally employed on the agricultural area of Dieng has evolved into a distinct local farming system. Similarly, the management of land in the potato farming system is undergoing changes. However, the identification and investigation of planting patterns and tree species/MPTS in this system are still lacking in widespread recognition. An important factor in promoting the adoption of agroforestry in land agriculture is to assess the farmers' specific cultivation practices (Bukomeko et al. 2019; Nguyen et al. 2021), the presence of essential crops, and the current land management (Etshekape et al. 2018). These factors should be taken into account when planning for agroforestry expansion (Fleming et al. 2019). According to the survey results, 73.46% of the total 260 potato farmers, which is equivalent to 191 farmers, employ plastic mulch for potato cultivation (Figure 2.A). Figure 2.B illustrates that out of the total number of farmers, only 73 engage in potato cultivation for the entire year, specifically during three planting seasons, accounting for 28.08% of the farmers. In contrast, 151 farmers grow potatoes in two planting seasons, making up 58.08% of the total. Additionally, 36 farmers only plant potatoes once in a year, representing 13.85% of the total.

Out of the 187 potato growers, the majority opt for crop rotation by planting different vegetable crops instead of potatoes or by leaving their property unused. Table 2

displays the predominant vegetable crop varieties that farmers commonly employed in their rotation of potato crops, along with the corresponding number of farmers who adopted each variety. There are only 8 species of vegetables that are usually cultivated by potato farmers when rotating their potato crops, namely *Capsicum frutescens* L., *Daucus carota* L., *Brassica oleracea* L., *Solanum lycopersicum* L., *Apium graveolens* L., *Allium fistulosum* L., *Nicotiana tabacum* L., and *Allium ascalonicum* L. The vegetable crops most often planted by farmers as intercropping are carrots (*D. carota)* and cabbage (*B. oleracea)*, which were mentioned by 58 and 40 potato farmers.

Carrot and cabbage crops are favored by farmers because of their favorable commodity prices, simplicity of marketing and cultivation, and fit for the local climate. A fascinating research finding reveals that 46 farmers who used to plant potatoes twice a year have stopped intercropping or leaving their land empty due to various reasons. These reasons include the lack of labor for post-harvest potato activities, difficulties in land processing, insufficient funds to purchase production facilities such as seeds and fertilizer, and the need to wait for the land to become fertile again (Figure 3.B).

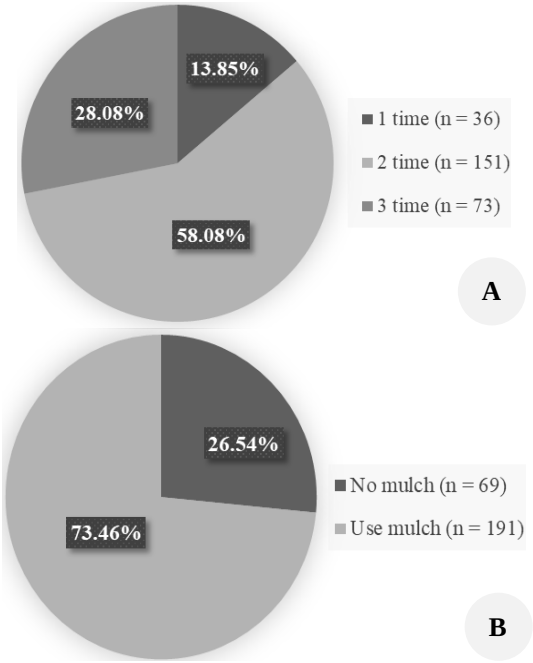

Figure 2. Land management carried out by potato farmers in Dieng, Indonesia: A. Use of plastic mulch in potato planting beds; B. Frequency of planting potatoes in one year

Figure 3. Land management when not planting potatoes: A. Carrots (*Daucus carota*) are the vegetables most often planted during potato crop rotation, B. Fallow land after potato harvest

Table 2. Species of vegetables and number of farmers who choose them as a potato rotation crop

Scientific name	Local name	Number of farmers who choose it as a rotation crop			Percentage from total crop rotation farmers (n = 187)
		One time planting (n = 36)	Two time planting (n = 151)	Number of farmers	
Capsicum frutescens L.	*Cabai*	9	13	22	11.76
Daucus carota L.	*Wortel*	21	37	58	31.02
Brassica oleracea L.	*Kubis*	2	38	40	21.39
Solanum lycopersicum L.	*Tomat*	2	0	2	1.07
Apium graveolens L.	*Seledri*	1	2	3	1.60
Allium fistulosum L.	*Loncang*	0	5	5	2.67
Nicotiana tabacum L.	*Tembakau*	1	8	9	4.81
Allium ascalonicum L.	*Bawang merah*	0	2	2	1.07
Empty/not planted			0	46	24.60

According to survey data collected from 130 farmers who have adopted agroforestry and through field observations, it has been shown that 127 farmers in Dieng utilize the agrisilviculture pattern, which involves combining crops with woody plants or MPTS (Multi-Purpose Trees and Shrubs), for the majority of their agroforestry activities. According to Figure 4, the adoption of the agrisilvopastoral pattern, which involves combining crops, woody plants or MPTS, and pasture for cattle, is limited to only 3 farmers. Potato farmers that embrace agroforestry commonly select for the crop pattern that involves potato plants and MPTS, as it is their preferred choice. One possible reason is that farmers receive indirect advantages from the integration of plants through ecosystem services, as well as direct benefits from agroforestry goods such as fruit, firewood, carpentry wood, animal feed, and others. Agroforestry approaches involve the utilization of several species of trees and Multi-Purpose Tree Species (MPTS). The majority of individuals that choose agroforestry engage in the practice of planting trees and Multi-Purpose Tree Species (MPTS) along the periphery of their land (Figure 5). Farmers' land management preferences are reflected in their choice of planting composition and crop patterns. It is common for farmers to plant trees or Multi-Purpose Tree Species (MPTS) on degraded ground or at the periphery of their property. This is due to the prevailing unfavorable view of growing trees near food crops, as observed in studies by Akodéwou and Godron (2022) and San et al. (2023).

