Climate Risk Management 45 (2024) 100646

Contents lists available at ScienceDirect

Climate Risk Management

journal homepage: www.elsevier.com/locate/crm

Factors associated with smallholders' uptake of intercropping in Southeast Asia: A cross-country analysis of Vietnam, Laos, and Cambodia

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ARTICLE INFO

Keywords:
Intercropping
Climate-smart agriculture
Southeast Asia
Adoption
Smallholders

ABSTRACT

While previous studies acknowledge intercropping as a climate-smart agricultural practice and confirm its prominence in developing countries, behavioral factors underlying farmers' decision in intercropping adoption remain poorly understood. This study assesses and compares the heterogeneity in adoption of intercropping among smallholder farmers in Vietnam, Laos, and Cambodia, through the lens of climate change adaptation. A sample of 1017 smallholder farmers was recruited for a household survey across the three countries using a convenient sampling approach. Principle component analysis (PCA) was performed to identify the main dimensions of farmers' perception towards climate change and adaptation. Next, generalized order logit regressions were employed to assess the association between farmers' adoption tendency of intercropping and their perception of climate change and adaptation, perceived usefulness, perceived ease of intercropping, and socio-demographic characteristics. The study shows that perceived climate severity was negatively associated with intercropping adoption tendency in Vietnam and Laos ($p < 0.001$). In all studied countries, farmers who perceived a higher level of climate change impact were less interested in intercropping. Perceived ease and perceived usefulness of intercropping were positively related to farmers' adoption of intercropping in the three countries ($p < 0.001$). Information acquisition on climate change adaptation reduced the willingness to intercrop in Vietnam ($p < 0.001$) but increased the adoption readiness in Laos ($p < 0.001$) and Cambodia ($p < 0.1$). Informal social support hampered readiness to adopt intercropping only in Vietnam ($p < 0.001$). Lastly, households with a home garden were more willing to adopt intercropping in Laos ($p < 0.1$) and Cambodia ($p < 0.001$), compared to households without a home garden. Policies focused on enhancing the perceived ease and benefits of

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https://doi.org/10.1016/j.crm.2024.100646
Received 5 November 2022; Received in revised form 13 August 2024; Accepted 21 August 2024
Available online 23 August 2024

intercropping, alongside improving the access and usability of information on climate change and adaptation, could incentivize adoption of intercropping among smallholder farmers,therefore strengthening their resilience against the impacts of climate change.

1. Introduction

During the last few decades, Southeast Asia has experienced extreme temperature events, changes in the seasonal rainfall pattern, and more frequent and severer climatic hazards (Pörtner et al., 2022). In the next decades, projections show that climate hazards, including floods and extreme heatwaves, will cause significant impacts on agricultural productivity in the region (Pörtner et al., 2022). Due to their heavy reliance on natural resources for their livelihoods and their limited adaptive capacity, smallholder farmers in South East Asia are among those, who are the most vulnerable to climatic and environmental changes (Brown et al., 2019; Landicho et al., 2019). Growing evidence suggests that climate changes will reduce agricultural yield and increase yield variability in Southeast Asia (Ray et al., 2015; Waibel et al., 2018a). For instance, climate change is estimated to cause 21 %, 20 %, and 25 % of the rice yield variability in Vietnam, Laos, and Cambodia, respectively (see Supplementary Data in Ray et al. (2015)). Projected climate hazards are expected to worsen food insecurity (Pörtner et al., 2022), which is already a challenge in most of the Southeast Asian countries (FAO et al., 2021).

To sustain and improve agricultural yields, Southeast Asian countries have increasingly promoted intensified farming systems, which are highly susceptible to pests and diseases (Liu et al., 2018), and thus exacerbating farmers' vulnerability to climate changes. In addition, prolonged intensive cropping systems have resulted in groundwater depletion, biodiversity erosion, and environmental pollution (Palombi & Sessa, 2013). Particularly on mono-cropped sloping land, the limited application of soil and water conservation technologies has led to the loss of a large amount of fertile topsoil. This process undermines future land productivity, causing declined farm yields and increased input costs (van Noordwijk et al., 2020). Intensive and mono-cropping systems are also problematic from an economic perspective. Research in Vietnam reported that relying on single crops such as coffee, which is associated with large price volatility, farmers, especially the poor, faced considerable market risks (Pham et al., 2020) and thus income variation. Adoption of agricultural practices that can reduce environmental impacts while ensuring yield stability are urgently needed.

Climate-Smart Agriculture (CSA) can be a potential solution to address interconnected pressures from climate change, food insecurity, and environmental degradation induced by intensified and simplified farming systems in Southeast Asia. Climate-Smart Agriculture is based on three pillars including sustainably increasing agricultural productivity and incomes, building climate resilience, and reducing greenhouse gas emissions (Palombi & Sessa, 2013). Among various CSA practices classified by FAO, intercropping is particularly common among smallholder farmers in developing countries (Maitra et al., 2020). Intercropping is the practice of growing two or more species at the same plot at the same time (Glaze-Corcoran et al., 2020). The practice has shown potential in improving farm income and food security via yield improvement and stabilization (Raseduzzaman & Jensen, 2017) while contributing to environmental sustainability via the reduced use of chemical inputs (Bedoussac et al., 2018).

Given its ability in soil conservation, pest management improvement, and efficient use of resources, intercropping can safeguard field cropping from anticipated climate change and the associated weather variability (Himanen et al., 2016). For instance, intercropping between legumes, which are nitrogen-fixing plants, with other crops enhances soil nitrogen level, thereby reducing the need for nitrogen fertilizer on farms (Himanen et al., 2016). With Global warming, the proliferation of pests and plant diseases is expected to accelerate (Nasution, 2024). The increased species richness provided by intercropping attracts beneficial insects, which can help control pest development (Maitra et al., 2021). In addition, shade cover created in intercropping systems reduces soil evaporation, leading to increased water availability and consequently lowering the amount of water required by farmers (Lin, 2010). This is particularly important for small holder farmers in regions facing water scarcity. The adoption of any CSA practice is a choice of individual smallholders. Therefore, to understand and support better the adoption of CSA in general and intercropping in particular, we need to understand what factors are decisive in smallholders' adoption processes.

