The effect of knowledge on farmers' intercropping adoption decisions

The perspective of Swedish farmers

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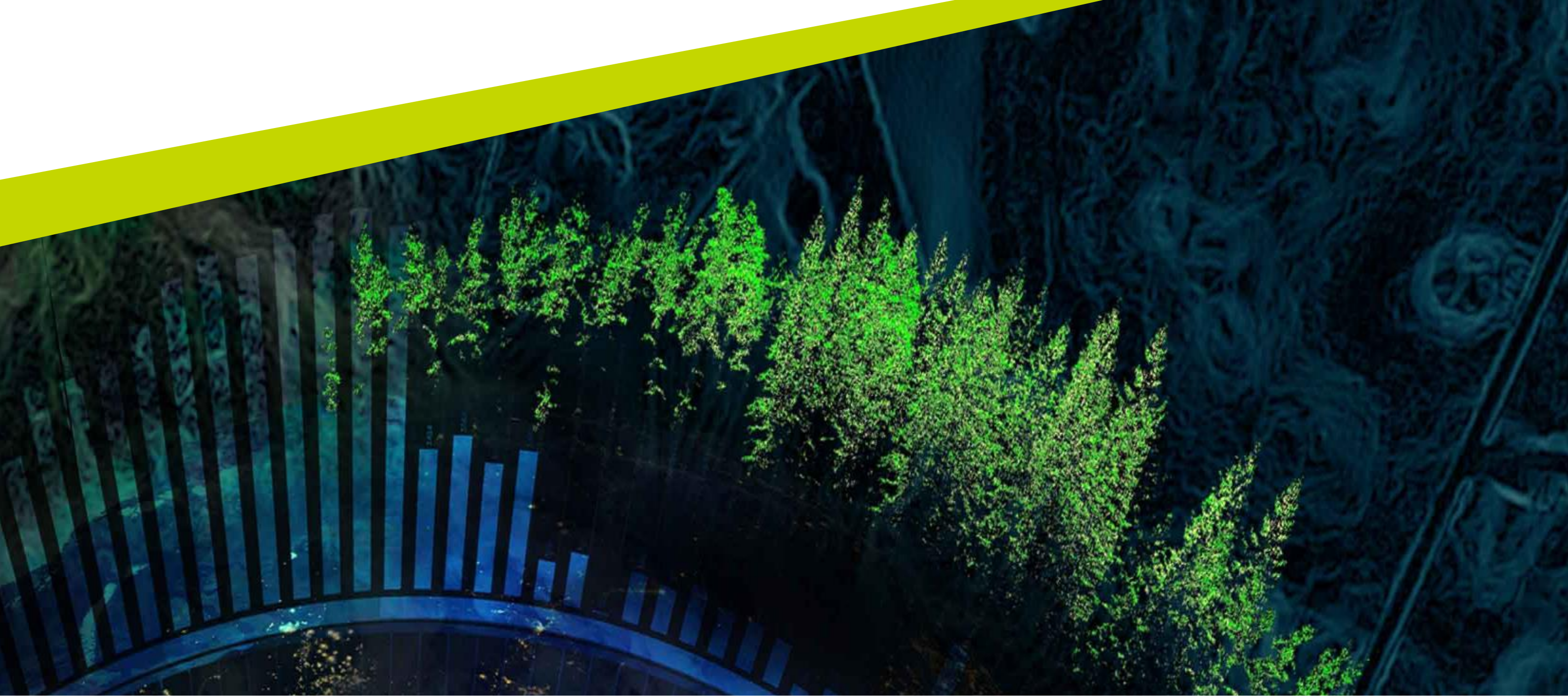

The effect of knowledge on farmers’ intercropping adoption decisions. The perspective of Swedish farmers

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Abstract

Intercropping is sustainable from both an economic and environmental point of view since it can increase yields, decrease input costs, make efficient use of available growth resources, increase crop biodiversity and natural biodiversity, suppress pests and diseases, and reduce land degradation. This makes the uptake of the practice important for future sustainable agricultural.

Since the agricultural sector has evolved around mono-cropping for decades there is a risk that farmers' knowledge is not adequate for the cultivation of intercropping. This study therefore examines how Swedish farmers' formal and informal knowledge affects their adoption and intensity decisions on intercropping, by using a double-hurdle model. The results show that the adoption decision is positively related to self-reported intercropping knowledge and negatively associated with agricultural training. Higher levels of formal education, agricultural training, discussing farm issues with other farmers and years of farming experience are associated with lower intercropping intensity.

These findings contribute to an understanding of the role of knowledge in the progression towards a more sustainable agriculture and are useful for shaping policies, information programmes, and agricultural training to increase the uptake of intercropping.

Keywords: Adoption, adoption intensity, double-hurdle model, knowledge, intercropping.

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Abbreviations

SLU	Swedish University of Agricultural Sciences
(r_s)	Spearman correlation coefficient

1. Introduction

Mono-cropping is causing decreased biodiversity, increasing emission of greenhouse gases, ecological imbalance, and degradation of natural resources (Lithourgidis et al. 2011; Mamine & Farès 2020; Maitra et al. 2021). Improved and sustainable management of soil, measures to increase and improve biodiversity and conservation of natural ecosystems can help mitigate emissions from agriculture (Jensen et al. 2020; IPCC 2022:33). This can also contribute to multiple synergies with the sustainable development goals, such as improving sustainable agricultural productivity, tackling land degradation and increasing food security (IPCC 2022:40). Both globally and in Sweden safe food must be produced on a finite amount of land to feed increasing populations. This needs to be done without increasing greenhouse gas emissions, decreasing biodiversity and degradation of natural resources (Lithourgidis et al. 2011; Ekepu & Tirivanhu 2016; Mamine & Farès 2020; Maitra et al. 2021). Therefore, it is important that feed and food production per area of land is high and that the land is well managed to avoid land degradation (Bonke & Musshoff 2020). Intercropping, also called mixed cropping, means that two or more crops are cultivated in the same field at a given time. This approach has potential to meet the requirements specified above by producing feed and food with less input, for example agrichemicals such as fertilizer and pesticides, compared to mono stands (Jensen et al. 2020; Maitra et al. 2021; Weih et al. 2022).

Intercropping makes more efficient use of the available growth resources as crops complement each other with different rooting abilities, canopy structures, heights, and nutrient requirements (Lithourgidis et al. 2011). Both crop biodiversity and the associated natural biodiversity can be increased by intercropping. Intercropped crops can contribute to increased yields and/or yield stability compared to when the same crops are grown in mono stands (e.g., Jensen et al. 2020). The practice also offers greater financial stability compared to sole cropping since it reduces the risk of crop failure (Lithourgidis et al. 2011; Weih et al. 2022) as well as being a more sustainable soil management practice by amongst other things improving soil fertility (Lithourgidis et al. 2011; Mamine & Farès 2020; Maitra et al. 2021; Weih et al. 2022). This makes intercropping sustainable from both an economic and environmental point of view.

Due to the environmental and economic sustainability of intercropping explained above, the uptake of intercropping is important for future sustainable agricultural practice. Based on the utility maximisation theory a farmer will chose to adopt intercropping if the expected utility of intercropping is higher than that of mono-cropping. However, for decades the agricultural sector has evolved around mono-cropping (Lemken et al. 2017; Bonke & Musshoff 2020; Weih et al. 2022). The traditional agricultural knowledge and innovation system is clearly production-oriented which has been internalised in many farmers' thinking and practices (Šūmane et al. 2018) and led to the emergence of path dependency (Bonke & Musshoff 2020). This applies to other stakeholders in the agricultural value chain as well (Mamine & Farès 2020; Weih et al. 2022). It is therefore a risk that farmers knowledge is not adequate for the cultivation of intercropping since it requires techniques and knowledge that is harder to acquire for the farmer (Lemken et al. 2017; Bonke & Musshoff 2020). Ingram (2008, see Šūmane et al. 2018) suggests that to be able to practice a nonprescriptive, knowledge-intensive and individual reflection demanding sustainable agriculture, a change of mindset and some re-learning might be needed from farmers. This is causing learning and opportunity costs for farmers adopting intercropping, which risks decreasing the potential benefits of the practice (Bonke & Musshoff 2020), and thereby the expected utility of intercropping.