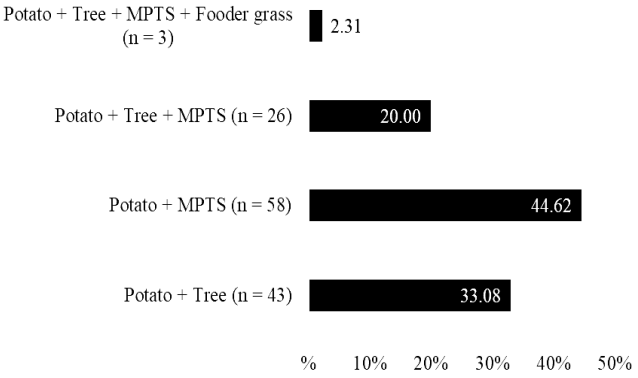

Figure 4. Plant combinations in agroforestry practices on potato farming land in Dieng, Indonesia

Figure 5. Potato monoculture practices and several combinations of planting patterns of agroforestry practices on potato farming land in Dieng, Indonesia: A. Monoculture potato with mulch (*Solanum tuberosum*), B. Combination of Potatoes and Carica fruit plants (*Carica pubescens*), C. Combination of Potatoes and Mountain pine (*Casuarina junghuhniana*), D. Combination of Potatoes, Carica (*C. Pubescens*), and Eucalyptus trees (*Eucalyptus* sp). For potato plants that involve planting trees or fruit, the majority are grown using a planting pattern on the edge of the land (Trees along the border), and a few are found in a random pattern (Random mixture)—source; Researcher documentation, taken during surveys and field observations, January to April 2023

We inventoried the species plants planted by 130 agroforestry adopters, categorizing them as either trees or MPTS and then analyzed the farmers' most commonly adopted plant species. Table 3 shows that many farmers mentioned planting multiple species of trees, or MPTS, on their land. Potato farmers only plant a few species trees; agroforestry adopters mentioned only 10 species. Naturally, climatic conditions and geographical location play a role, limiting the variety of tree species that can thrive in the highlands. We also ensure that tree species that are identical to productive plants that are usually planted in state forests managed by Perhutani, such as *Pinus merkusii* Jungh. & de Vriese, *Eucalyptus* sp., *Cupressus sempervirens* L. and *Schima wallichii* (DC.) Korth., are plants that exist in potato farming land. The farmers said that most of the trees on their land came from a greening program assisted by the government and other institutions. Farmers say that *C. sempervirens* and *S. wallichii*, despite their scarcity, have been around for a long time, possibly due to intentional forest plantings by their parents or previous landowners.

Mountain pine (*Casuarina junghuhniana* Miq.) was adopted by 38 farmers (29.23% of total agroforestry adopters), *Acacia decurrens* Willd. by 18 farmers (13.85% of total adopters), and *Eucalyptus* sp. by 14 farmers (10.77% of total adopters). It is the species of tree most often found on farmers' land. Our interviews reveal that farmers tend to this tree due to its rapid growth, quick regrowth after pruning, and small leaves that allow sunlight to penetrate. Adopters of agroforestry view these plants' characteristics as not too disruptive, allowing them to coexist peacefully with their potato plants, mainly when planted on the land's edge. In Dieng, potato-based farming has become a local, cultural, and traditional agricultural system. The negative impact of trees on potatoes is also still high, so, naturally, they will be more selective when deciding whether to keep trees on their potato land. The trees growing on potato farms can indicate the farmers' acceptance of these trees, as they align with their interests. It aligns with the viewpoints of Nguyen et al. (2021) and Hasannudin et al. (2022), who assert that the species and composition of plants on community land indicate their compatibility with local culture and social acceptance, their alignment with local interests, and their economic or business viability for planting on the land. It is evident that Dieng farmers no longer prioritize economic factors as their main concern. This shift is a result of negative experiences related to prices and marketing, which stem from the challenges they face while attempting to sell trees on their land. Thus, it may be inferred that farmers generally prioritize the appropriateness of trees for potato crops, as well as their role as boundaries and providers of firewood, rather than ecological factors like water conservation and economic factors focused on maximizing revenue from wood sales.

There are more MPTS species mentioned by farmers adopting agroforestry than tree species; approximately 15 species of MPTS are cultivated, as shown in Table 4. The MPTS most commonly found and proven to be productive on agricultural land adopting agroforestry are *Carica pubescens* (A.DC.) Lenne & K.Koch, *Coffea arabica* L., and *Solanum betaceum* Cav.. Coffee plant in Dieng, although still low, can produce 5-8 kg/year of wet coffee beans per plant. Meanwhile, Carica and Dutch eggplant, whose fruit can be harvested every month, each plant can produce 3-5 kg/month and 2-3 kg/month, respectively. Even though *C. pubescens* is not a native plant to the Dieng Plateau; it is mainly found in the potato farms of agroforestry adopters. So far, *C. pubescens* has been a specific crop typical of Dieng and has been proven to be an alternative income source of local economic improvement besides potatoes. Diversification of income sources and increasing revenue are the main reasons for fruit crop-species selections in various parts of the world. This aligns with the findings of the research conducted by Nguyen et al. (2021), which declares agroforestry systems in the highlands of Vietnam involving fruit are preferred by many vegetable farmers because it has a higher selling value and a stable price.

Our interactions with potato growers have revealed that there are various factors influencing their choices to preserve trees or MPTS on their property. When evaluating MPTS, the appropriateness for potato plants was not taken into consideration. The primary factor taken into account is the economic worth of MPTS fruit. The successful growth and productivity of the MPTS plants will enhance their motivation to remain on the property. Despite being frequently overlooked by farmers during plant selection, the ability of plants to grow and thrive on a certain piece of ground serves as an indication of the land's compatibility for that specific plant (Rahmawaty et al. 2020; Mugiyo et al. 2021).

Table 3. Species of trees and the number of farmers adopting them in potato farming

Scientific name	Family	Local name	Number of farmers adopter	Percentage from total agroforestry adopters (n = 130)
Toona sinensis (A.Juss.) M.Roem.	Meliaceae	*Suren*	12	9.23
Elaeocarpus ganitrus F.Muell.	Elaeocarpaceae	*Jenitri*	7	5.38
Casuarina junghuhniana Miq.	Casuarinaceae	*Cemara gunung*	38	29.23
Samanea saman (Jacq.) Merr.	Fabaceae	*Saman*	6	4.62
Schima wallichii (DC.) Korth.	Theaceae	*Puspa*	2	1.54
Acacia decurrens Willd.	Fabaceae	*Kasia*	18	13.85
Eucalyptus sp.	Myrtaceae	*Ekaliptus*	14	10.77
Pinus merkusii Jungh. & de Vriese	Pinaceae	*Pinus*	1	0.77
Cupressus sempervirens L.	Cupressaceae	*Bintamin*	1	0.77
Paraserianthes falcataria (L.) I.C.Nielsen	Leguminoceae	*Albasia*	3	2.31

Table 4. Species of MPTS and the number of farmers adopting them in potato farming