There is a growing research interest in farmers' adoption of climate-smart practices in Southeast Asia. In this respect, Bairagi et al. (2020) investigated the impact of adopting climate-resilient strategies on food security in Cambodia while Saptutyningsih et al. (2020) examined the willingness to participate in the climate change adaptation process among Indonesian farmers. However, studies explicitly focusing on the factors that determine the adoption of CSA are limited in Southeast Asia. While intercropping, a CSA practice (Ng'ang'a et al., 2020), is more common in developing countries (Maitra et al., 2021), little is known about the enabling and disabling factors associated with smallholders' adoption of intercropping in developing countries, particularly Southeast Asia. Noticeably, cross-country analyses that compare the adoption of climate-smart practices, particularly intercropping across space are even more scarce in this region. Such comparative analysis would contribute useful insights into how conditions for adoption vary across different countries with different economic, cultural, and political conditions in Southeast Asia. Vietnam, Laos, and Cambodia are heterogeneous in culture (Kim, 2002) and the economic development (World Bank, 2022). Such heterogeneity might lead to discrepancies in smallholders' adoption of climate-smart practices in these countries. However, such discrepancies have not been well understood.

Accordingly, this study aims to assess and compare the heterogeneity in adoption of CSA in Vietnam, Laos, and Cambodia, through the lens of climate change adaptation. In particular, we focus on intercropping as a promising CSA in the region and compare the socio-economic and psychological factors associated with farmers' adoption tendency in those countries. The study has three contributions to the literature. First, building upon previous literature, we consider a range of potential psychological factors associated with intercropping as a climate-smart practice. These include perceived social support, perception of the severity of climate change and its impact, information acquisition about adaptation, perceived ease, and perceived usefulness of intercropping adoption. Perceived usefulness is defined as the extent to which farmers believe that intercropping can help them adapt to climate change. Second, we examined the association between home gardens and the adoption tendency toward intercropping. Evidence on the species richness and the dominance of cultivated plant species in home gardens in developing countries (Lemessa & Legesse, 2018; Srithi et al., 2012) suggests that intercropping might have been implemented in these informal production systems. Thus, there might be a link between home garden and intercropping. Third, this is the first cross-country study that analyses country differences and/or similarities in factors associated with the uptake of a typical climate-smart practice in Southeast Asia. With these theoretical contributions, the current study provides useful insights to support the design of agricultural resilience policies that aim to foster the adoption of climate-smart practices.

2. Literature review and positioning of the present study

Literature on famers' adoption of CSA practices and agricultural technologies can inform studies on intercropping uptake among smallholders in Southeast Asia. Previous research has identified a range of factors that shape farmers' decision to adopt CSA practices and agricultural technologies in developing countries (Khoza et al., 2021). Amadu et al. (2020) pointed out that understanding the driving forces that influence farmers' decisions to adopt CSA practices requires integrating perceptions, knowledge and experiences of farmers who observe and experience climate changes from different perspectives. Among multitude of perception dimensions, perceived climate change appears an important predictor of farmers' adaptation decision. Research from Southeast Asia found that perception of climate change and/or the perception of vulnerability was positively correlated with the number of adopted adaptation practices (Hasan & Kumar, 2019) and the choice of adaptation measures (Waibel et al., 2018b). The association between climate change perception and adaptation decision can be traced back to Protection Motivation Theory (Rogers, 1975), which postulates that individuals who perceive a threat to them would take actions to reduce such threat. Applied in intercropping, if farmers consider this practice as an adaptation measure, a high risk perception of climate change will motivate them to intercrop to eliminate the perceived risks.

Farmers' awareness and knowledge of CSA practices are shaped by their prior experiences, access to information about climate change, CSA practices, and climate-induced challenges that affect their agricultural production (Mashi et al., 2022). Access to weather forecast, in particular, helps farmers to plan effectively their farming activities (e.g. land preparation, planting date, crop variety selection, scheduling of fertilizer application, and harvest time (Djido et al., 2021). Climate information can be disseminated to farmers through various channels, including mobile phones (e.g., SMS), radio, televisions, printed media, extension officers (Yegbemey & Egah, 2021), and peers (Thinda et al., 2020). Access to climate information via extension service (Djido et al., 2021), radio and mobile phones (Thinda et al., 2020) has been shown to encourage the adoption of adaptation strategies in developing countries. However, simply providing information may not lead to adoption if there is a disconnect between what information providers consider useful and what users perceive as usable (Sarku et al., 2022). Additionally, the presence of passive adaptation (Tripathi & Mishra, 2017) suggests that farmers may lack knowledge of intentional adaptation strategies. Passive adaptation occurs when farmers unintentionally implement agricultural practices that serve adaptation strategies, but their primary goal is to increase income rather than adapt to climate change (Tripathi & Mishra, 2017). Thinda et al. (2020) suggest that effectively disseminating information on adaptation strategies to small-scale farmers can motivate them to adopt such practices. Based on this literature it is expected that acquiring information on climate change and adaptation will be associated with the adoption of intercropping.

Technology Acceptance Model (TAM) developed by Davis (1989) postulates that perceived usefulness/benefit and perceived ease of use explain attitudes toward a technology, and subsequently determine technology acceptance. An array of empirical evidence on CSA adoption provides support for this theoretical framework. For instance, Meshesha et al. (2022) found that farmers viewed the usefulness or benefit of CSA practices from economic and non- economic dimensions and both of them were key determinants of farmers' adoption of a CSA practice. According to Teklewold, Mekonnen, et al. (2019) farmers evaluated new agricultural innovations and practices based on the expected benefits provided by such innovations. That is, some CSA practices may generate multiple and importantly perceived usefulness in helping farmers in adapting to climate changes whereas others can have limited perceived usefulness. Moreover, different farmers might view the usefulness of a CSA practice like intercropping differently and the adoption of this practice might not necessarily be a response to climate change. For instance, while farmers in Pakistan perceived crop diversification as an adaptive practice (Abid et al., 2019), farmers in Uganda considered it as an income generation activity (Jassogne et al., 2013). In the current study, "usefulness" can be understood as the extent to which intercropping with its potential benefits enables climate change adaptation of farmers. Some examples of such potential benefits are soil conservation, yield stability, reduced water use, and better pest control, as compared to monocropping (Himanen et al., 2016; Lin, 2010; Maitra & Ray, 2019).

Perceived ease of use might also be associated with intercropping adoption. Literature shows that farmers' perception of their own capacity and confidence to use CSA practices is associated with their CSA adoption (Lalani et al., 2016). Such perception of ease is subsequently dependent on the belief whether they have necessary means and resources to practice CSA (Lalani et al., 2016). Theoretically, perceived ease of use can be linked to the concept "perceived behavioural control", one of the main psychological constructs in Theory of Planned Behaviour (TPB) (Ajzen, 1991). According to TPB, without the belief about one's own ability in performing a behaviour (perceived behavioural control), individuals might fail to carry out that behaviour, despite holding a positive evaluation towards the behaviour. In other words, perceived behavioural control or perceived ease of use can explain the intention to perform a behaviour. Intercropping, in particular, is a complex practice that requires a large amount of labour and comprehensive knowledge of crop management (Bybee-Finley & Ryan, 2018; Glaze-Corcoran et al., 2020). As such, farmers' perceived ease of intercropping might play an important role in shaping their decision towards intercropping adoption.