This study will therefore examine how farmers' formal and informal knowledge affect their decision to adopt intercropping. By studying the association between formal and informal knowledge on the adoption of intercropping this study contributes to an understanding of the role of knowledge in the progression towards a more sustainable agriculture. By understanding how the farmers' knowledge affect their decision to adopt intercropping the uptake of the practice can be further diffused and diversified, which can result in a greater contribution to sustainable agriculture. Better understanding of how farmers' knowledge affect adoption decisions is useful for shaping policies, information programmes, and agricultural training to spread the uptake of intercropping.

The determinants of farmers' decision to adopt intercropping have mostly been studied in low income countries (e.g., Iqbal et al. 2006; Ekepu & Tirivanhu 2016; Ouko et al. 2022). The same decision was studied by Lemken et al. (2017) and Bonke & Musshoff (2020) with respect to German farmers. Adoption of intercropping can be seen as an adoption of new technology and the decision-making process is similar, which makes research on different technology adoption relevant to this study. The determinants of farmers' decisions to adopt new technologies have been studied broadly, both in low income countries (e.g., Adesina et al. 2000; Nkamleu & Manyong 2005; Lambrecht et al. 2014; Chuang et al. 2020; Kenfack Essougong et al. 2020) and in the context of countries with higher income (Mishra et al. 2018; Barnes et al. 2019; Paudel et al. 2020).

However, no study on the adoption decision of intercropping among Swedish farmers has been identified as part of the literature review for this thesis. This study will therefore provide a meaningful addition to existing literature. Additionally, a double-hurdle model will be used in this study, resulting in two decisions being examined. Firstly, how farmers' formal and informal knowledge effects the decision to adopt intercropping and secondly, how farmers' formal and informal knowledge affects the decision of the optimal amount of land used for intercropping (Cragg 1971). This study will therefore also contribute to the literature on adoption of new technologies by using the double-hurdle model and thereby immerse the understanding of the adoption decision and the intensity of the up-take in a context of a high-income country.

The findings of this study indicates that formal and informal knowledge does not contribute to the adoption or at least not the intensity of the adoption. The results also suggests that there is a threshold value for self-reported intercropping knowledge for a farmer to be able to adopt intercropping. Additionally, this thesis concludes that the adoption and intensity decisions are separate decisions which are influenced by different variables. Self-reported intercropping knowledge is critical for the adoption decision, together with having a higher net profit, and higher perceptions about land suitability and intercropping being environmentally friendly. For the intensity decision, having higher perception about intercropping being environmentally friendly acts as the main driving factor, while higher level of education, participating in agricultural training, more years of farming experience and discussing farm issues with other farmers appears to lower the intercropping intensity.

The paper will continue with describing the conceptual framework. In section 3 a literature review will be provided. The data and method used in this study will be described in section 4. In section 5 the results will be presented. It will be followed by a discussion and conclusions.

2. Conceptual framework

Multiple studies on farm productivity and animal welfare including Hansson et al. (2018) suggest that farmers recognise two types of economic values: use values and non-use values. Regarding animal welfare, Hansson et al. (2018) explains the use values as the economic value farmers derive from treating the animals in such way that they can produce. Non-use values are on the other hand the values farmers derive from the welfare of the animals (ibid). In Lazo et al.'s (1997) study of non-use values related to groundwater clean-up they state that the total value can be defined as containing of four components outlined in Table 1:

Table 1: Use and non-use values of clean groundwater

Value	**Description**
Use value	Direct value of clean water consumption
Altruistic value	Perceived value of others having access to clean water now
Bequest value	Current perceived value on future availability of clean water
Existence value	Intrinsic value of widely available clean water, regardless of use

Adapted from Lazo et al. (1997)

When applying use and non-use values to intercropping, the use values would be the direct economic values farmers derive from the crop yield and from the benefits of intercropping, like soil fertility and reduced input costs. The non-use values would be the values derived from the benefits of intercropping, for example avoiding/decreasing water pollution and thereby increasing water quality for others (altruistic value), increasing soil durability and biodiversity for future generations (bequest value), and simply knowing that the practice benefits the environment (existence value). Following Hansson et al. (2018), who explained farmers' motivation to work with animal welfare, I posit that the non-use values, in addition to the use values, are important motivational factors underlying farmers decision making. The non-use values can help explain why farmers take action to provide environmentally friendly soil and crop management, like intercropping, beyond the requirements imposed by productivity and profitability.

As in a variety of papers evaluating what factors affect farmers decision to adopt different types of agricultural technologies, this study will use a utility maximisation framework (Adesina et al. 2000; Nkamleu & Manyong 2005; Iqbal et al. 2006; Ekepu & Tirivanhu 2016; Danso-Abbeam et al. 2019). Based on the reasoning above, there are two main decision parameters when farmers are to decide how to position their farms in production space. These two parameters are non-use values and farm profit. The farmer is assumed to have an underlying utility function. The function can be written as:

$$U_i = (\pi_i, non - use_i)$$

Where π_i and $non - use_i$ are the farm profit respective non-use values for the ith farmer. The utility function is strictly increasing in both its arguments. The same utility function can be seen as the objective function when farmers make the decision to adopt intercropping. The adoption decision is made by maximising the utility function. If the expected utility of adopting intercropping is higher than the utility of sole cropping the farmer will decide to adopt.

Šūmane et al. (2018) states that local farmers' knowledge is linked to specific values of ethical (all non-use values), environmental (existence and bequest values), and social (altruistic values) type, i.e., non-use values. These values are reflected in practices in general and in sustainable practices especially (Willock et al. 1999; Šūmane et al. 2018). Both Willock et al. (1999) and Nguyen et al. (2019) state that knowledge has an indirect influence on behaviour through its effect on attitudes and beliefs. Modifications in an individuals' attitudes, behaviours, and practices within their environments can be obtained by changes in the individuals' levels of knowledge (ibid).

Davenport & Prusak (1998:5) define knowledge as "a fluid mix of framed experience, values, contextual information, and expert insight that provides a framework for evaluating and incorporating new experiences and information. It originates and is applied in the minds of knowers". They also state that in organisations the knowledge becomes embedded in the routines, processes, practices, and norms of the organisation (Davenport & Prusak 1998). Even though this study analysis the decision to intercrop among farm managers the farm can be seen as an organisation and the statement of Davenport & Prusak (1998) holds for a farm as well.

Nonaka and Takeuchi (1995 see Wójcik et al. 2019:131) recognize two types of knowledge, explicit and tacit. Explicit knowledge is explained by Nonaka and Takeuchi (1995 see Wójcik et al. 2019:131) as "that which is documented, public, structured, disseminated and awareness-raising" while tacit knowledge is "that which goes unarticulated, is fuzzy and secret, subjective, personalised, personal and quiet".

Lundvall (1996) expands this two-fold division of knowledge by distinguishing four types of knowledge called *know-what*, *know-why*, *know-how*, and *know-who*. The *know-what* is identified as descriptive and information-related knowledge. It is relating to facts and closely linked with what is termed information. *Know-why* is explanatory and prognostic knowledge, which is concerned with principles and laws. These two knowledge types are categorised as formal knowledge and accessible through traditional means such as education, libraries, media and so on (Lundvall 1996). *Know-how* is related to skills and is practical and prognostic knowledge. Person-related knowledge is referred to as *know-who* and is encompassing information on what is known by whom and how to do things. These two knowledge types are categorised as informal knowledge and accessed via individual experience as well as social relationships (Lundvall 1996).

Since farmers' knowledge is associated with farmers' attitudes and beliefs (Willock et al. 1999; Nguyen et al. 2019) as well as non-use values (Šūmane et al. 2018) changes in knowledge will have an indirect effect on the farmer's utility function and thereby the adoption decision. This study will therefore focus on the effect of farmers' formal and informal knowledge on their adoption and intensity decisions regarding intercropping.

3. Literature review

3.1 Knowledge acquisition and the role of knowledge in adoption decision

Already in the first half of the 20th century economists started to realise the importance of knowledge in the agricultural development and farm practice. Wilcox (1943) aimed to examine the nature of capital investment problems in agriculture. He found that even though farm families tend to save a higher proportion of their income than other groups, many farm families still maintain inadequate working capital investments, i.e., investments smaller than necessary to equate marginal return and marginal cost, with allowance of risk included (Wilcox 1943). Wilcox (1943) establishes that one reason that working capital investments are too low is the lack of knowledge that investment will increase profit. One problem is the lack of knowledge in distinguishing between using financial credit for production and for consumption purposes. The author suggests that this has led to misconceptions regarding the appropriate use of credit, and he argues that the only way to overcome this is through information. Having a low level of income does not only affect the working capital investments, it also restricts capital investments in the farmer (Wilcox 1943:55).