Scientific name	Family	Local name	Number of farmers adopter	Percentage from total Agroforestry Adopters (n = 130)
Coffea arabica L.	Rubiaceae	*Kopi Arabika*	19	14.62
Artocarpus heterophyllus Lam.	Moraceae	*Nangka*	8	6.15
Musa paradisiaca L.	Musaceae	*Pisang*	3	2.31
Bambusa sp.	Poaceae	*Bambu*	11	8.46
Arenga pinnata (Wurmb) Merr.	Arecaceae	*Aren*	1	0.77
Phyllostachys aurea (André) Rivière & C.Rivière	Poaceae	*Bambu Gendani*	8	6.15
Psidium guajava L.	Myrtaceae	*Jambu biji*	6	4.62
Carica papaya L.	Caricaceae	*Pepaya*	2	1.54
Solanum betaceum Cav.	Solanaceae	*Terong Belanda*	19	14.62
Citrus sp.	Rutaceae	*Jeruk*	1	0.77
Macadamia integrifolia Maiden & Betche	Proteaceae	*Makadamia*	3	2.31
Persea americana Mill.	Lauraceae	*Alpukat*	2	1.54
Carica pubescens (A.DC.) Lenne & K.Koch	Caricaceae	*Carica*	55	42.31
Sandoricum koetjape (Burm.fil.) Merr.	Meliaceae	*Kecapi Dieng*	1	0.77
Pennisetum purpureum Schumach.	Graminae	*Rumput Gajah/odot*	3	2.31

Perception and interest

Regarding other determinants that affect the adoption of agroforestry, we also include potato farmers' perceptions of various natural phenomena or internal factors based on their perceptions. This research include perceptions about potato productivity over the last 5 years (Figure 6.A) and perceptions about the presence of trees/MPTS on potato farming land (Figure 6.B). It can be seen that 49%, or 127 farmers out of 260 farmers surveyed, stated that there was a decline in potato productivity.

Even though potatoes (*Solanum tuberosum* L.) are known as shade-tolerant C3 plants (Schulz et al. 2019), several field studies have shown differently. Studies by Pardon et al. (2018) on Belgian agricultural land show that the presence of rows of old trees, with a height of 26 to 31 meters at the edge of the field, reduces potato productivity by up to 30 meters from the planting boundary; that is equivalent of a decrease of 24 % of treeless potato productivity. Meanwhile, the results of demonstration plot trials for Guava (*Psidium guajava* cv. Allahabad safeda) with a planting distance of 5 x 5 meters with a height of 3 meters were carried out by Parmar et al. (2022) in the eastern sub-Himalayan region showed a decrease in potato productivity of up to 7% from the productivity of control potatoes without shade. Figure 6.B shows a vast negative perception of trees/MPTS in potato fields. There are (83%), 216 out of 260 potato farmers think that the presence of trees/MPTS in the land can reduce potato productivity. Although these two perceptions do not substantially impact agroforestry uptake in Dieng, more attention must be paid to planning the selection of plant species to promote agroforestry. The species of plant and the tree's size determine the magnitude of the tree's influence on crop yields and the distance of its influence on annual plants on agricultural land (Pardon et al. 2018).

Almost 90% or 233 farmers said rainfall in the past 5 years has increased (Figure 7.A). Household perceptions of changes in rainfall and temperature patterns and past experiences with risks due to bad weather can influence decisions to adopt technologies such as agroforestry (Coulibaly et al. 2017). However, this did not influence farmers' decisions to adopt agroforestry in Dieng. Rain-fed farmers in Tanzania consider changes in rainfall patterns a risk and uncertainty. When they perceive rainfall to be stagnant or not changing, they consider it a risk that is not urgent and does not need to be addressed immediately, so the old cropping pattern is maintained. On the other hand, even though they are aware of the uncertainty of the risks that must be borne due to changes in rainfall patterns, namely floods when rainfall is too high or drought when rainfall is too low, this does not affect their desire to adopt agroforestry. From a farmer's perspective, water is better utilized for other crops than trees. Ultimately, they preferred to maintain their primary food crop (Jha et al. 2021). In the case of Dieng, potato farmers said they preferred the dry season as the best season for potato cultivation. However, this is not related to risks due to changes in rainfall patterns but is more related to the economic benefits that can be obtained. Potato productivity can be maximized during the dry season with lower operational costs than during the rainy season. A study from Turasih and Kolopaking (2016) state that potato farmers in Dieng know that in the last 40 years, the intensity of rainfall and erosion on their land has become increasingly higher, threatening their potato-based livelihoods. However, what is happening now is that they still prefer to adapt by increasing the use of pesticides and fertilisers, advancing the planting season, or planting other vegetable crops combined with potatoes rather than adapting through agroforestry or other more sustainable agricultural systems. In general, dry land farmers will consider ecosystem services and the direct benefit value of trees rather than focusing on agro-climatic requirements such as rainfall when selecting trees or deciding to adopt trees on their land (Bukomeko et al. 2019).

Regarding perceptions about land fertility in the last 5 (five) years, Figure 7.B shows that farmers who think their agricultural land has increased in fertility by 50 people (19.23%), at the same fertility by 118 people (45.38%) and decreased at 92 people (35.38%). The statistical analysis

results show that perceptions about soil fertility are not significant in Dieng's level of agroforestry adoption. It is usual because, generally, small farmers consider fertile land a scarce resource, so they prefer to optimize it for planting annual crops rather than planting trees or MPTS (Dinh et al. 2017; Rois-Díaz et al. 2018). Perceptions about land fertility and rainfall show farmers' knowledge of a decline in soil quality and an increase in rain intensity on agricultural land, but they don't affect to implement of agroforestry, in line with research by Jha et al. (2021) on Tanzanian agricultural land.

From the farmer's perspective regarding the incidence of floods and landslides in their potato fields, 132 farmers (50.77%) said it had increased, 83 farmers (31.92%) said it had remained the same, and 17.31% or around 45 farmers said it had decreased (Figure 8.A). Meanwhile, planting desires independently by potato farmers shows that as many as 142 farmers (54.62%) of the 260 indicated their disinterest in planting wood at this time; furthermore, 41 farmers (15.77%) expressed doubts, and 29.62% or 77 farmers said they were still interested in planting trees and MPTS independently (Figure 8.B).