Farmers' perception of their access to resources in terms of informal social support (or informal safety net/social protection) can be related with intercropping adoption in developing countries. Informal social support, in this study, refers to support from families, friends, neighbours, and other social actors within individuals' kinship and/or community networks. This type of support can be considered as a bonding social capital that is an important asset for farmers to cope with extreme climate events (Adger, 2010). In Southeast Asia's rural areas, where strong bonding relationship among farmers, their relatives, neighbours, and friends is common (Tran & Rodela, 2019), informal social support might be particularly relevant. In this region, social support include informal loans, group sharing losses, supporting the worst off (Resurreccion et al., 2008), and sharing of knowledge and information (Tran & Rodela, 2019). Since intercropping is costly and labour intensive (Maitra et al., 2020), smallholders who have access to financial, information, and labour support from their informal social networks will be able to remove production constraints, and thus are able to practice intercropping.

Previous literature has also highlighted the role of socio-economic and demographic characteristics in influencing farmers' adoption of a particular CSA practice (Ali, 2021). More specifically, these characteristics can be associated both with farmers' perception of climate-induced risks to agricultural production and with their capacity to implement risk management strategies including CSA practices. Studies regarding farmers' technology adoption often accounted for the role of gender, age, education, farming experience, income, farm size, and tenure (Ashrit & Thakur, 2021; Zhang et al., 2020). Similarly, research from developing countries on farmers' adoption of climate change adaptation strategies reports that age, gender, education, livelihood (e.g., having off farm job), and farm size were among the predictors of the adoption (Aryal et al., 2021; Thinda et al., 2020).

Home gardens in developing countries are informal food production systems among households (Rammohan et al., 2019). In these countries, home gardens are common and they have proven to enhance food security and malnutrition, provide livelihood opportunities for resource-poor families, and deliver ecosystem services (Galhena et al., 2013). We argue that in developing countries, intercropping can be implemented in not only formal production systems such as farmers' fields but also informal production systems like their home gardens. A home garden can include cultivated plants and naturally grown plants and both of these two are managed by

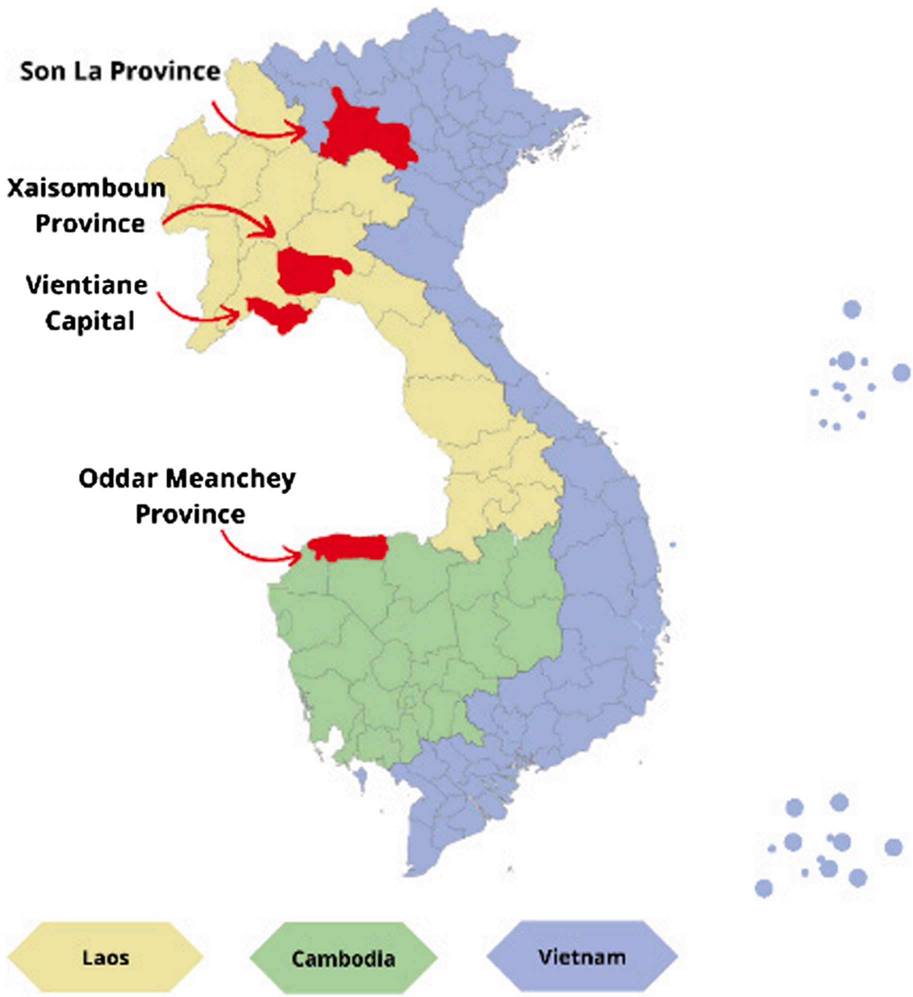

Fig. 1. Map of Vietnam, Laos, and Cambodia and studied provinces.

households for their usefulness (Srithi et al., 2012). Home gardens in developing countries are characterizedby a high level of diversity of plants, especially cultivated plants such as fruit, vegetables, cereals, legumes, herbal medicine, and timber (Lemessa & Legesse, 2018; Srithi et al., 2012). This is evidence of the prevalence of intercropping in home gardens. Households with home gardens might be interested in intercropping on their gardens to obtain a range of food for family consumption. Experiences from intercropping in home gardens might translate into a motivation to intercrop on fields. As such, there might be a link between home garden and intercropping adoption.

Drawing upon a rich literature on the determinants of CSA uptake, in this study, we investigate the association between a range of psychological drivers and smallholders' adoption of intercropping. They include perception of 1) social support, 2) climate change severity, 3) climate change impact, 4) information acquisition of climate change and adaptation and, 5) the ease, and 6) the usefulness of intercropping. We also examine the association between intercropping adoption with smallholders' characteristics (age, education, farming experience) and households' socio-economic conditions (poverty status, land area, the presence of off-farm jobs, home gardens). These socio-economic and demographic variables serve as control variables in our analysis.

3. Method and data

3.1. Study area

Our study area covers four provinces including Son La (Vietnam), Xaysomboun and Vientiane (Laos), and Oddar Meanchey (Cambodia) (see Fig. 1). Son La and Xaysomboun are mountainous provinces, Oddar Meanchey is a hill land region, and Vientiane is a low land region (see the map in Fig. 1). In these provinces, droughts and floods have occurred frequently. It is worth noting that we planned to select mountainous or highland provinces only, which are vulnerable to climate change. However, due to the outbreak of COVID19 and social distancing policies in Laos during the survey, we had to select a low land province (Vientiane) to reach the expected sample size. The heterogeneity in geographical typology among the selected provinces is one of the limitations of this study.