In the study of Hayami & Ruttan (1971) they aim to extend the theory of induced innovation and test the model against the long-term (1880-1960) experience of the development of agriculture in the United States and Japan. Agricultural production is constrained by factors characterised by relatively inelastic supply (Hayami & Ruttan 1971). The process by which public sector investment in agricultural research is directed toward releasing these constraints are included in the model by Hayami & Ruttan (1971). They argue that the potential production function may shift with the general accumulation of scientific knowledge. Variables such as knowledge and education are included in the model as of an endogenous nature. They also argue that relative price changes transmit information and the reason for the success of agricultural growth in the United States and Japan is due to the capacity of their farmers, research institutions and farm supply industries to absorb that information and exploit new opportunities based on it.

More recently farmers' learning and uptake of knowledge has been examined (e.g., Šūmane et al. 2018; Wójcik et al. 2019). Šūmane et al. (2018) study farmers' knowledge and learning practices in forming sustainable and resilient agriculture. Šūmane et al. (2018) state that local farmers' knowledge is linked to specific values of ethical, environmental, and social types. These values are reflected in practices in general, and in sustainable practices especially (Willock et al. 1999; Šūmane et al. 2018). When farmers choose which knowledge to acquire they are guided by rational, ethical, and emotional considerations, their own motivations and values (Šūmane et al. 2018). The authors group these motivations and values as business and ethical/social (ibid). Wójcik et al. (2019) examine how farmers take up knowledge from family and neighbours, especially in multi-generational environments, as well as the knowledge acquisition from institutions (including media), laws, and regulations. Similar groups are made by Wójcik et al. (2019) but with a narrower study they referred to the groups as business-related or non-production-related aspects of the functioning of farming families.

Farmers' own knowledge gained from experience, the knowledge passed through generations in farming families, and the knowledge and experience of farming colleagues were found as important knowledge sources for farmers in the study of Šūmane et al. (2018). Similarly Wójcik et al. (2019) observe that younger generations gain farming knowledge from older generations through work. Knowledge about the farmland is passed from the older generations to the younger and knowledge about the land is relatively stable and takes time to build up and/or change (ibid). Formal knowledge from agricultural, administration, and regulatory institutions is also used but not on a daily basis (Šūmane et al. 2018). These sources of formal knowledge have become harder to take up due to more complex regulation systems for the farmers (Wójcik et al. 2019). This has led to, according to Wójcik et al. (2019), the increased reliance on and use of advisors and other persons selling that type of knowledge, especially amongst younger farmers and more specialised farmers. By purchasing this knowledge, the farmer can save time to devote to other matters on the farm (ibid). Wójcik et al. (2019) also concluded that formal knowledge is becoming more important and that younger and more educated farmers find it easier to acquire this knowledge. In the study of Šūmane et al. (2018) they argue that this is due to the industrialisation of agriculture which has led to a more productivist logic, standardised solutions, and decline in the size of farming communities which in turn has decreased the importance of farmers' knowledge. Šūmane et al. (2018) conclude that when complementary knowledge from different sources is optimally combined, they can create sustainable agricultural solutions.

In the study of Nguyen et al. (2019) they explored whether farmers' knowledge influenced their attitude towards their behaviour concerning climate change mitigation and adaptation. It was found that most farmers hold declarative knowledge about climate change causes and effects. Though, Nguyen et al. (2019) discovered that farmers' declarative knowledge of climate change did not directly drive their adaptation practices. It did however influence their attitudes towards climate change causes (ibid). Chuang et al. (2020) who investigated the associations among Smart Agriculture-related knowledge, attitudes, and adoption behaviours found that farmers positive attitude towards the practice positively influenced their adoption decision. Nguyen et al. (2019) argues that climate projections need to be translated into declarative knowledge and should be accessible by farmer so they can make use of them to support their decisions while developing mitigation and adaptation plans and actions. Chuang et al. (2020) conclude that inadequate information, missing knowledge, lack of awareness of the technologies, and lack of perceived practical value can describe lower levels of Smart Agricultural technologies adoption. Farmers' understanding of their systems' strengths and vulnerabilities is crucial to identify appropriate mitigation and adaptation options (Nguyen et al. 2019). Nguyen et al. (2019) asserts that this understanding should be enhanced through a process of learning within socio-economic and agricultural systems.

3.2 The role of socio-economic and psychological factors in adoption decision

The adoption of intercropping can be seen as an adoption of new technology and the literature reviewed here includes papers on adoption of multiple sorts of sustainable agricultural technologies such as intercropping, soil conservation, alley farming, and agroforestry. These papers have contributed to the understanding of the determinants for farmers' decision to adopt a new technology and have been the driving factor in the decision of variables included in the analyse.

3.2.1 Farmers' and farm characteristics

Multiple farmers' characteristics have been assessed as important for adoption decisions of various sorts by several researchers (Barnes et al. 2019; Paudel et al. 2020; Ouko et al. 2022). Age has for example been found to have a significant positive effect on the adoption of sugarcane-soybean intercropping among smallholder farmers in Awendo sub-county, Kenya (Ouko et al. 2022). Ouko et al. (2022) argues that their findings are due to the accumulated resources and expertise that older farmers have acquired compared to younger ones.

Other studies have on the other hand found age to be negatively associated with adoption (Barnes et al. 2019; Paudel et al. 2020). Barnes et al. (2019) noticed a negative relation between age and the uptake of machine guidance as a precision technology in a cross-country analysis of five different EU countries. (Paudel et al. 2020) argues that there are three reasons for U.S. cotton producers to adopt precision technologies which are profitability, environmental benefits, and to be at the forefront of agricultural technology adoption. They find that age is significantly negative for all three reasons. The negative association found by Barnes et al. (2019) and Paudel et al. (2020) are explained by the short planning horizon of older farmers and the shorter period to recoup the investment both in terms of money, time, and energy spend on the adoption. In addition to this Paudel et al. (2020) report that the longer plans the farmer have regarding continue farming in the future the more important is the profitability reason for adoption which supports the argument that the range of the recoup period affects the adoption decision. From the reviews of Knowler and Bradshaw (2007) and Serebrennikov et al. (2020) age was found to have positive, negative, and insignificant effects on the adoption decision of soil and water conservation. Thus, it is difficult to conclude on general whether age affects the adoption decision or not.

Another variable found significant in multiple studies is education (Nkamleu & Manyong 2005; Danso-Abbeam et al. 2019; Paudel et al. 2020). Nkamleu & Manyong (2005) examined what factors affect farmer's adoption decision of six different types of agroforestry in Cameroon. Education was found to have a significantly positive effect on the adoption of one of the agroforestry types, namely agroforestry for apiculture (ibid). In the study of Danso-Abbeam et al. (2019) education was also found significantly positively associated with the decision to adopt Zai technology, also referred to as "micro-pits", amongst farmers in the Garu and Tempane district in Ghana. The authors argue that farmers' ability to obtain, process, and use information relevant for the adoption of a new technology increases with higher levels of education (ibid). For U.S. cotton producers education decreased the importance of being at the forefront of agricultural technology adoption as a reason to adopt precision technologies (Paudel et al. 2020). Paudel et al. (2020) argues that more educated farmers are not driven to adoption by being at the forefront of agricultural technology adoption since letting others do the initial investments one can observe its outcome and profits and thereby minimise losses when one decides to adopt. Education, both specific or general, was found to be positively correlated with adoption in several of the studies reviewed by Knowler and Bradshaw (2007). However, it was also found insignificant in some of the analyses. Prager and Posthumus (2010) found that farmers with higher education were more likely to adopt conservation practice in one of their reviewed studies. One of the studies reviewed by Serebrennikov et al. (2020) found that higher education had a positive effect on the probability of adopting soil and water conservation while another found that general education did not have an impact on the decision but that special agricultural training had. Consequently, regarding education it is also hard to draw general conclusions about its effect on adoption decisions. Thus, in this study the adoption decision will be analysed among farmers with general education, agricultural education, and agricultural training.