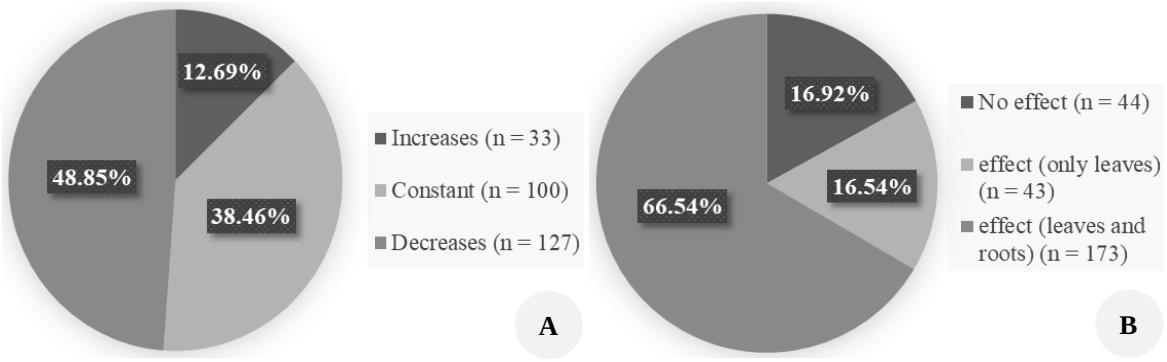

Figure 6. A. Perception of potato productivity conditions in the last 5 years, B. Farmers' perceptions about the presence of trees and MPTS in their potato fields on potato productivity

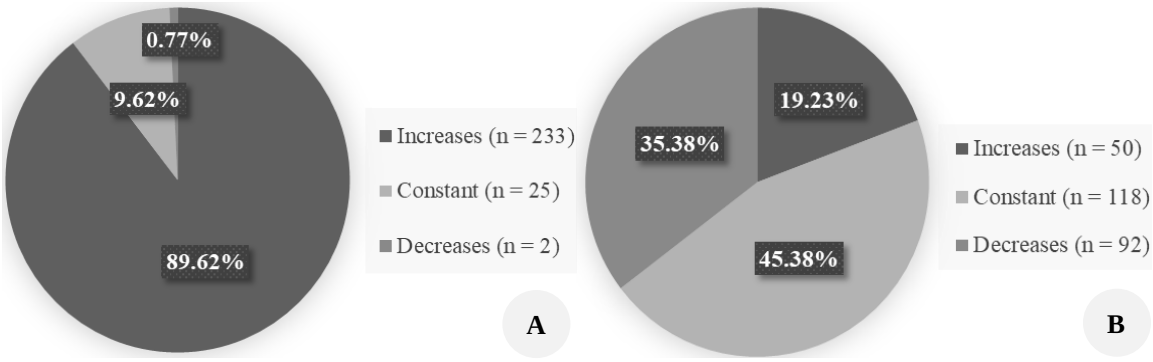

Figure 7. A. Perception of rainfall in the last 5 years, B. Farmers' perceptions of land fertility in the last 5 years

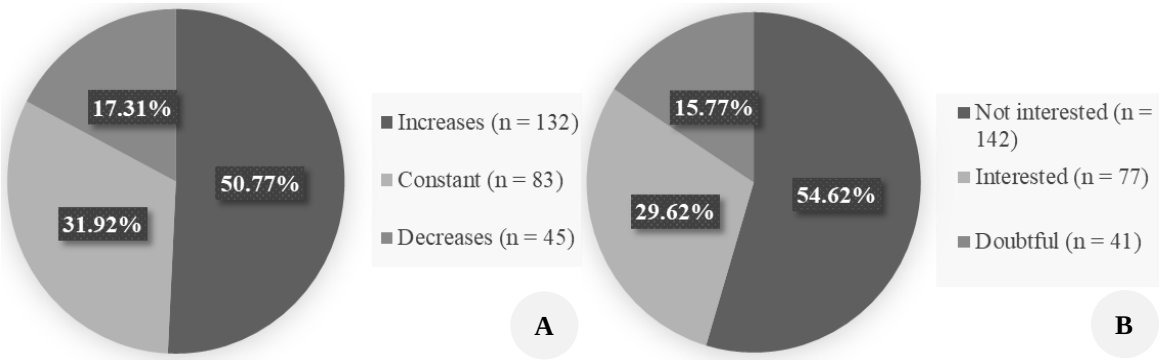

Figure 8. A. Perception of flood and landslide events in the last 5 years, B. Farmers' interest in planting trees and MPTS independently

Factors influencing agroforestry adoption in Dieng

Before conducting logistic regression, we investigated the correlation among independent variables. The results showed no symptoms of multicollinearity in the model we proposed, indicated by the tolerance value for all independent variables being bigger than 0.10. In the regression test, the suitability of the model with the Hosmer-Lemeshow test has a p-value higher than 0.05, namely 0.461, indicating the suitability of the proposed regression model. The coefficient of determination test reached 0.482, and the model classification accuracy level also reached 77.7%. The variables of research that impact agroforestry adoption are shown in Table 5. Of the 17 independent variables studied, 4 (four) variables significantly influence agroforestry adoption on potato farming land in Dieng, namely species of energy source, use of mulch, frequency of potato planting, perception of flooding and landslides, and also farmers' interest in planting independently.

The energy source farmers use is the only socio-economic component that significantly influences agroforestry adoption. It indicates that other factors (see Table 1) in the case of adopting Agroforestry on potato farming land in Dieng were not considered or influenced farmers' decisions to maintain the presence of trees/MPTS on their land or vice versa. The coefficient of determination test results reaching 0.482 must also be considered because it demonstrates that just 48.2% of the independent factors under research can adequately explain their impact on adoption. In comparison, the remaining 51.8% is explained by other factors outside the variables studied, including external factors. In this research, external factors obtained from in-depth interviews with selected informants/KII and considered to influence agroforestry adoption are analyzed narratively to explain their influence on agroforestry adoption.

Species of energy sources

Potato farmers who use electricity, LPG, and firewood as energy sources ($p = 0.054$) or use electricity, LPG, and charcoal ($p = 0.015$) positively influence the adoption of agroforestry. It indicates that potato farmers who use LPG energy sources and electricity plus charcoal or firewood have more potential to adopt agroforestry than those who only use LPG and electricity as energy sources alone. The use of firewood and charcoal for cooking and heating at night is still relatively in demand in Dieng. Most farmers today still maintain the existence of traditional wood-fired kitchens (*Pawon*); for some Dieng people, it is not only a place to cook but also a place to chat with family and guests they consider as families. Even though many people now use modified gas heating devices, the firewood and charcoal uses are still highly demanded. Firewood is obtained from forests around the village and their land, while wood charcoal is purchased from the market. In many African and Asian countries, one factor that motivates farmers to adopt Agroforestry is its ability to provide firewood (Nigussie et al. 2017; Sharmin et al. 2021). Households that use or dependent on firewood also have the potential to adopt agroforestry greater than households that only use gas or electricity energy sources (Bruck and Kuusela 2021; Kouassi et al. 2021; Ullah et al. 2022).