Son La province's climate is tropical and humid with a cold winter and two distinct seasons including dry and the rainy season. Give the influence of medium–high mountains along the Vietnam and Laos border, during March and April, Son La is affected by the southwest wind, which is dry and hot and thus the weather is fairly harsh. The annual average temperature is above 20 °C and vary between regions (Vietnam Ministry of Information and Communication, 2023). A warming climate has been observed in the province. From 1986 to 2020, the number of hot days (≥35 °C) increased, while the number of cold days (≤15 °C) and very cold days (≤13 °C) decreased (Yen Chau and Bac Yen Hydro-Meteorological Station, 2020). The total rainfall per year is from about 1,400–1,700 mm. Rainfall is unevenly distributed over time with heavy rain being concentrated during June to August, leading to frequent floods and droughts. Climate change has severely impacted the agricultural ecosystem, causing flash floods, landslides, and hailstorms that have devastated crops and livestock (Yen Chau and Bac Yen Hydro-Meteorological Station, 2020).

Vientian capital has a tropical climate with a wet and a dry season while Xaysomboun has a humid subtropical climate with dry winters. The average temperature is between 23.4 and 28.8 °C for the former and from 18.3 to 24 °C for the later. However, in mountainous areas like Xaysombouan, the temperature could be lower than 5 °C during December and January but exceed 40 °C in hot season between April and May (Laos Ministry of Agriculture and Forest, 2022). During 2020 to 2022, the average annual precipitation increased from 1500 to 2007 mm in Vientiane Capital and from 1445 to 2012 mm in Xaysombouan province (Laos Ministry of Agriculture and Forest, 2022). In lowland areas like the rural districts of Vientiane Capital, a large proportion of farmers rely on paddy rice cultivation, being affected by flood during the raining season and drought during dry season. In mountainous areas such as Xaysombouan, flood and landslides occur frequently (CFE-DM, 2024).

Oddar Meanchey Province is characterized by a tropical savanna climate with distinct wet and dry seasons (Cambodian Ministry of Environment, 2016). Average temperatures range from 27 °C to 28 °C, with extremes exceeding 35 °C in the hot season and rarely falling below 15 °C in the cool season. The province receives 1,200–1,500 mm of annual rainfall from May to October, leading to cyclical flooding and droughts (Cambodian Ministry of Environment, 2016). Floods damage crops and infrastructure during the wet season, while droughts hinder growth and reduce yields during the dry season (Cambodian Ministry of Environment, 2016). Extreme weather events like hailstorms exacerbate these issues, threatening food security and livelihoods (Cambodian Ministry of Environment, 2016). These patterns align with broader regional trends of increased extreme weather events, posing a substantial threat to rainfed agriculture (IPCC, 2021).

In the chosen provinces, we selected five districts, namely Yen Chau and Van Ho (Son La), Anouvong (Xaysomboun), Naxaythong (Vientiane capital), and Banteay Ampil (Oddar Meanchey). The foremost criteria to select these districts include i) they are representative for agricultural production of their corresponding province, ii) their agricultural production is greatly affected by climate change, iii) crop production is one of the main agricultural activities, and iv) if possible, farmers are from different ethnic groups. We consulted local authorities to identify potential districts, which meet the above criteria. Unfortunately, surveyed farmers in Banteay Ampil include Khmer only since ethnic minorities in Cambodia prefer to live in low land regions. In contrast, the survey samples in Laos and Vietnam were diverse in ethnicity, including both ethnic majority (Lao and Kinh in Laos and Vietnam, respectively) and ethnic minorities. It is worth mentioning that that we did not use information about ethnicity in the paper and we only contacted groups that we think belong to certain ethnicities.

Our group discussions with local informants in selected districts revealed different intercropping patterns across the districts. In Yen Chau and Van Ho districts (Son La), intercropping between maize and legumes such as soybeans, red peanuts, and small peas is common. Since Son La is specialized in fruit production, farmers are also interested in growing a mixture of different types of fruit trees or intercropping between fruit trees and cereals. In Naxaithong (Vientiane province), rice-taro intercropping is the most common and in Anouvong district (Xaisomboun province), pumpkin and sponge gourd are often intercropped with rice and maize. In Banteay Ampil district (Oddar Meanchey province), not many farmers practice intercropping. Some crops are commonly intercropped with orchard trees include pumpkin, maize, and bean.

3.2. Household survey

Our household survey was conducted during April to August 2021 and given budget constraints, we used convenience sampling to recruit participants, who are the representatives of farm households (household representatives). We considered the balance in gender among surveyed household representatives by setting a predetermined ratio 1 male to 1 female respondent to be interviewed by each enumerator. The percentage of surveyed male farmers versus females in Vietnam, Laos, and Cambodia is 52 % versus 48 %, 56 % versus 44 %, 47 % versus 53 %, respectively (Table 1). Moreover, we also took into account the presence of farmers from varying economic statuses (see Table 1, self-reported economic status). This was done by i) varying survey locations within a district (e.g., selecting communes with different distance from the district centre), ii) selecting communes within a district with varying levels of agricultural productivities, and iii) collaborating with community leaders who understand farmers' economic status to identify and reach out to farmers from diverse economic backgrounds. In total, 1017 household representatives including 417 from Vietnam, 299 from Laos and 303 from Cambodia participated in the survey. Kobo Toolbox, a free and open digital data collection platform was used. This tool also allows an effective control of data quality (Lakshminarasimhappa, 2022). The survey questionnaire was scripted into a digital form and this form was then deployed on mobile devices for data collection in both online and off-line conditions. All enumerators were provided training to ensure they understood the survey question and knew how to administer the digital questionnaire.

Table 1 shows the socio-demographic characteristics of surveyed farmers and their households. The mean age of surveyed farmers was the lowest in Vietnam and the highest in Cambodia. Cambodian farmers had the lowest education levels and the largest farm size. Household size was the largest in Laos and smallest in Cambodia. Noticeably, the percentage of households that claimed themselves as poor is the highest in Cambodia. In general, the survey data revealed considerable differences in social-demographic characteristics of surveyed households across the three studied countries.

3.3. Variable measurement

Dependent variable: Intercropping adoption was measured by different levels of adoption tendency to reveal smallholders' adoption process. Adoption tendency of intercropping was assessed via the statement: "Intercropping means growing two or more crops on the same piece of land at the same time. Please select only one of statement that applies to your household: 1) I am not intercropping and I am not willing to do it in the future, 2) I have not intercropped yet but I am thinking of doing it in the near future, 3) I am currently intercropping". Respondents who are selected the first, the second, and the third option were categorized as "laggards", "potential adopters", and "current adopters", respectively.