Experience of different sorts are also found relevant for adoption decisions in multiple studies (Nkamleu & Manyong 2005; Lemken et al. 2017; Barnes et al. 2019; Paudel et al. 2020; Ouko et al. 2022). In the review of Knowler & Bradshaw (2007) the role of experience in adoption decision disclosed both positive correlations as well as insignificant results. The reviewed literature for this study also revealed contradicting results. In the study of Nkamleu & Manyong (2005) experience was found positively affecting the adoption of improved fallow. Ouko et al. (2022) found a negative association between having experience of sugarcane farming and adopting sugarcane-soybean intercropping. Having mastered sugarcane farming due to experience and knowledge acquired over a long period of time of observation and experimentation in combination with higher age these farmers are more likely to be risk-averse which can be a plausible explanation for the reported association according to Ouko et al. (2022).

Lemken et al. (2017), on the other hand, found that having land distributed to legumes as sole crops increased the probability of adopting cereal-legumes intercropping amongst German farmers. They argue that the result can be explained by the fact that these farmers have experience of legume crop management and awareness of soil benefits generated from legumes. Lemken et al. (2017) also found that adopters of reduced tillage were more likely to adopt intercropping as well. Barnes et al. (2019) reports that adopters of other precision technologies than machine guidance and variable rate nitrogen technologies are more likely to adopt the technologies in question. They consider this as innovation behaviour as well as an indication that those farmers have the capacity to handle the technologies.

Additionally, Paudel et al. (2020) found that for farmers using a computer for farm management activities the importance of the profitability reason for adopting increases. The importance of profitability and environmental benefits as reason for adoption are found positively affected by farming experience in the study of Paudel et al. (2020). The authors argue that experienced cotton farmers report environmental benefits as a reason for adoption in the short-term, but the long-term the reason is profitability. Paudel et al. (2020) explain this with the argument that the experienced farmers know that their traditional cotton production has been contributing to environmental degradation, negatively affecting future yields and economic well-being. In addition, agricultural precision technologies hold a promise of minimising environmental degradation and in that way contributing to maintenance of yields and associated economic benefits in the future (ibid).

Different farm characteristics, like farm size (Lahmar 2010; Barnes et al. 2019; Ouko et al. 2022), have been found significant for adoption decisions. Larger farms are the leading adopters of conservation agriculture among European framers according to Lahmar (2010). In 2019 Barnes et al. confirms this with their findings that the size of farm is significant and positive for the adoption of both precision technologies in question. Lahmar (2010) explains this by the fact that larger farms has larger ability to absorb risk and Barnes et al. (2019) use a similar reasoning. In the study of Ouko et al. (2022) using larger land is observed to decreased the likelihood of adopting sugarcane-soybean intercropping. Ouko et al. (2022) argues that the high fixed costs of small farms constrain them from adopting new technologies. The contrasts in these results might be explained by the wide differences of the technologies and context of the studies, amongst large intensified farms in the EU (Lahmar 2010; Barnes et al. 2019) and amongst smallholder farmers in Kenya (Ouko et al. 2022).

Serebrennikov et al. (2020) found that farm size has a positive effect on the probability of adopting in two of the studies they reviewed regarding soil and water conservation while Knowler and Bradshaw (2007) found inconclusive results from their review. However, Knowler and Bradshaw (2007) observed that the effect of farm size differs with regions. In the review of Serebrennikov et al. (2020) there are contradicting views in the literature they reviewed, at least regarding organic farming. One of the studies uses farm size as a proxy for farm financial strength and argues that larger farms have more resources to invest in sustainable technologies. Contradicting to that another study implies that farms that are larger and with better finances are reluctant to adopting organic farming to avoid risk negative consequences of this technology, such as yield uncertainty.

To build a hypothesis of the effect of farms size in this study is hard due to the contrasting results of the reviewed literature since, for example, the technology studied here is intercropping but the farmers’ context in this study is more similar to the one of Barnes et al. (2019). However, the results of Barnes et al. (2019) also indicates that there may be a threshold value of farm size in the adoption decisions. This implies that farm size needs to be included in the participation decision, i.e., adopting decision, of the double-hurdle model used in this study since it seems like there is a threshold for adoption.

3.2.2 Financial factors

Various financial factors have been rated as important for adoption decisions of various technologies. Lahmar (2010) studied the main findings and lessons of

Knowledge Assessment and Sharing on Sustainable Agriculture (a specific support action funded by the European Commission) related to European experience with conservation agriculture. The author found that the adoption process is mainly farmer driven and that the major driving factors are cost reduction and labour saving (ibid). Iqbal et al. (2006) describes that to have a large income based solely on the farmer's own farm is the main factor that positively determines adoption of rubber-tea intercropping among smallholder farmers in Sri Lanka. Access to credit was identified by Danso-Abbeam et al. (2019) to positively affect both the adoption decision and the intention of the adoption of Zai technology. However, one should keep in mind that in multiple parts of the world the access to credit and wealth is also associated with the gender of the farmer. As Danso-Abbeam et al. (2019) explain males are mostly the head of the household, they tend to have access and control over the household resources involving the decisions to allocate lands for agricultural activities. In the studies of more wealthy countries this is not discussed as a problem (Lahmar 2010; Lemken et al. 2017; Barnes et al. 2019; Bonke & Musshoff 2020; Paudel et al. 2020), which might be because the gender inequalities are less problematic in those settings or at least assumed to be so.

Household income was reported as significantly positive for the adoption of the precision technologies in question in the study of Barnes et al. (2019). They explain this as capacity to reconcile longer payback periods is created by higher levels of income. This capacity infers the availability of cash reserves to handle longer time periods for paying back the technology. They also argue that it is an indication that precision technologies have high entry costs which means that higher income farmers are more likely to adopt (ibid). Household income is also reported as being a threshold variable for adoption (Barnes et al. 2019) indicating that this variable should be included in the first hurdle of the double-hurdle model. Both Knowler and Bradshaw (2007) and Serebrennikov et al. (2020) found in most of the studies reviewed that farm financial indicators had a positive effect on adoption. However, contradicting results were also found in the two reviews (ibid). Prager and Posthumus (2010) found that economic factors are crucial for the adoption decision, for example cost reduction or financial incentives like subsidies. These results indicate the importance to include financial factors in the analysis of this study.

3.2.3 Perceptions and attitudes

The perception of land suitability was assessed by Iqbal et al. (2006) who found that perception of not having land suitable for cultivation of tea had a negative effect on the probability to adopting rubber-tea intercropping. Lemken et al. (2017) identifies that farmers that perceive technical barriers of intercropping are less likely to adopt the practice. Additionally, farmers that have a positive attitude towards intercropping's worthiness and compatibility with framer's objective are more likely to adopt (Lemken et al. 2017). According to Bonke & Musshoff (2020) the intention to adopt is the most important factor for adoption of intercropping. Bonke & Musshoff (2020) found that a positive attitude towards intercropping increases the intention to adopt the practice. Perceived behavioural control as an index of having necessary knowledge, technical capacity, and market possibilities was also found positively significantly related to the intention to adopt intercropping (ibid). In addition, Barnes et al. (2019) reports that having a positive perception of the payback of the technology will increase the probability of adopting machine guidance.

Though, Lahmar, (2010) states that environmental concerns are not essential for the adoption decision, an indirect effect of perceived ecological benefits was observed in the study of Bonke & Musshoff (2020) meaning that ecological benefits relate to higher attitude which in turn leads to higher intention to adopt. Serebrennikov et al. (2020) also found evidence in their review that environmental perceptions affect adoption decisions. For example, it was found in tow of the studies that a strong preference for environmental protection motivates farmers to adopt soil and water conservation.

Perceived social pressure from other farmers was found to increase the intention to adopt, but a negative association was found in the case of perceived social pressure from society and politics in the study of Bonke & Musshoff (2020). Descriptive group norms, i.e., knowing farmers that have adopted intercropping, was also found positively significantly effecting the intention to adopt (ibid). A stronger association was found between the group norms and intention to adopt than the perceived social pressure from other farmers, an indication that what other farmers actually do is of greater importance to the intention to adopt (Bonke & Musshoff 2020). Being a member of a marketing co-operative positively affects the uptake of machine guidance according to Barnes et al. (2019). The findings of Barnes et al. (2019) might be explained by the findings of Bonke & Musshoff (2020) that the farmers perceive increased social pressure from other farmers when being a member of a co-operative. Adesina et al. (2000) observed that farmers belonging to a famers' association had positive effects on the probability of adopting alley cropping among farmers in Cameroon. Similar results were found by Nkamleu & Manyong (2005) on the adoption of different agroforestry techniques. Barnes et al. (2019) questioned the adopters about external influences on adoption and found that use of advisors was significantly positive for the adoption. Since these findings indicate that farm-related social relations influence adoption decisions, it warrants including discussing farm issues with other farmers and/or production advisors in the study.