Use of mulch

Statistically, the use of mulch on potato beds shows a significant value ($p = 0.017$) and has a positive effect on adopting agroforestry. It indicates that farmers who use plastic mulch on their potato beds have a greater opportunity to adopt agroforestry than those without mulch. Plastic mulch has several essential benefits, such as reducing soil water loss and maintaining soil moisture, reducing soil erosion, enriching soil fauna and improving the properties of the soil and nutrients (El-Beltagi et al. 2022). Research by Agustina et al. (2019) in Dieng on the effectiveness of plastic mulch in maintaining the quality of potato agricultural land using the Soil Biological Quality Index (QBSar) based on the presence of microarthropods shows that the QBSar index of land using plastic mulch is much higher (76-77), compared to agricultural land without mulch is only (43-70). Field trials on corn plants in the Middle Hills of Nepal during the rainy season conducted by Chalise et al. (2020) showed that soil loss on fallow land reached 20.6 Mg/ha, land that had terraces and no mulch was 15.2 mg/ha, while land with terraces and with mulch only 9.5 Mg/ha. According to Luo et al. (2018) and Huang et al. (2024), plastic mulch can also increase crop yields. The results of trials on potato plants in Punjab, India, conducted by Sekhon et al. (2020), mulch has been proven to reduce water use and increase soil temperature. The productivity of potato plants without mulch is 11,993 tons/ha, straw mulch is 14,567 tons/ha, and plastic mulch is 15,991 tons/ha.

In the case of Dieng, it is difficult to explain a direct link between the increased use of mulch and the interest of potato farmers in planting or maintaining trees and MPTS on their land. Potato farmers in Dieng use plastic mulch to do more to maintain potato plant productivity and other benefits. They argue that potato maintenance costs are cheaper due to the reduced frequency of weed removal. It is more cost-effective because it can be used many times, and there is no need to cultivate the land again in the case of plant rotation; it also lowers soil erosion than the open system. We suspect potato farmers have received these benefits when using plastic mulch without realizing the possibility of additional support from the agroforestry system they adopted. Potato plants are prone to pest and disease attacks and require climatic conditions that suit their growth. It cannot be overcome and fulfilled just by using plastic mulch, but the agroforestry system can support overcoming this deficiency. Besides the productivity function, ecologically agroforestry can improve habitat health by reducing pest and disease risk compared to growing only a few tree species across an agricultural landscape (Barrios et al. 2018; Cerda et al. 2020). Apart from that, agroforestry patterns with plant structure and species diversity can influence the microclimate in an area (de Carvalho et al. 2020).

Table 5. The result of logistic regression of potato farmers' decisions to adopt agroforestry. Only significant variables are shown

Factor	Coef	p-value	Sig.
Sosio Economic			
Species of Energy Sources-Electricity, LPG, Firewood	.985	.054	*
Species of Energy Sources-Electricity, LPG, Charcoal	1.335	.015	**
Biophysics and Land Management			
Use of Mulch-Yes	1.043	.017	**
Potato Planting Frequency-2 time	-1.514	.017	**
Potato Planting Frequency-3 time	-1.405	.066	*
Perception and Interest			
Perception of Flood Landslides in 5 years-constantly	-1.393	.003	***
Interest in planting independently-doubtful	2.034	.006	***
Model Fit Test (Hosmer and Lemeshow test)	0.461		
Coefficient of Determination (Nagelke R Square)	0.482		
Classification Accuracy	77.7 %		
Observations Number	260		

Note: *** Level of Significant at P<0.01 (99%); ** Significant at P<0.05 (95%); * Significant at P<0.1 (90%)

Potato planting frequency

Table 5 shows the frequency of planting potatoes negatively influences adopting agroforestry, both at the frequency of planting potatoes twice (p = 0.017) and three times (p = 0.66) in one year. This means that the more frequently farmers plant potatoes, the more farmers' interest in adopting agroforestry on their land will decrease. Potato plants have a cultivation period of 90-110 days or approximately four months from early planting to harvest. Likewise, potato breeding is carried out after harvest, and storing the tubers until they become seeds ready for planting takes more than three months. From 1980 to 2000, most potato farmers still cultivated potatoes 3 times a year or a full year. However, now it is different; only 73 potato farmers (28.08%) out of 260 farmers maintain potato cultivation for a full year (3 plantings), while the rest prefer to cultivate other vegetable crops (Figure 2.B).

Field tests in Poland conducted by Blecharczyk et al. (2023) to compare two species of rotation and fertilization showed that potato-alphafa-wheat crop rotation and the addition of kendang fertilizer had the highest productivity, reaching 34.4 tons/ha. Meanwhile, the potato monoculture rotation and fertilizer was 18.4 tons/ha, the potato-alphafa-wheat rotation without potato fertilizer was 17.4 tons/ha, and the potato monoculture rotation without fertilizer was only 6.8 tons/ha. The trial by Pertiwi and Cempaka (2021) in the Dieng areas shown the once-a-year potato planting pattern in the Pekalongan district has better growth and yields than the twice-a-year potato planting pattern in Wonosobo district and three times in Banjarnegara district. There is spare time and vacancies in the land when farmers rotate crops or plant potatoes only once or twice. In reality, even though there are opportunities to increase tree planting or MPTS on their land, farmers still prefer to rotate potatoes with other productive vegetable crops. The change in the frequency of potato planting is also indicated by many empty/fallow areas, even during the planting season. The existence of empty land in the potato farming system in Dieng is a form of adaptation to the subsistence system of farmer households due to climate change, usually carried out in the dry season; land accessibility is low and far from water sources, and planting potatoes are no longer efficient due to watering cost (Turasih and Kolopaking 2016).

Flood and landslide perception

Table 5 shows farmers' perception that floods and landslides in the last five years still negatively influence the level of agroforestry adoption (p = 0.03). This indicates that potato farmers who perceive flooding and landslides on their land in the five years were constant or stable incidences will have a smaller opportunity to implement agroforestry than farmers who believe the floods and landslides are increasing or decreasing.

A research by Jariyah and Pramono (2013) in Dieng stated that 87% of the upper Serayu watershed area is very vulnerable to flooding. The agroforestry system, through the function of the canopy, litter, and organic materials, also has the potential to reduce the danger of erosion or flooding incidences (Yustika et al. 2019; Hombegowda et al. 2020; Muñoz-Villers et al. 2020). It has been supported a research by Ngadisih et al. (2020) in the Merawu Dieng watershed; agroforestry agricultural land experienced a substantially lower infiltration rate of 254 mm/hour compared to the potato agricultural field's 340 mm/hour, which impacted the number of land erosion.

Figure 8.A shows that although more than 50.77% of farmers think that flood and landslide incidences are increasing on their land, this does not influence their decision to adopt agroforestry. This is common in highland areas with annual crops-based floods and landslides wiping out seeds and wood plants/MPTS on land with high slopes are obstacles to adopting agroforestry in agriculture. That also occurred in the Chure Highlands of Nepal (Khadka et al. 2021). Likewise, a research by Dai et al. (2017) on the highlands based on vegetable and agricultural crops in Xinjiang, China, even though extreme weather such as snow, natural disasters, floods/landslides, and droughts often cause the failure of their annual crops, farmers are still reluctant to plant trees/MPTS. However, they still prefer to plant vegetables and seasonal plants to prepare for disaster or extreme weather conditions than trees/MPTS. On the other hand, the perception of farmers in Western

Nepal that the increase in extreme rain occasions, floods and landslides due to climate change has significantly impacted agricultural production, requires them to adapt by changing their agricultural patterns. They planted flood-resistant rice and sugar cane species, leaving the land and allowing tree species such as napier, vetiver, and *Acacia catechu* to grow along riverbanks and flood plains. Meanwhile, hill and mountain farmers will leave areas that have been prone to landslides for years, carry out intercropping and agroforestry, and plant trees along slopes that are prone to landslides (Shrestha et al. 2022).