Independent variables

Thirteen independent variables were used in the analysis (bold variables, Table 3). Four of them are components retained from Principal Component Analysis (see detailed information in Section 3.3). They include SocialSupport, PerceivedClimate, PerceivedClimateImpact, and Information. These four components relate to perception of CSA including perception of 1) informal social support, 2) climate change severity, 3) climate change impact, and 4) access to information on climate change and adaptation. Each component consists three or four single question items that were assessed using 5-point Likert scale with a higher score meaning a higher level of support, agreement, and impact (Table 3). These items were adapted from Na et al. (2019), Waibel et al. (2018b), and Southall et al. (2018). It is worth noting that items 13 (InformationVolume) in construct "Inform" only refers to information access rather than

Table 1
Sociodemographic characteristics of surveyed farmers and their households in Vietnam, Laos, and Cambodia.

	Vietnam (n = 415)		Laos (n = 299)		Cambodia (n = 303)	
	Mean or %		Mean or %	SD	Mean or %	SD
% of female farmers	51.81	N/A	56.86	N/A	47.52	N/A
Age	37.76^{a}	10.45	41.45^{b}	13.78	48.29^{b}	13.29
Education	1.63^{a}	1.24	1.71^{a}	1.47	0.89^{c}	0.96
Number of children equal or less than 12 years old per household	1.47^{a}	0.99	2.86^{b}	1.83	1.06^{c}	1.05
Household size	4.93^{a}	1.56	7.54^{b}	2.96	4.40^{c}	1.55
Farm size (ha)	1.67^{a}	1.97	3.28^{b}	5.77	4.99^{c}	8.44
Farming experience(years)	21.59^{a}	11.47	21.23^{a}	13.08	27.30^{c}	15.12
Self-reported economic status (% household)						
Very poor	2.41^{a}	N/A	6.02^{b}	N/A	6.60^{b}	N/A
Poor	33.0^{a}	N/A	18.39^{b}	N/A	30.03^{a}	N/A
Average	56.14	N/A	57.19	N/A	56.77	N/A
Well-off	7.95^{a}	N/A	14.38^{b}	N/A	4.62^{c}	N/A
Very well-off	0.48^{a}	N/A	4.01^{b}	N/A	1.98^{b}	N/A

Note: [a,b,c] Scores in one row with a different superscript are statistically significantly different at $p < 0.05$ using oneway ANOVA and post hoc Tukey test for mean values and Wald test for percentages. N/A denotes not applicable. Education was coded as 0 (no schooling), 1(primary school), 2 (secondary school), 3(high school), 4 (vocational training), 5 (university), 6 (post graduate).

Table 2
Percentage of respondents by tendency to adopt intercropping in Vietnam, Laos, and Cambodia.

Categories of adoption tendency	Whole sample (n = 1017)		Vietnam (n = 415)		Laos (n = 299)		Cambodia (n = 303)	
	Freq.	%	Freq.	%	Freq.	%	Freq.	%
Laggards	381	37.46	78	18.80	167	55.85	136	44.88
Potential adopters	308	30.29	98	23.61	89	29.77	121	39.93
Current adopters	328	32.25	239	57.79	43	14.38	46	15.18

Table 3
Descriptive statistics of the independent variables by studied countries.

Variables/variable number	Description	Vietnam{Mean (SE)	Laos {Mean (SE)	Cambodia {Mean (SE)
SocialSupport	Perceived informal social support1 (very little) – 5 (very much)			
1.SupportFromOthers	Receive support from others	4.04^{a}(0.04)	2.61^{b}(0.06)	3.30^{c}(0.08)
2.SupportFromRelatives	Receive support from relatives or friends	3.92 ^{a}(0.048)	2.84^{b}(0.061)	3.24^{c}(0.081)
3.ProvideSupport	Provide support to others	4.30 ^{a}(0.03)	2.85^{b}(0.06)	3.56^{c}(0.07)
PerceivedClimateSeverity	Perception of climate severity1 (strongly disagree)- 5 (strongly agree)			
4.PerceivedLessRain	Perceived less rain	4.24 ^{a}(0.03)	3.22^{b}(0.07)	4.21^{a}(0.05)
5.PerceivedDrySeason	Perceived longer dry season	4.33 ^{a}(0.03)	3.28^{b}(0.06)	4.32 ^{a}(0.05)
6.PerceivedExtreme Event	Perceived more frequent occurrence of extreme events	3.72 ^{a}(0.04)	3.00^{b}(0.05)	3.95^{c}(0.06)
7.PerceivedHotterSummer	Perceived hotter summer	4.56 ^{a}(0.03)	2.47^{b}(0.06)	4.32^{c}(0.06)
PerceivedClimateImpact	Perception of the impacts of climate change 1 (very low) – 5 (very high)			
8.IncomeImpact	Impact of climate change on household income	3.77 ^{a}(0.05)	2.86^{b}(0.06)	3.77 ^{a}(0.06)
9.Food SupplyImpact	Impact of climate change on household food supply	3.61 ^{a}(0.05)	2.53^{b}(0.07)	3.70 ^{a}(0.06)
10.CropProductionImpact	Impact of climate change on household crop production	4.25^{a}(0.04)	3.18^{b}(0.07)	3.71^{c}(0.07)
Inform	Information acquisition of climate change and adaptation1 (very poor/little) – 5 (very good/very much)			
11.BeInformed	How well the household is informed about adaptation strategies	2.25 ^{a}(0.04)	2.15^{b}(0.12)	1.95^{b}(0.05)
12.KnowledgeLevel	Subjective knowledge of climate change	2.42 ^{a}(0.04)	1.89^{b}(0.06)	1.95^{b}(0.05)
13.InformationVolume	Volume of information on climate change adaptation received from extension services	1.61 ^{a}(0.04)	1.75 ^{a}(0.05)	1.37^{b}(0.04)
14.PerceivedEase Intercropping	Perceived ease of intercropping1 (very difficult) – 5 (very easy)	3.11 ^{a}(0.05)	2.31^{b}(0.05)	2.26^{b}(0.06)
15.PerceivedUsefulness Intercropping	Perceived usefulness of intercropping in helping farmers in adapting to climate change (e.g., crop yield stability) 1 (very little) – 5 (very much)	2.86 ^{a}(0.04)	2.23^{b}(0.07)	2.37^{b}(0.05)
16.Age	Respondent's age	37.77 ^{a}(0.51)	41.40^{b}(0.80)	48.36^{c}(0.76)
17.Education	Respondent's education, from 0 (no schooling) to 6 (postgraduate)	1.63 ^{a}(0.06)	1.72 ^{a}(0.09)	0.89^{b}(0.06)
18.Poor	Self-reported poverty status (=1 if poor, = 0 otherwise)	0.35 ^{a}	0.25^{b}	0.36^{a}
19.FarmExperience	Farming experience in years	21.59 ^{a}(0.57)	21.21 ^{a}(0.76)	27.34^{c}(0.87)
20.Land_area	Agricultural land area in ha	1.67 ^{a}(0.10)	3.21^{b}(0.33)	5.01^{c}(0.49)
21.HomeGarden	=1 if having home-garden, = 0 otherwise	0.713^{a}	0.51^{b}	0.40^{c}
22.OffFarmJob	=1if having off-farm job, = 0 otherwise	0.42 ^{a}	0.45 ^{a}	0.16^{c}