The reviewed literature has highlighted multiple factors and characteristics important for different adoption decisions. For multiple factors, for example age, education, farm size, it is hard to draw any general conclusions of their effect on adoption. However, the reviewed studies indicate that there might be important effects of these variables and they will all be examined to see if they can be included in the model. Additionally, variables like perception of land suitability, affordability, difficulties, and perceived or experienced environmental benefits seem important for adoption and intensity decisions and will be analysed for this study. Financial factors have also been assessed as important for the adoption decision and will be include in the model.

4. Method

4.1 Data

The data used for the analysis of this study originates from a survey conducted during 2021 in Sweden. This survey is a part of a funded project on intercropping at the Department of Economics at SLU. Data were collected by the project team and were made available for this study by the supervisors who are directly involved in the project. The survey was sent to 2,000 farmers randomly sampled from a list of 33 300 farmers. Only commercial farmers were included in the sample, i.e., those devoting more than 400 working hours to farming a year. The contacted farmers were free to choose to participate and 700 farmers responded. The survey included 37 questions with different structures, such as single choice, multiple choice, and matrix questions, assertion questions, ranking questions as well as open questions with numerical answers. This generated a dataset including 186 variables. For this study 354 replies were without partial loss or other problems and could be used for the analysis.

The focus of the analysis considers variables of farmers' formal and informal knowledge. The variables (Lundvall 1996) related to formal knowledge are:

- Level of education.
- Participation in agricultural training during the past five years.

The variables (ibid) related to informal knowledge are:

- Years of farming.
- Years of intercropping.
- Discussing farm issues with other farmers.
- Discussing farm issues with production advisors.

Another variable in focus is farmers' self-reported knowledge of intercropping.

Respondents were asked to rate their knowledge regarding intercropping with respect to crop management, harvesting, crop variety performance, and characteristics of crop varieties on a five-level scale ranging from 1. very bad to 5. very good. The results of these questions were then aggregated to the joint variable *Self-reported intercropping knowledge* ranging on a scale from 5 to 25 points. The reliability of this variable was tested by using a Cronbach's alpha which tests if the five item share covariance and probably measure the same thing (Goforth 2015). The reported mean alpha equated 0.944 which is an acceptable level according to Goforth (2015) and (Weesie n.d.). Of all the farmers, 15.8 percent rated that their knowledge was very bad in all perspectives. Only four respondents rated themselves as very good in all perspectives. 12.4 respective 21.0 rated on level 2 respective level 3 on average with respect to all the questions.

The variable level of education is ordinal data, and the respondent could choose primary school, secondary school, agricultural secondary school, university, or agricultural university as their highest level of education. Another type of formal knowledge included in the survey was farmers participation in agricultural training during the past five years. The farmers who had participated in agricultural training reported whether it was short courses, continuing training, seminar series, or several of them. A dummy variable for each type of agricultural training was generated and most common type of training was short courses where 39 % of the farmers had participated.

Farming experience, related to informal knowledge, has been included as a variable for how many years the farmer has been engaged in farming. On average the farmers in the study have been engaged in farming for 30 years but the data includes a range from 0 to 74 years. For the quantity decision a variable for how many years the farmer has been intercropping has also been included. For the farmers intercropping the average number of years doing so is five and a half. In addition, discussing farm issues with other farmers and/or production advisors have been included as informal knowledge related variables. The respondents were asked to report whether they discussed farm issues with other farmers and/or production advisors on a six-level scale representing from 1-6: never, annually, quarterly, monthly, weekly, or daily. On average the respondents discuss farm issues with other farmers between quarterly and monthly, closer to monthly. Between annually and quarterly, closer to annually the respondents discuss farm issues with production advisors on average.

From the reviewed literature variables have been assessed to be important to include as control variables for the adoption decision, in addition to variables for knowledge. These are age (Barnes et al. 2019; Paudel et al. 2020; Ouko et al. 2022); household income (Barnes et al. 2019); farm net profit (Knowler & Bradshaw 2007;

Prager & Posthumus 2010; Chuang et al. 2020; Serebrennikov et al. 2020); business strategy (Nkamleu & Manyong 2005); perception of land suitability (Iqbal et al. 2006); perception about affordability of intercropping (Barnes et al. 2019); perceptions of level of difficulty to apply intercropping (Lemken et al. 2017), and perception of intercropping being environmentally friendly (Chuang et al. 2020; Serebrennikov et al. 2020). Control variables are included to generate a model with good fit controlling for multiple factors affecting the adoption decision and a reliable result for the effect of different knowledge on the decision to adopt intercropping (Stock & Watson 2020). Descriptive statistics can be seen in Table 2.

Table 2 Descriptive statistics

Variable	Mean	Std. dev.	Min value	Max value
Knowledge related variables				
Highest education level				
- Primary school	0.079	0.270	0	1
- Secondary school	0.288	0.454	0	1
- Agricultural secondary school	0.243	0.430	0	1
- University	0.232	0.422	0	1
- Agricultural University	0.158	0.365	0	1
Participating in agricultural training during the past 5 years				
- Short courses	0.384	0.487	0	1
- Continuing training	0.045	0.208	0	1
- Seminar series	0.093	0.291	0	1
Years of farming	30.1	15.8	0	74
Years of intercropping	5.55	11.14	0	52
Self-reported intercropping knowledge	12.6	4.87	5	25
Discussing farm issues with other farmers	3.76	1.47	0	6
Discussing farm issues with production advisors	2.23	1.264	0	6
Control variables				
Net profit	2.23	1.89	1	9
Household income	4.62	2.47	1	10
Business strategy				
- Specialized	0.449	0.498	0	1
- Diversified	0.415	0.493	0	1
- Multiple agricultural enterprises	0.136	0.343	0	1
Perception of land suitability	3.15	1.03	1	5
Perception of intercropping being environmentally friendly	3.38	0.810	1	5

4.2 Double-hurdle model

The double-hurdle model is used for limited dependent variables (Cragg 1971). The characteristic feature for such variables is that the range of values they may assume has a lowest bound and a fair number of observations in the data take on this endpoint value. This is usually seen in studies of consumer purchases of durable goods. The double-hurdle model allows different variables or parameters to determine the size of the dependent variable when it is not zero compared to the variables that determine the probability of it being zero. This contrasts with a Tobit model, which assumes adoption and intensity decision to be one joint decision effected by the same factors. Probit or logit models only model the probability of adoption and do not examine the intensity of adoption. Applying the double-hurdle model on the decision to adopt intercropping is suitable since multiple farmers chose not to adopt, resulting in a corner solution, together with the fact the probability of farmers deciding to adopt can depend on different parameters than the decision to what extent the adoption will take place. For example, the finding of Barnes et al. (2019) that there would be a threshold value for farm size and household income on the intercropping adoption decision indicates that these variables would affect the adoption decision but not necessarily the intensity.

The first part of the double-hurdle model is called the participation decision (García 2013), estimating the probability of, in this study, adopting intercropping. The second part is called the quantity decision (García 2013) and estimates the effects of different variables on the decision of the optimal level of arable land being intercropped. If y_i denotes the observed number of hectares farmer i intercrops of the total area arable land, we can model the decisions as

$$y_i = \begin{cases} x_i\beta + \epsilon_i, & if \min(x_i\beta + \epsilon_i, z_i\gamma + u_i) > 0 \\ 0, & Otherwise \end{cases}$$

$$\begin{pmatrix} \epsilon_i \\ u_i \end{pmatrix} \sim N(0, \Sigma), \Sigma = \begin{pmatrix} 1 & \sigma_{12} \\ \sigma_{12} & \sigma \end{pmatrix}$$

Letting $\Psi(x, y, \rho)$ denote the cumulative distribution function of a bivariate normal with correlation ρ, the loglikelihood function for the double-hurdle model is

$$Log(L) = \sum_{y_i=0} [log\left\{1 - \Phi(z_i\gamma, \frac{x_i\beta}{\sigma}, \rho)\right\}$$
$$+ \sum_{y_i>0} \left(log \left[\Phi \left\{ \frac{z_i\gamma + \frac{\rho}{\sigma}(y_i - x_i\beta)}{\sqrt{1-\rho^2}}, \right\} \right] \right.$$
$$\left. - \log[\sigma] + \log\left\{\phi\left(\frac{y_i - x_i\beta}{\sigma}\right)\right\} \right)$$

The participation decision is modelled by $x_i\beta + \epsilon_i$ which means that it is applied when the dependent variable assumes a zero value. $z_i\gamma + u_i$ models the quantity decision and is applied when a non-zero value occurs for the dependent variable (Cragg 1971; García 2013). The model estimates values for $\beta, \gamma, \rho,$ and σ where $\sigma = Var(\epsilon)$. The variance of u is restricted to equal 1 for the model to be identified (García 2013).