Interest in planting independently

Table 5 shows farmers interested in planting trees/MPTS independently but still hesitant ($p = 0.006$) have a greater chance of adopting agroforestry than other farmers. Potato farmers who do not intend to plant trees/MPTS are 54.62%, and around 29.62% of farmers are still interested in planting trees/MPTS (figure 8.A). In agricultural areas, the decline in interest in planting trees/MPTS independently is related to factors such as the availability of seeds (Gebru et al. 2019; Kachaka et al. 2020; Mahmood and Zubair 2020), quality of seeds (Khadka et al. 2021; Ullah et al. 2022) and locations/plots that are difficult to reach (Pello et al. 2021; Beshir et al. 2022). However, they are not a problem in Dieng because most of the tree seedlings in Dieng are aided by stakeholders, while MPTS also come from independent seedlings. Transportation roads to villages in Dieng are also relatively easy to reach. In the case of Dieng, it needs to be considered whether the low interest in planting trees/MPTS is due to being self-sufficient or other factors. In terms of principal crops, potatoes have significantly improved the economic welfare of farmers, which has also impacted Dieng community's culture and social life. The contribution of potatoes in Dieng is also still very large, reaching 69.70% of the total income of families, with an R/C value above 1 (Munandar 2016; Pratiwi and Hardyastuti 2018). Most farmers in Dieng perceive that the potato farming system is also considered will be sustainable entirely (Nugrahapsari et al. 2020) because it is supported by the typical climate and soil conditions of the Dieng mountains, which are suitable for vegetable cultivation (Cahyono and Purwanto 2017). Interviews showed that several farmers claimed to have benefited from adopting agroforestry at different levels. Many agroforestry farmers in the villages of Karang Tengah, Parikesit, and Patakbanteng, who are also small industry processors and traders, choose to plant Carica and Dutch eggplant closer together on their land and admit that the contribution from selling those fruits is quite enormous. However, for other farmers who only sell agroforestry products, they consider their economic contribution to be minimal. On the other hand, other farmers in Sumberejo Village and Buntu Village said that the contribution of agroforestry products is relatively small; the fruit and wood from farming land are only for their consumption. In general, the contribution of trees and wood still needs to be higher, and that is another reason why farmers are hesitant, even reluctant, to plant trees or MPTS on their land.

External factors

The interviews with potato farmers in Dieng revealed in 2010 when the government was intensively promoting the environmental greening program, they were very enthusiastic about planting trees/MPTS, especially eucalyptus plants, due to its various benefits. Apart from free seeds and incentives for planting eucalyptus trees, they are also known to have a high, stable price, and the leaves can be refined to increase farmers' income. Eucalyptus trees have been proven to grow very quickly and well, but farmers find them difficult to sell when they grow up. They also feel that the government is not promoting it again and are unaware of this eucalyptus product's price and market demand; consequently, many potato farmers have decided to cut down these trees and change to other species. It should be noted that the market demand and price of agroforestry products are the main drivers of agroforestry adoption (Kouassi et al. 2021; Ullah et al. 2022). When tested with the UGM Laboratory of Forestry Faculty, the yield of eucalyptus oil was very low, not even commensurate with the cost of refining it. These phenomena set a bad precedent in the potato farmers' perspectives, which could affect the next agroforestry programs. Ruppert et al. (2020) state negative experiences with previous tree planting activities/MPTS farmers could hinder agroforestry adoption.

On the other hand, farmers said that although potato prices fluctuate, they are still high and considered more profitable than planting trees or MPTS, as recommended by the government. Concerning how to care for trees/MPTS, farmers are not concerned about costs and cultivation knowledge, they assumed cultivating trees and MPTS was easy and cheap. They ignored those trees, left them alone, and did not care to fertilize intensively because they though fertilizer was already on the potato fields. About the price of agroforestry products in the form of fruit, the latest information states that carica and tamarillo plants in the villages of Parikesit, Patakbanteng, and Pekasiran have been cut down by some farmers because of their low prices. The motivation to get additional income from producing fruit, construction wood, and firewood is another driving factor for adopting agroforestry (Etshekape et al. 2018; Beyene et al. 2019). Naturally, farmers feel they do not get additional income from adopting agroforestry; they prefer a conventional farming system that is considered more familiar and profitable (Rois-Díaz et al. 2018).

Regarding government policy, the interview with KII also revealed that importations of Indian and Chinese potatoes were opened in 2010 due to AFTA free trade affecting potato prices to fall freely, consequently increasing farmers' interest in planting trees/MPTS on their land. Potato farmers throughout Indonesia then organized a large-scale demonstration in Jakarta so that the import quota would be prohibited again. Therefore, potato prices increase again in line with the decreasing interest of potato farmers in planting trees/MPTS due to import restrictions. The central and regional governments also launched various programs and activities such as comparative studies at Arabica coffee production centers in Pangalengan,

agroforestry management in Bogor, Eucalyptus oil refining trials, and Eucalyptus sawmills. From an institutional perspective, in 2007, the Dieng Area Handling Coordination Team (TKPKD, *Tim Koordinasi Pemulihan Kawasan Dieng*) was formed in Banjarnegara and Wonosobo (Turasih 2019). Government programs based on vegetation planting have also been carried out since 2009-2015 in Dieng, such as Forest and Land Rehabilitation (RHL, *Rehabilitasi Hutan dan Lahan*), Community Seed Gardens (KBR, *Kebun Bibit Rakyat*), Sustainable Farming Businesses (UTL, *Usaha Tani Lestari*) and Strengthening Community-Based Forest and Watershed Management (SCBFWM). The introduction of productive food crops such as wheat and MPTS such as macadamia and arabica coffee has also been implemented. Training on the processing and packaging of carica, coffee, and Dutch eggplant products, as well as various grants on coffee and carica production facilities, have also been carried out by various parties from the government, private sector, and BUMN. Vegetative-based CSR (Corporate Social Responsibility) and community development from BUMN and private parties are also widely implemented in Dieng. Even though most of the programs are always accompanied by training activities, mentoring, or direct incentives in the form of free seeds, planting costs, and operational costs for up to 3 years, it is insufficient for farmers' intention to plant or maintain trees/MPTS on their land.