Note: ^{a,b,c} Scores in one row with a different superscript are statistically significantly different at $p < 0.05$ using Kruskal-Wallis and Dunn's test (for ordinal variables) and oneway ANOVA and post hoc Tukey test (for continuous variables). N/A denotes not applicable. Variables with a number are original survey items. Variables without a number are components retained from PCA.

information usability and therefore does not consider the difference between the two.

The nine remaining independent variables are perceived ease, perceived usefulness of intercropping, age, education, farming experience, poverty status, agri-land area, the presence of home-garden and off-farm job. Survey items measuring perceived ease and perceived usefulness were adapted from Caffaro et al. (2020). To capture perceived usefulness, respondents were asked the following question: "To what extent intercropping can help you to adapt to climate change better, e.g., via stabilizing yield, reducing water use, and protecting the soil".

3.4. Data analysis

The ANOVA and post hoc Turkey tests were performed on continuous variables while Kruskal-Wallis and Dunn's test were employed on ordinal variables to compare the mean score of the variables of interest across the studied countries (see Tables 1 and 3).

Principle component analysis (PCA)

Principle component analysis is a data reduction technique that transforms a large and correlated dataset into a smaller number of uncorrelated principle components with minimum loss of original information (Jolliffe, 2002). Thirteen survey items that capture various perceptions towards climate change and adaptation (items number 1–13, Table 3) were interrelated. Thus, they were subjected to PCA to form principle components that reflect different dimensions of climate change perception (Table 4). We chose PCA where components retained are uncorrelated to avoid multicollinearity issue in subsequent regression analysis.

The Kaiser-Meyer-Olkin (KMO) value of 0.84 and the significant result of Bartlett's Test of Sphericity indicate that the data are suitable for PCA. Four components with Eigenvalues greater than 1.0 were retained, as suggested by Jolliffe (2002) and they were denoted SocialSupport, PerceivedClimateSeverity, PerceivedClimateImpact, and Inform. Table 4 shows that all factor loading values are greater than 0.6, larger than the minimum acceptable level of 0.5, recommended by (Hair et al., 2017).

Generalized ordered logit regression

Covariates included in regressions are nine survey items (number 14 to 22 in Table 3) and factor scores of the four components retained from PCA. We used generalized ordered logit regression (gologit) as adoption tendency has the ordinal nature and gologit can relax the proportional odd assumption. This means the effect of an independent variable can vary across cut-points (Williams, 2006). There were two cut points in this study: the first cut point contrasts the first category (laggards) with the second (potential adopters) and third categories (actual adopters); the second cut point contrasts the first and the second categories with the third. The assessment of the proportional odd assumption shows the existence of variables violating the assumption (four for Vietnam, 3 for Laos, and 1 for Cambodia). Accordingly, we applied partial proportional odds models that allow the constraints for proportional odd assumption to be relaxed for violated variables. Stata 17.0 with gologit2 command (Williams, 2006) was used to estimate the models.

4. Results and discussion

Table 5 presents the results of the estimated gologit models for the three countries. Overall, perceived ease and perceived usefulness of intercropping were the two most important predictors of intercropping adoption for all three countries. Moreover, the association between either perceived ease or perceived usefulness and adoption tendency was relatively strong. In the Vietnam and Laos subsamples, these two variables exert either the largest or the second largest effect on adoption. In the Cambodia subsample, the effect of perceived ease was also the largest. In the Vietnam subsample, the effect of perceived ease was higher in the first threshold while that of perceived usefulness was higher in the second threshold. This means with the same increase in perceived ease of intercropping, the likelihood for a farmer to move from a "laggard" to a "potential adopter" would be higher than the likelihood to turn a "potential adopter" into an "actual adopter".

Research from developing countries on intercropping adoption indicates that farmers have recognized the usefulness of intercropping systems in enhancing their climate resilience and thus incline to apply this practice (Pham et al., 2020). In the Central highland of Vietnam, where drought is the main concern, farmers intercrop coffee with black pepper and fruit trees, which consume less water to improve income and stabilize coffee yield, particularly during severe droughts (Pham et al., 2020). In Mozambique, though maize-legume intercropping is labour- and cost intensive, farmers prefer to implement the practice because it improved yield and reduced production risks (Maitra et al., 2020). However, management complexity is a key challenge for intercropping systems (Jensen et al., 2020). This is supported by our survey result, which reveals that the mean score of perceived ease of intercropping ranges between 2.5 and 3.0 out of 5, which is relatively low (Table 5). These results imply the existence of barriers to intercropping adoption. Like farmers in Africa, Southeast Asian farmers might also lack training on intercropping and access to capital and inputs (Jassogne et al., 2013).

Previous studies have also confirmed a positive relationship between perceived ease of use, perceived usefulness and farmers' adoption of various types of sustainable farming practices, which are also climate-smart (Lalani et al., 2016; Rezaei et al., 2020). For instance, Rezaei et al. (2020) found that attitude, perceived usefulness, and perceived ease of use explained 41.3 % of the variance in the farmers' uptake of integrated pest management (IPM) practices. A strong association between either perceived ease or perceived

Table 4
Results of principle component analysis on perception towards climate change and adaptation.

	Social Support	Perceived ClimateSeverity	Perceived ClimateImpact	Inform
SupportFromOthers	0.90			
SupportFromRelatives	0.86			
ProvideSupport	0.85			
PerceivedLessRain		0.83		
PerceivedDrySeason		0.82		
PerceivedExtreme Event		0.69		
PerceivedHotterSummer		0.61		
IncomeImpact			0.87	
FoodSupplyImpact			0.85	
CropProductionImpact			0.68	
BeInformed				0.79
KnowledgeLevel				0.75
InformationVolume				0.72
Eigenvalue	4.09	2.07	1.41	1.29
% of variance explained	31.49	15.95	10.83	9.91
Cronbach alpha	0.874	0.773	0.787	0.714

Table 5
Results of the generalized ordered logit regression of adoption tendency towards intercropping in studied countries.