4.3 Model specification

To evaluate if the double-hurdle model was suitable the area intercropped of total arable land, which would be the dependent variable, was tabulated and it was found that 63% (224 of 354 farmers) of the respondents has zero present intercropping and the distribution of the rest are spread over the other values. The same result can be seen in the histogram in Figure 1.

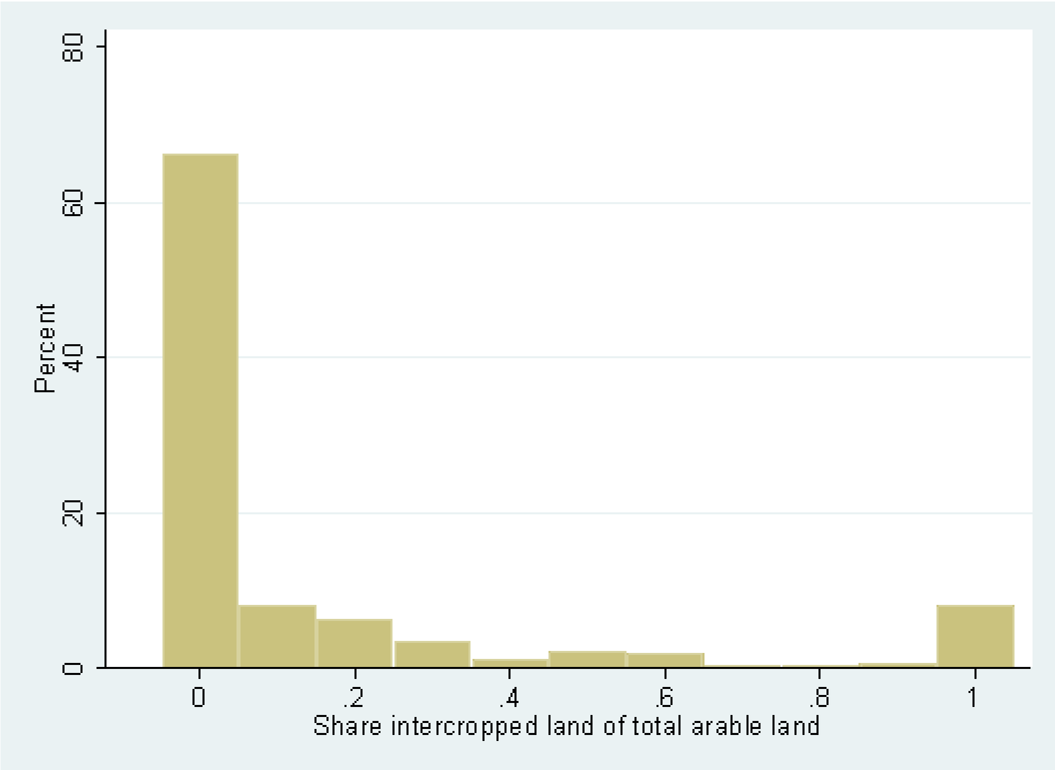

Figure 1 Histogram of share intercropped land of total arable land

Likelihood ratio tests were conducted between the Tobit and the double-hurdle model to test the assumption that the adoption and intensity decisions are separate decisions, following the example of Danso-Abbeam et al. (2019) and Bekele & Mekonnen (2010). This was done by computing the log likelihood ratios for a probit, truncated and Tobit regression models. This approach is possible since the double-hurdle log likelihood can be written as the sum of log likelihoods of the probit model, representing the participation decision of the double-hurdle, and truncated model, representing the quantity decision (ibid). The log likelihood test statistics are then produced as follow:

$$L = 2\left(LR_{prob} + LR_{trunc} - LR_{tobit}\right)$$

(Danso-Abbeam et al. 2019) where LR_{prob}, LR_{trunc}, and LR_{tobit} are the log likelihood ratios for the probit, truncated and Tobit models respectively. The estimated L is then tested towards the χ^2 distribution with the degrees of freedom equal to the number of independent variables plus the intercept of the model (ibid). If the estimated L is grater than the test value, the use of double-hurdle is justified (Bekele & Mekonnen 2010; Danso-Abbeam et al. 2019).

To test if the knowledge variables jointly were contributing to explaining the dependent variable another likelihood ratio test was computed between the full double-hurdle model and a one without the knowledge variables. Additionally, checks for multicollinearity and heteroskedasticity has been performed to avoid them causing biased results. The double-hurdle model was conducted with both standard errors and robust standard errors. It was found that the errors differs in the two models which is a sign of heteroskedasticity and to control for this the robust standard errors was used (Stock & Watson 2020).

To check for multicollinearity between the variables included, both the ones of interest and the control variables, a Spearman rank correlation matrix was analysed. According to Prion & Haerling (2014) the "rule of thumb" for interpreting the Spearman correlation coefficient (r_s) is that the correlation is negligible if between 0 and ± 0.2. From ± 0.21 to ± 0.40 they classify it as weak. Between ± 0.41 and ± 0.60 is moderate according to Prion & Haerling (2014). The correlation is strong if between ± 0.61 and ± 0.80 and considered very strong when above ± 0.81 (ibid). To lower the risk of multicollinearity in the model a threshold of ± 0.60 has been used in this study. So, due to risk of multicollinearity the variable for age which is highly correlated with years of farming ($r_s = 0.69$) has been dropped from the model. So has perception about affordability of intercropping, and perceptions of level of difficulty to apply intercropping, due to high correlations between each other ($r_s = 0.60$) and with the variable for perception of land suitability ($r_s = 0.62$ and $r_s = 0.71$ respectively).

Thus, the model specification for the analyse can be described as

$$Log(L) = \sum_{y_i=0} [log\left\{1 - \Phi(z_i\gamma, \frac{x_i\beta}{\sigma}, \rho)\right\} + \sum_{y_i>0} \left(log\left[\Phi\left\{\frac{z_i\gamma + \frac{\rho}{\sigma}(y_i - x_i\beta)}{\sqrt{1-\rho^2}}, \right\}\right] - \log[\sigma] + \log\left\{\phi\left(\frac{y_i - x_i\beta}{\sigma}\right)\right\}\right)$$

where x_i represents the ith independent variable included in the decision to adopt intercropping. $x_1, x_2 \ldots x_n$ are the variables level of education; participation in agricultural training during the past 5 years; years of framing; self-reported intercropping knowledge; discussing farm issues with other farmers; household income; farm net profit; business strategy; perception of land suitability; and beliefs about intercropping being environmentally friendly. For the decision of adoption intensity z_i represents the ith independent variable in the decision. $z_1, z_2 \ldots z_n$ are almost the same variables as $x_1, x_2 \ldots x_n$. The only difference is that a variable for number of years that the farmer has been intercropping will be added to the quantity decision. The software used for the analysis of the study is STATA 16.0.

5. Results

The likelihood ratio test showed that the knowledge variables, i.e., level of education; participation in agricultural training during the past 5 years; years of farming, years of intercropping; discussing farm issues with other farmers and production advisors; and self-reported intercropping knowledge, jointly contribute to explaining the dependent variable (LR statistics = 42.53, p<0.001). The reports form the loglikelihood test between the Tobit model and the double-hurdle model can be seen in Table 3. It confirms the assumption that adoption and intensity decisions are separate decisions, indicating that the use a double-hurdle model for this analyse is justified (Bekele & Mekonnen 2010; Danso-Abbeam et al. 2019). The results of the probit, truncated, and Tobit models (presented in Appendix 1) also indicates the suitability for a double-hurdle model since the probit and truncated models reports different significant variables for the two decisions. Additionally, the pseudo R^2 for the Tobit model is 0.4545 which is notably less than for the double-hurdle model (0.6948) implying that the double-hurdle model to a greater extent explains the variation in the dependent variable.