The farmers' perspective had long been uncomfortable because they were considered the most responsible party leading cause of land damage in Dieng. It is in line with the research from Turasih (2019), which states that stakeholders continue to use Dieng farmers as the main causes of land degradation; therefore, in the planning and preparation programs to address degradation in Dieng, they often do not include these social problems that the farmers have a high dependence on potato production on their land optimally. Meanwhile, according to the farmer, the government programs emphasize conservation more; farmers perceived the government wanted to replace their potato plants. Khadka et al. (2021) stated that promoting agroforestry more focusing on conservation sometimes conflicts with the principles of optimizing productivity usually adhered to by seasonal crop farmers, ultimately becoming a barrier to adoption.

Local agricultural systems and how they influence agroforestry adoption

Local agricultural systems, including plant species, land management methods, or cultivation techniques, are usually inherited between generations. The local agricultural system adopted by the majority of Dieng farmers is potato-based. For some farmers, planting potatoes is a tradition and pride. Even though potato productivity is currently experiencing a decline, only 10-15 tons/ha, much lower than the 1980-1990 period, which reached 30 tons/ha, farmers still prefer to plant potatoes that have proven profitable today. There have been changes in how potato land is managed regarding mulch use and the frequency of planting potatoes in one year. Planting potatoes twice a year, rotating them with other vegetable crops, and increasing mulch use have become the dominant practice in the current potato farming system.

There is a significant increase in potato production cost per season, especially in seeds and plant medicinal (*ngobat).* In the rainy season, the frequency of farmers watering potatoes mixed with *ngobat* (a mixture of pesticides, fungicides, and insecticides) becomes 20-23 times per planting season. They must spend 2.5 to 3 million rupiah/ha for each treatment; this number is double that of the 1990-2000 period, which was only 10 times. Unsurprisingly, many farmers rotate with other vegetables or even leave their land empty, and this usually happens to small farmers with small capital and land size of less than 1 ha. Meanwhile, many large farmers still plant potatoes 2-3 times yearly, and others prefer to rent them to other parties; it happens often in Sumberejo, Buntu, and Pekasiran villages. The only reason many small farmers continue to plant potatoes during the rainy season, even though they know there is a risk of loss, is to get potato seeds. They sell the seeds to other farmers outside the area at high prices and use the rest to plant during the dry season. Many farmers or other parties say that cultivating potatoes during the rainy season has many disadvantages because production and labor costs are high, potato prices tend to fluctuate, and there is the potential for crop failure due to pest attacks and plant diseases.

Potato farmers in Dieng may give different answers when asked how much their harvest is or what the productivity of their land is. Most farmers think that what is meant by potato productivity is high-quality potatoes (grade *AB, C*), which can be sold directly to large distributors at high prices and usually ranges from 70-80% of total production. Meanwhile, low-quality potatoes for the local market (Grade *BS, Rindil*) and potatoes for seeds are not considered production products included in the land productivity calculation. So it is natural that when converted to rupiah value, potato farmers seem to suffer losses, especially compared with production costs during the rainy season, which are very high and can exceed 100 million/ha. For example, if potato farmers harvest 10 tons/ha for 10 thousand rupiah/kg, they can get 100 million rupiah/ha. Many farmers will still say they are losing money. Even though it fluctuates, the price of Dieng potatoes has always been higher than that of potatoes in other areas. If low-quality potatoes and seed potatoes are included in the calculation of land productivity or converted into rupiah, potato cultivation in Dieng has relatively high productivity and is still economically profitable, even during the rainy season. It could be one of the factors causing the low level of agroforestry adoption on potato farming land in Dieng.

There are 25 species, consisting of 10 tree species and 15 MPTS species, on potato farming land in Dieng. The *C. junghuhniana, A. decurrens, Eucalyptus* sp., *C. pubescent, C. arabica*, and *S. betaceum* are some examples of trees and MPTS that are often found and are still maintained by potato farmers on their land. Most of these plants aid in planting activities, but there are also species of MPTS that farmers deliberately plant. Farmers decide to cut down or maintain trees and MPTS on their land with various

considerations, reasons, and perceptions. Farmers' perception that trees or MPTS can disrupt the productivity of their potato crops is still very high (see Figure 6.B). It causes differences in reasons and considerations when farmers decide to adopt trees or MPTS on their land. Our findings, to date, consider the suitability of trees for potato crops, the use of trees for property boundaries, and firewood, which are the reasons most often cited by farmers when retaining trees. In the field, many farmers maintain trees up to a large diameter but trim the branches and leaves to the top. The most common species of trees on the land are those that proliferate, sprout quickly, have small leaves, and have thin canopies, ensuring they do not overshadow the potato plants. The majority of farmers said they maintained MPTS because the plants were able to grow and produce well. Among farmers who adopt agroforestry, agrisilviculture systems often coexist alongside the dominance of potato monoculture, which most potato farmers still favor. Planting on the edge of the land is the most common method, with consideration given to not disturbing the potato plants.

In general, monoculture potato farming, which farmers still maintain, agroforestry systems with a diversity of tree species and MPTS combined with potato plants, and planting patterns on the edge of land, which farmers widely adopt, are specific forms of land management that have created local agricultural systems on a potato farm in Dieng. These local farming systems must be accounted for when incorporating technology or intervening in potato farming systems to increase agroforestry adoption. The plants selected and the land management technology that will be developed should be similar to local agricultural systems and existing plants and must involve farmers' participation. Planting patterns, species, and combinations of plants that grow on community land show their preference and perspectives on these plants and their land management system (Sanudin et al. 2020; Legesse and Negash 2021). Much evidence shows that agroforestry programs fail because they ignore local agricultural systems in the community. Jacobi et al. (2017) field research on 42 agroforestry projects in Bolivia showed that many agroforestry programs failed because they prioritized external knowledge and only introduced one species of plant rather than considering local knowledge and the various species of local planting already existing.

Priority to increase the adoption of agroforestry

So far, initial setup costs are expensive (Etshekape et al. 2018; Do et al. 2020), lack of access to information (Binam et al. 2017; Arimi and Omoare 2021), lack of skills and knowledge (Khadka et al. 2021; Ullah et al. 2022), lack of knowledge about reforestation and conservation programs (Rois-Díaz et al. 2018; Gladkikh et al. 2020), and lack of incentives and subsidies (Dai et al. 2017) be an obstacle in implementing agroforestry. In Dieng's areas, these obstacles should not be a problem and should not be the focus of our discussion. Vegetative-based programs in the Dieng area from the past until now have always been accompanied by socialization, training, technical guidance, and the provision of subsidies and incentives. Geographically, all Dieng areas also have adequate accessibility. Dieng has various potential and important values from upstream to downstream. Hence, it is unsurprising that all central and regional stakeholders are involved in Dieng's recovery activities. Unfortunately, to minimize failures that have occurred in the past, vegetative-based programs are currently mostly carried out in the Dieng buffer zone, not the main Dieng areas. They are still carried out using the same pattern.