Variables	Vietnam		Laos		Cambodia	
	1st cut pointCoef. (SE)	2nd cut pointCoef. (SE)	1st cut pointCoef. (SE)	2nd cut pointCoef. (SE)	1st cut pointCoef. (SE)	2nd cut pointCoef. (SE)
SocialSupport	−0.56*** (0.19)	−0.56*** (0.19)	0.26 (0.20)	0.26 (0.20)	0.05 (0.11)	0.05 (0.11)
PerceivedClimate Severity	−0.84** (0.34)	−1.67*** (0.30)	−0.35** (0.16)	−0.35** (0.16)	−0.12 (0.12	−0.12 (0.12)
PerceivedClimate Impact	−0.56*** (0.16)	−0.56*** (0.16)	0.53*** (0.20)	−0.58** (0.26)	−0.28** (0.14)	−0.28** (0.14)
Information	−0.49*** (0.16)	−0.49*** (0.16)	0.74*** (0.16)	0.74*** (0.16)	0.28* (0.15)	0.28* (0.15)
EasyIntercropping	1.36*** (0.20)	0.93*** (0.16)	0.80*** (0.22)	0.80*** (0.22)	0.61*** (0.14)	0.61*** (0.14)
Usefulness Intercropping	0.77*** (0.24)	1.42*** (0.26)	0.77*** (0.16)	1.75*** (0.32)	0.30** (0.15)	0.30** (0.15)
Age	−0.08** (0.03)	−0.05 (0.03)	0.02 (0.01)	0.02 (0.01)	−0.01 (0.01)	−0.01 (0.01)
Education	0.24* (0.12)	0.24* (0.12)	0.14 (0.11)	0.14 (0.11)	0.09 (0.14)	0.09 (0.14)
Poor	−0.27 (0.27)	−0.27 (0.27)	0.11 (0.36)	0.11 (0.356)	0.10 (0.26)	0.10 (0.26)
FarmExpierence	0.07** (0.03)	0.07** (0.03)	−0.00 (0.01)	−0.00 (0.01)	0.00 (0.01)	0.00 (0.01)
AgriLand_area	−0.03 (0.12)	0.32 (0.12)	−0.06* (0.04)	−0.06 (0.04)	0.00 (0.01)	0.00 (0.01)
HomeGarden	0.31 (0.26)	0.31 (0.26)	0.14 (0.32)	1.02* (0.52)	0.78*** (0.27)	1.63*** (0.38)
OffFarmJob	−0.42 (0.26)	−0.42 (0.26)	0.04 (0.31)	0.04 (0.31)	0.51 (0.32)	0.51 (0.32)
cons	−2.39* (0.97)	−5.81*** (1.06)	−4.71*** (0.97)	−11.393*** (1.54)	−2.07*** (0.74)	−4.87*** (0.81)
Model fit						
Pseudo R^2	0.25		0.41		0.13	

Note: ***, **, and * indicate significant level at 0.01, 0.05, and 0.1, respectively.
The 1st cut point contrasts the 1st category (laggards) with the 2nd (potential adopters) and 3rd categories (actual adopters); the 2ndcut point contrasts the 1st and the 2nd categories with the 3rd.

usefulness with adoption readiness toward intercropping revealed in this study is theoretically supported by Technology Acceptance Model (TAM) developed by Davis (1989).

Perceived impact of climate change was also significantly associated with intercropping adoption tendency, across all studied countries. Nevertheless, perceived climate change severity was related to the adoption tendency toward intercropping in Vietnam and Laos, but not Cambodia. Generally, both the two variables perception of climate change severity and perception of climate change impact were negatively associated with the tendency to adopt intercropping, with an exception: perceived impact caused a positive effect in the first cut point of the Laos model. The negative association above implies that farmers who perceived a higher level of impact and/or the severity of climate change were less interested in intercropping.

In line with previous surveys in Southeast Asia (Hasan & Kumar, 2019; Waibel et al., 2018b), our study found that surveyed households perceived climate change. Table 2 shows that the mean scores of survey items relating to the perception of climate change and impact were in the range of 2.5 to 4.5 out of 5, which are relatively high. What distinguishes our results from those of previous CSA studies (e.g., Waibel et al. (2018b) and Hasan and Kumar (2019)) is the negative association between the perception of climate change and the adoption tendency of intercropping. A possible reason for our finding is that intercropping is an ancient practice in developing countries and farmers' motivations to intercrop are due to other reasons rather than climate change. It is also possible that intercropping farmers did not view intercropping as an adaptation but mitigation strategy and thus did not relate this practice with climate change.

The association between information acquisition of climate change adaptation and adoption tendency toward intercropping was statistically significant across all countries, but with ununiformed directions: a negative sign for Vietnam and a positive sign for Laos and Cambodia. In other words, Vietnamese respondents were less likely to intercrop while Laotian and Cambodian respondents were more likely to intercrop when they obtained more information on climate change adaptation. Knowledge and information shape individuals' adaptive capacity, exposure, and sensitivity directly and indirectly (Thomas et al., 2019). Particularly, access to weather and climate information service along with agro-advisories allows smallholder farmers to understand, anticipate, and cope with the changing weather (Djido et al., 2021) and this might lead to a higher adoption rate of CSA practices.

Our findings on the positive association with information acquisition for the Laos and Cambodia are supported by empirical evidence from Ghana (Djido et al., 2021) and Malawi (Mulwa et al., 2017). In these studies, farmers' uptake of weather and climate information services was found to enhance the adoption of climate-tolerant crops, crop diversification (Djido et al., 2021; Mulwa et al., 2017), water management, and early planting techniques (Djido et al., 2021). However, Mulwa et al. (2017) also found a negative correlation between climate information access with the adoption of soil and water conservation measures. This result is similar to our finding for the Vietnamese subsample, where the association between information acquisition and intercropping adoption was negative. It is possible that Vietnamese farmers did not perceive the relevance of climate information and, therefore, did not apply it to their intercropping practices. It is worth noting that increasing access to information, such as its volume or frequency, does not necessarily enhance its usability. Information may be underutilized when it does not align with local farming conditions or fails to resonate with farmers' interests, values, and perspective (Sarku et al., 2022). The current study shows that while information acquisition on climate change adaptation is positively associated with intercropping adoption in Laos and Cambodia, this is not the case in Vietnam.

Social support was significantly associated with intercropping adoption in the Vietnam subsample but not in Laos and Cambodia. Noticeably, the adoption tendency of intercropping was more likely for respondents with a lower level of social support in Vietnam. The finding from Vietnam is contrary with that of Teklewold, Gebrehiwot, et al. (2019), where membership in several institutions decreased the likelihood to choose crop diversification. Social practices such as joining kin-based or neighbourhood networks can increase the adaptive capacity, as network members share access to information or other resources (Thomas et al., 2019). However, social practices may encourage free-riding behaviour. Farmers who receive support from their social networks might increasingly rely on their supporters and as noted by Teklewold, Gebrehiwot, et al. (2019), those farmers might be disincentive from working actively to increase farm productivity. Another possible reason is that farmers with stronger social support felt they had resources to cope with yield instability and other production risks and thus were not interested in intercropping.