Table 3 Results of log likelihood test between the double-hurdle and Tobit models

Model	Double-hurdle		Tobit	Test statistics ($\chi^2_{df=18}$)
	Probit	Truncated		
Log likelihood ratios	- 21.978	6.946	- 137.160	244.25 (36.16) ***

*Notes: *** significant at the 0.01 level*

The results of the 'churdle' command in STAT 16.0, which is the command used in this study, reports coefficients for the participation decision that are interpretable as marginal effects on the probability of, in this case, adopting intercropping (STATA n.d.). For the reported coefficients of the quantity decision to be interpretated as marginal effects on the share of intercropped land of total arable land, the marginal effects need to be calculated (ibid). Therefore, both coefficients and marginals are reported for the quantity decision in table 3. The Wald χ^2 test of the estimated double-hurdle model shows that the model is significant, and the results of the model are reported in Table 4.

Table 4 Results from the double-hurdle regression

Variable	Participation decision	Quantity decision	
	Coefficients (RSE)	Coefficients (RSE)	Marginals (RSE)
Knowledge related variables			
Highest level of education:			
- Primary school	Omitted	Omitted	Omitted
- Secondary school	0.320 (0.387)	- 1.09 (0.384) ***	- 0.200 (0.151)
- Agricultural secondary school	0.622 (0.383)	- 1.28 (0.380) ***	- 0.203 (0.151)
- University	0.653 (0.398)	- 0.893 (0.399) **	- 0.134 (0.153)
- Agricultural University	0.374 (0.411)	- 0.851 (0.438) *	- 0.156 (0.161)
- Short courses	- 0.449 (0.186) **	- 0.297 (0.237)	- 0.091 (0.040)
- Continuing training	- 0.342 (0.398)	- 1.48 (0.605) **	- 0.153 (0.029)
- Seminar series	- 0.311 (0.282)	- 0.283 (0.370)	- 0.072 (0.050)
Years of farming	- 0.004 (0.006)	- 0.014 (0.007) *	- 0.003 (0.001)
Years of intercropping	-	0.009 (0.007)	0.002 (0.001)
Self-reported intercropping knowledge	0.149 (0.020) ***	0.036 (0.020)	0.022 (0.005)
Discussing farm issues with other farmers	0.069 (0.074)	- 0.140 (0.074) *	- 0.018 (0.015)
Discussing farm issues with production advisors	- 0.045 (0.01)	- 0.034 (0.106)	- 0.011 (0.022)
Control variables			
Net profit	0.119 (0.052) **	- 0.024 (0.060)	0.008 (0.013)
Household income	- 0.010 (0.037)	0.030 (0.038)	0.004 (0.007)
Business strategy			
- Specialized	Omitted	Omitted	Omitted
- Diversified	0.017 (0.173)	- 0.027 (0.207)	- 0.003 (0.041)
- Multiple agricultural enterprises	0.383 (0.268)	- 0.271 (0.243)	- 0.012 (0.049)
Perception of land suitability	0.192 (0.089) **	0.111 (0.084)	0.039 (0.019)
Perception of intercropping being environmentally friendly	0.478 (0.117) ***	0.245 (0.116) *	0.093 (0.026)
Constant	- 5.27 (0.699) ***	- 1.04 (0.705) *	
Number of observations: 354			
Pseudo R^2: 0.6948			
Log likelihood: -43.54			
Wald χ^2 test: 60.43 ***			

*Notes: *** significant at the 0.01 level, ** significant at the 0.05 level, * significant at 0.10 level. RSE=Robust standard errors.*

From the model of the decision to adopt intercropping or not, i.e., the participation decision, we can see that farmers' self-reported intercropping knowledge has a significant association with the decision. The only knowledge variable additionally found significant for the adoption decision is participating in agricultural training during the past five years via short courses. It is found to have a significant negative relation with the decision to adopt intercropping. Other variables significant for the decision to adopt intercropping are *Net profit*, *Perception of land suitability*, and *Beliefs about intercropping being environmentally friendly*, which all have a positive impact on the adoption decision.

For the quantity decision there are multiple significant knowledge variables affecting the intensity of the adoption. Compared to having primary school as the highest level of education, secondary school, agricultural secondary school, university, and agricultural university seems to lower the percentage of land intercropped of total arable land. Participating in agricultural training during the past five years also has a negative relation to the intensity of intercropping when participating in continuing training. Similar results are found for years of farming and discussing farm issues with other farmers. Additionally, *Perceptions of intercropping being environmentally friendly* was found to positively affect the intensity of intercropping on the farm.

6. Discussion

Self-reported intercropping knowledge

The results presented above suggest that the variable of farmers *self-reported intercropping knowledge* has a significant effect on the adoption decision. Bonke & Musshoff (2020) reports similar findings in their study where they found that farmers perceived behavioural control positively impacts the intention to adopt intercropping. Additionally, Chuang et al. (2020) found that farmers' knowledge of Smart Agriculture has a positive significant relation with adoption of the technology. This, together with the studies stressing the importance of knowledge for developing and adopting agricultural practices (Wilcox 1943; Willock et al. 1999; Šūmane et al. 2018; Wójcik et al. 2019) implies that the result in question is reliable; however, the magnitude of the effect should be carefully interpreted due to possible bias.

The fact that *self-reported intercropping knowledge* seems to only affect the adoption decision indicates that there might be a minimum level of perceived knowledge for a farmer to adopt the practice. This is reasonable since intercropping requires additional knowledge to the traditional agricultural knowledge (Lemken et al. 2017; Bonke & Musshoff 2020). Though, one could expect that increased self-reported intercropping knowledge also would increase the intensity, it could not be seen in the results of this study. I argue that the perceived benefits and paybacks of the practice plays a more important role for the intensity decision, based on the findings of (Barnes et al. 2019; Bonke & Musshoff 2020). These perceived benefits and paybacks have however not been included in this analyse and any conclusions about this argument cannot be drawn.

Formal knowledge

Participating in *short courses* during the past five years is the only variable related to formal knowledge that was found to have a significant association with the adoption decision. In contrast to expectations, it was found negatively related with the decision. The same was found for the variables related to formal knowledge that was significantly associated with the intensity decision, i.e., *continuing training* and *level of education*. Strauss (2016) shows in their study that farmers value and need formal training and information regarding production practices and economics. However, both Šūmane et al. (2018) and Strauss (2016) studies also call attention to the limitations of the existing formal agricultural knowledge system, meaning that it does not adequately establish the knowledge needed for farmers to adopt sustainable agricultural practices (Šūmane et al. 2018) nor to adapt and address change (Strauss 2016). Both studies argue that standardised, disciplinary knowledge is not sufficient to address the complexity farmers must handle in these situations (Strauss 2016; Šūmane et al. 2018). These findings of Šūmane et al. (2018) and Strauss (2016) might explain the unexpected signs of the significant formal knowledge related variables in this study. Additionally, one should keep in mind that the question about agricultural training in the questionary asked if the respondent had participated in any agricultural training. This means that the training reported in the survey could have focused on any agricultural practice and even some that might undermine the adoption of intercropping.

Informal knowledge

None of the informal knowledge related variables show significant relations with the adoption decision and only two show significant relations with the quantity decision. *Years of farming* is one of them and has a significantly negative association with the intensity decision. The negative affect of farming experience can be explained by its strong correlation with the farmer's age. Age has been found to negatively related to adoption decisions (Barnes et al. 2019; Paudel et al. 2020) since a higher age associates with shorter planning horizon and shorter period to recoup the investment both in terms of money, time, and energy spend on the adoption (Barnes et al. 2019). I argue that this can apply for the intensity decision as well. Even if the first hurdle has been overcome and intercropping has been adopted, investments in terms of money, time, and energy will still be induced to intensify the adoption. Having years of experience of farming with for example mono-cropping will increase the knowledge of that specific practice and restrict the intensity of intercropping if that is associated with additional learning costs compared to mono-cropping. Implying that a lower share of intercropping will be applied for the farmer's utility to be maximised.

Discussing farm issues with other farmers is the second informal knowledge related variable that significantly relates to the intensity decision. Previous studies have found that perceived social pressure from other farmers, group norms (Bonke & Musshoff 2020) and member of co-operative (Barnes et al. 2019) positively affects the adoption decision. In contrast this study finds that *discussing farm issues with other farmers* negatively relates to the intensity decision. Bonke & Musshoff (2020) argues from their results that what other farmers actually do is of great importance to the intention to adopt. However, *Discussing farm issues with other farmers* does not tell what issues are discussed, in contrast to the variables of social pressure from other farmers and group norms included in Bonke & Musshoff (2020). It might be that the farmers are discussing farm issues and solutions that are conflicting to adoption of intercropping which may explain the unexpected sign of the result.