Apart from considering existing local agricultural systems, the following things need to be considered and may be a priority to increase small farmers' awareness, participation, and interest in planting trees and MPTS on their land. Problems related to prices and marketing of agroforestry products are the priority that the government must resolve. Many farmers doubt the long-term prospects of Agroforestry because of this problem. From this research, many trees and MPTS have been proven to be productive and have economic value in Dieng. Unfortunately, many potato farmers are cutting down trees/MPTS that have proven productive on their land due to low prices and marketing difficulties. Even though they are not directly intervening in prices, the government, through its policies, is expected to increase agroforestry products' value and market share. They can strengthen the quality and competitiveness of agroforestry products through technical support, funding, training, workshops, and exhibitions. Encouraging the creation of a continuous marketing network and facilitating partnerships between farmers and private companies in product marketing can also be done. In India, facilitated by the government, cooperation between wood farmers and the paper industry through the Public Private Partnership (PPP) program guarantees security in the wood market for fast-growing trees on community land. Farmers no longer worry about how to sell wood and its price because it has been agreed since the early agreement. This policy has successfully increased the planting of trees on community land and the land cover on community land intentions (Chavan et al. 2015).

Multi-party involvement in overcoming product pricing and marketing problems is essential. In America, the U.S. Department of Agriculture (USDA) issues funding grants to develop agroforestry products, such as forest herbs in Virginia, pawpaw (a native fruit that grows in the eastern United States) in Ohio, and elderberry and pecan in Missouri. The University of Missouri provides grants for research on various varieties of elderberries and pecans. They also send experts to train farmers on cultivating and handling pests and diseases of these plants. The Ohio federal government instituted a tax reduction program for agroforestry products to increase interest in planting. The USDA Agriculture Marketing Service continuously helps promote products directly and online and assists farmers in establishing partnerships with various parties. One of them is collaborating with the Hawaii Department of Agriculture to facilitate the formation of the 'Ulu cooperative, a breadfruit processing cooperative in Hawaii. They also built marketing shops in Hawaii and included breadfruit in teacher learning programs and school menus (National Agroforestry Center 2021).

Economic factors are still the primary consideration in land management in the potato farming system in Dieng. Most potato farmers are still concerned about the impact of trees on potato productivity if they adopt agroforestry. Even though, in the long term, agroforestry can be very promising both economically and environmentally, the fact that the harvest period takes a long time and the results do not necessarily meet farmers' expectations is one of the barriers that hinder the adoption of agroforestry. Small farmers prefer continuous income and harvests, even if the amount is small, rather than taking the risk of adopting a system such as agroforestry, which they consider will not necessarily guarantee their income in the future or could further disrupt their daily livelihood (Rois-Díaz et al. 2018; Achmad et al. 2022). So, efforts to increase farmers' awareness of the importance of conservation, including agroforestry, must be implemented without fearing farmers losing their daily economic resources. Relevant stakeholders must continue to provide training and incentives, but implementation requires innovation, development, and farmers' readiness. Therefore, the Payment Environmental Services (PES) scheme can potentially overcome those sustainability problems, especially lowering the economic and environmental conflict. Unfortunately, this program has never been implemented in Dieng. According to Achmad et al. (2022), forestry services like carbon capture and upstream-downstream compensation can boost farmers' income while protecting the environment, even though they still resist its executions. The PES scheme for integrating faidherbia albida (fertilized trees) in monoculture farming systems in Ethiopia's CSA (Climate Smart Agroforestry) program has increased farmers' tree cover and food security. Farmers prefer prepayment and food as a means of compensation rather than cash. In addition, the low number of trees required to be planted and short-term contracts positively influence farmers' decisions to plant/maintain trees on their agricultural land (Haile et al. 2019). One thing that the PES scheme must ensure is the small farmer's involvement. PES will only be effective when small farmers receive sufficient compensation for the loss of income from their primary crop production and, therefore, have sufficient incentives to participate further. On the other hand, wealthy farmers who participate and receive more compensation will also make PES schemes inefficient and unfair to other farmers (Benjamin et al. 2018). Suppose this PES scheme is to be implemented it must involve all relevant stakeholders, including small farmers who will be the targets and perpetrators of the activity. The key to successful planning for introducing innovation to increase agroforestry adoption is the inclusion of all opinions and the involvement of various stakeholders (Barlagne et al. 2021).

Moreover, improving the extension system is another priority that must be awarded. It is hard to intentionally convince farmers to plant trees or MPTS and convince them that agroforestry is a sustainable agricultural system. Therefore, field instructors must do this in their daily duties. Field instructors are government representatives at the site level, responsible for delivering government information and policies to farmers. They have direct contact with farmers, so they comprehend field conditions and the character of local farmers. Technically and qualitatively, they have sufficient knowledge and skills because of the competency of field instructors' development through various training sessions. Hence, field instructors involved in planning and assisting vegetation-based programs should simplify program implementation. Unfortunately, the number of field instructors is decreasing. In Batur and Kejajar sub-districts, only 10 agricultural instructors and 2 forestry instructors were to supervise 24 villages. Therefore, the government needs to consider adding field instructors to increase the adoption of MPTS further.

Ultimately, it can be concluded that land management has changed significantly compared to potatoes' early glory days. Until now, the monoculture system is still dominant in the potato farming system in Dieng. Amidst the dominance of monoculture potato farming practices and the effect of the failure of vegetative-based programs in the past, potato farmers still continue to adopt agroforestry. Agrisilviculture, a combination of potato and MPTS mostly found in farmers adopting agroforestry land. Therefore, to increase agricultural yields and restore degraded land, agroforestry has been considered an appropriate sustainable agricultural method. It has been proven in various regions but has yet to become the primary preference for Dieng potato farmers to implement on their land. The research revealed several factors influencing farmers' decisions to implement agroforestry, such as the species of energy source, use of mulch, frequency of planting potatoes, perception of floods and landslides, and farmers' interest in planting trees/MPTS. From the farmers' perspective, external factors such as experience regarding planting activities, prices and market demand for agroforestry products, primary product prices, and government policies also influence their decisions in managing land. Great attention must be paid to increasing agroforestry products' selling value and marketing. The local agricultural system regarding land management and plant preferences must also be considered. The majority of trees and MPTS on potato farming land come from aid. Therefore, various previous vegetative-based programs or other innovations accompanied by socialization, incentives, mentoring, and training must continue to be enforced. By providing economic compensation for farmers who maintain trees and MPTS on their land, the PES scheme is feasible to be implemented in Dieng. We suggest considering factors that have been proven to influence the adoption of agroforestry, local agricultural systems, and farmers' perspectives when planning various programs to increase the uptake of agroforestry in Dieng potato farming areas.

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