The results show that farmers'- and farms' characteristics did not play an important role in explaining the tendency to intercrop. The association between age, education, years of farming experience and adoption tendency was significant for the Vietnam sample only. Intercropping was more likely to be adopted by experienced, younger, and highly educated Vietnamese farmers. The finding on years of farming experience in Vietnam is in line with Tu et al. (2018) and Thi Lan Huong et al. (2017), which focuses on the adoption of eco-friendly rice production in Mekong Delta and adaptation measure like changing crop varieties in upland Vietnam, respectively. The effect of farm holding was significant only in the first cut point in Laos' data and insignificant for both Vietnam and Cambodia. Off-farm jobs, a livelihood strategy of smallholder farmers, was not linked to the adoption tendency of intercropping in all three countries.

In all studied countries, households with home gardens appear more inclined to intercrop. However, the relationship between home gardens and intercropping adoption was significant for Laos and Cambodia only. This finding leads us to the argument that intercropping was likely to be implemented in home gardens in Laos and Cambodia's rural areas and with experiences gained from intercropping in home gardens, households would be more willing to adopt intercropping in their fields. Previous research from developing countries provide evidence on the popularity of intercropping in home gardens. High and Shackleton (2000) reported that households in Bushbuckridge Lowveld (South Africa) used an average of 3.5 cultivated crop plants from their home garden. Similarly, Srithi et al. (2012) found that on average, a home garden in Northern Thai Lan contained 3.6 plant species with 93 % of recoded species being cultivated. In Bali, Indonesia, Sujarwo and Caneva (2015) recorded 1.8 cultivated plant species per home garden. Furthermore, numerous studies from developing countries consistently report households' preference in maintaining a variety of plants and crops in home gardens for domestic consumption and a supplementary income (Castañeda-Navarrete, 2021; Mohri et al., 2013; Srithi et al., 2012; Subba et al., 2017). In our study, the average land area per home garden in Vietnam, Laos, and Cambodia is 992 ± 2918 m^2, 1688 ± 3130 m^2, and 131 ± 416 m^2, respectively. Given this small land holding and the location advantage of home gardens (home garden is nearby residential houses), it might be convenient for rural households to intercrop on their home gardens. The purpose is to provide a source of diverse, safe, and nutritious food for family consumption, save money from buying vegetables and fruits, and have small income opportunities (Nguyen et al., 2017; Rammohan et al., 2019). By linking intercropping and home gardens, this study highlights the relevance of this practice in informal food production systems like home gardens in developing countries. These informal production systems are small-scale, subsistent (Issahaku et al., 2023), and sustainable due to limited use of chemical inputs (Ha et al., 2020), therefore contributing to improved biodiversity and nutrient recycling (Mitchell & Hanstad, 2004).

This study shows that some results from Vietnam seem to differ from those in Laos and Cambodia. The contradicting results regarding the variable "information acquisition" between Vietnam and the two remaining countries might be due to the fact that the availability and the accessibility of climate information in Vietnam is better than Laos and Cambodia, as shown by Coulier et al. (2018). Unfortunately, better information access in Vietnam did not translate into a higher willingness to adopt intercropping, a CSA practice. The differences in results with regards to social support and home garden between Vietnam versus Laos and Cambodia might be due to the difference in culture and intercropping adoption in home gardens. More research is needed to explain this variation.

This study presents some limitations that need to be addressed in future research. First, using observational data, we were unable to reveal causal relationships between the independent variables of interest and the adoption tendency of intercropping. Future studies that are based on experimental data (e.g., random control trial) or using matching methods for observational data (e.g., propensity score matching) are needed to solve this issue. Second, farmers might adopt simultaneously several climate-smart practices at the same time. Focusing on a single practice like intercropping, the results of this study cannot generalize to all climate-smart practices that are currently implemented by Southeast Asian smallholders. Third, the self-reported measure of economic status is bias since different farmers might interpret each concept "poor" and "well-off" differently. To reduce the bias, we validated farmers' response by observing their housing condition, furniture, vehicles, and other assets to have insight into households' economic status and crosscheck with farmers' responses. Future research should avoid this bias via the utilization of standard measure of wealth such as International Wealth Index (IWI), which is suitable to poor- and developing countries (Smits & Steendijk, 2015).

5. Conclusions and practical implications

This study, for the first time, revealed similarities and differences in factors associated with farmers' adoption tendency of intercropping, a climate-smart agricultural practice in Vietnam, Laos, and Cambodia. Other novelties of this study are the inclusion of a range of psychological factors and the presence of home gardens to explain adoption readiness toward intercropping.

Overall, our results imply that farmers' adoption of climate adaptation and mitigation measures are linked to perception, information, and knowledge. Specifically, the results suggest that perceptions of the ease and the usefulness of intercropping represent two important factors associated with intercropping adoption among smallholder farmers across the studied countries. Thus, policy measures to improve farmers' perceived usefulness and perceived ease of intercropping could be effective in fostering intercropping adoption. This can be achieved through the development and implementation of tailored capacity building programs designed specifically for intercropping. In this regard, the importance of extension and advisory services in supporting smallholder farmers to address the climate change impacts on agricultural production cannot be over-emphasized. We also found that farmers perceived the presence of climate change and its impact and such perception were significantly negatively associated with their tendency to intercrop. Future research on whether farmers view intercropping as an adaptation strategy or a climate-smart practice will be useful in advancing our understanding of the association between the perception of climate change and intercropping adoption.

Furthermore, the relationship between information acquisition on climate change adaptation and intercropping adoption readiness was negative in Vietnam but positive in Laos and Cambodia. As such, in Laos and Cambodia, intercropping adoption can be accelerated by enhancing the provision of weather forecasts and the dissemination of effective adaptation measures taken by other farmers. This study also suggests that social support, which is largely offered by kinship and neighbourhood networks, might have hampered the adoption readiness of intercropping in Vietnam. This type of support might have led to smallholders' reliance on the support or have formed their confidence about resource mobilization, and thus discouraged the implement of CSA practices. Lastly, having a home garden was significantly positively associated with intercropping adoption in Laos and Cambodia. Via the identified link between intercropping and home gardens, this study stresses that intercropping is highly relevant to informal small-scale food production systems like home gardens in Southeast Asia.

CRediT authorship contribution statement

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Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

Acknowledgement

The authors of this manuscript appreciate the financial support from Asia-Pacific Network for Global Change Research for the project CRRP2020-10SY-Ha.

Author's credit statement

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