Control variables

Amongst the control variables included in the model *Net profit* was found to have a positive significant relation with the adoption decision. This is in line with multiple studies where financial factors have been found associated with adoption decision (Iqbal et al. 2006; Knowler & Bradshaw 2007; Lahmar 2010; Prager & Posthumus 2010; Barnes et al. 2019; Danso-Abbeam et al. 2019; Serebrennikov et al. 2020). Iqbal et al. (2006) found that farmer's income had significant positive association with adoption and Barnes et al. (2019) found similar results about household income. This study does not find a significant association between household income and adoption. In contrast to the study of Barnes et al. (2019) this study has included both net profit and household income. This might explain the difference in the results, since household income to some extent controls for net profit which might be the reason it is significant in the study of Barnes et al. (2019) and not here. This reasoning is supported by the findings of Iqbal et al. (2006) who found a positive relation between having income primarily from the farm and adoption of intercropping. Access to credit is another finance related factor that has been found positively significant related to adoption decisions (Danso-Abbeam et al. 2019) and a higher net profit would result in easier access to credit in the context of this study.

Perception of land suitability positively affects the decision to adopt intercropping which is the in line with the findings of Iqbal et al. (2006). The fact that *Net profit* and *Perception of land suitability* only affect the adoption decision indicates that there might be threshold values for these variables. Barnes et al. (2019) argus in their study that there is a threshold value for household income which supports the argument for *Net profit*. It is reasonable that there is a threshold value for *Perception of land suitability* since it would be an irrational decision for a farmer to adopt intercropping if he/she does not perceive the land as suitable. Additionally, without perceiving the land as suitable, the perceived payback, which Barnes et al. (2019) reported as positive for adopting machine guidance, will arguably decrease as well and hinder the adoption.

Both adoption and intensity decisions of intercropping were found positively affected by *Perceptions of intercropping being environmentally friendly*. This is consistent with some of the studies reviewed by Serebrennikov et al. (2020) who found that farmers' attitudes and beliefs, for example a strong preference for environmental protection, seemed to positively affect adoption decisions. It is also in line with the findings of Chuang et al. (2020) who found that perceived importance of Smart Agriculture was significantly positively related with the adoption of the precises. In the study of Bonke & Musshoff (2020) an indirect effect of perceived ecological benefits was observed, meaning that ecological benefits relate to higher attitude which in turn leads to higher intention to adopt. A significant Spearman correlation has been reported between *Perceptions of intercropping being environmentally* and *self-reported intercropping knowledge* ($r_s = 0.19, p < 0.05$) among the adopters. This indicates that adopters with higher self-reported intercropping knowledge also have somewhat higher beliefs that intercropping is environmentally friendly which might be a result from the fact that adopters perceive environmental benefits and therefore report high beliefs. Additionally, Paudel et al. (2020) argues that perceived improved environmental quality increases the importance of environmental concerns on the adoption decision. Lahmar, (2010) states environmental concerns are important for the adoption when farmers are involved in innovation and learning processes and for a farmer that has recently chosen to adopt intercropping a learning process is still ongoing.

Limitations

There are some limitations with the analysis of this study based on the findings in the reviewed literature. For example, Nkamleu & Manyong (2005) report in their study that different variables affected the adoption decision for different types of agroforestry methods. In the current study the dependent variable has included intercropping of unidentified type which means that it probably includes intercropping of multiple sorts. This results in lack of information on factors that influence a particular type of intercropping. For example, both lay and other intercropping types have probably been included in this analysis by participants and just over 40% of the arable land in Sweden is used for production of ley which is the most commonly practiced intercropping in Sweden (Swedish Board of Agriculture, n.d.). It might therefore be more interesting and important to only study what affects the adoption of other types of intercropping.

Self-reported intercropping knowledge is, as stated by the name, self-reported and there is always a risk of misreporting. Kondylis et al. (2015) studies misreporting of farmers knowledge and adoption of three agricultural practices: intercropping, mulching, and strip tillage. They report, for example, that jargon can interfere with observing farmers true level of knowledge. They find that self-reported measures of knowledge seem to be underestimating the true knowledge level. In this study this would cause a biased estimate of the effect of knowledge on the adoption decision. Another problem with the variable *Self-reported intercropping knowledge* is the aggregated scale (from 5 to 25). This scale is not comparable to other perception-related variables (that are on a scale from 1 to 5). Therefore, comparisons of the strength of the relationship these variables have with dependent variable is not credible.

7. Conclusion

The main objective of this study has been to examine how farmers' knowledge affects their decision to adopt intercropping. Self-reported intercropping knowledge appears to be an important factor for the adoption decision, together with having a higher net profit, and higher perceptions about land suitability and intercropping being environmentally friendly. The adoption decision is however negatively associated with whit agricultural training when the farmer has participated in short courses during the past five years. For the intensity decision having a higher perception that intercropping is environmentally friendly acts as the main driving factor. Higher level of formal education (general or agricultural), agricultural training, discussing farm issues with other farmers and years of farming experience is on the other hand associated with lower intercropping intensity.

These findings indicates that formal and informal knowledge does not contribute to the adoption or at least not the intensity of the adoption. They also suggest that there is a threshold value for self-reported intercropping knowledge for a farmer to be able to adopt intercropping. Therefore, to increase the uptake of the practice the focus should be on increasing the farmers perceived intercropping knowledge. This insight is useful for shaping policies, information programmes, and agricultural training to spread the uptake of intercropping. However, for future studies I suggest that the indirect effects off informal and formal knowledge on adoption through its effect on farmers perceived intercropping knowledge should be examined as well. This would contribute to a greater understanding of the role of informal and formal knowledge on intercropping adoption and more useful insights for policies etc.

For the context of this study, a conclusion can be drawn that the adoption and intensity decisions are separate decisions which are influenced by different variables. For future research I therefore suggest that when both decisions are examined, the assumption of the decisions being joint or separate needs to be tested. Furthermore, I suggest including group discussions and/or interviews with farmers to create a greater in-depth understanding of adoption and intensity decisions.

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Appendix 1

Variable	Probit	Truncated	Tobit
	Coefficients (RSE)	Coefficients (RSE)	Coefficients (RSE)
Number of observations:	354	130	354
Knowledge variables			
Highest level of education:			
- Primary school	Omitted	Omitted	Omitted
- Secondary school	3.93 (0.540) ***	- 0.837 (0.236) ***	- 0.114 (0.148)
- Agricultural secondary school	4.47 (0.449) ***	- 1.09 (0.253) ***	- 0.057 (0.154)
- University	4.58 (0.528) ***	- 0.587 (0.220) ***	- 0.065 (0.150)
- Agricultural University	4.58 (0.682) ***	- 0.499 (0.265) *	- 0.022 (0.164)
Short courses	- 0.680 (0.505)	- 0.110 (0.203)	- 0.138 (0.070) **
Continuing training	1.09 (0.536) **	- 0.861 (0.535)	- 0.069 (0.165)
Seminar series	- 0.914 (0.537) *	- 0.078 (0.276)	- 0.062 (0.101)
Years of farming	- 0.002 (0.013)	- 0.013 (0.005) **	- 0.012 (0.003) ***
Years of intercropping	4.33 (0.940) ***	0.007 (0.005)	0.025 (0.003) ***
Self-reported intercropping knowledge	0.004 (0.036)	0.030 (0.015)	0.032 (0.008) ***
Discussing farm issues with other farmers	- 0.200 (0.176)	- 0.111 (0.053) **	- 0.026 (0.026)
Discussing farm issues with production advisors	0.249 (0.147) *	0.010 (0.082)	0.006 (0.034)
Control variables			
Net profit	0.052 (0.115)	- 0.012 (0.047)	0.020 (0.018)
Household income	0.027 (0.065)	- 0.0004 (0.027)	- 0.011 (0.013)
Business strategy			
- Specialized	Omitted	Omitted	Omitted
- Diversified	1.213 (0.284) ***	0.089 (0.058)	- 0.004 (0.064)
- Multiple agricultural enterprises	- 0.469 (0.730)	- 0.305 (0.216)	- 0.040 (0.091)
Perception of land suitability	0.242 (0.133) *	0.020 (0.058)	0.043 (0.039)
Beliefs about intercropping being environmentally friendly	0.378 (0.250)	0.258 (0.086) ***	0.913 (0.046) ***
Constant	- 9.07 (1.525) ***	0.089 (0497)	- 0.913 (0.261) ***

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