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Towards a holistic approach to sustainable risk management in agriculture in the EU: a literature review

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Abstract. Agriculture is one of the sectors most exposed to a plethora of risky phenomena such as weather, pests and diseases, changes in prices and government policies, instability of global markets. We review the literature on risk management (RM) in agriculture focusing on five key issues: i) why evidence on RM is often controversial; ii) how farmers behave in selecting among available RM instruments; iii) why some of these instruments are underutilised; iv) how to assess the impacts of innovative RM tools to (further) improve their design; v) how agricultural policy measures aimed at increasing the environmental sustainability of the sector could affect RM choices. We address all these issues to get a holistic vision of RM, and point at areas where further analyses are needed.

Keywords: risk management choices, behavioural factors, adoption of risk management tools, use of chemicals, feasibility studies.
JEL Code: Q12, D81, D83, O31.

1. INTRODUCTION

Although risk concerns all economic activities, agriculture is one of the most concerned sectors, due to its exposure to a plethora of risky phenomena such as weather, pests and diseases, changes in prices and government policies, instability of global markets, and other factors (Moschini and Hennessy, 2001; Hardaker et al., 2015; Komarek et al., 2020). Furthermore, the multifaceted risks farmers must cope with are very likely to occur simultaneously, producing a compounded negative effect (Hardaker et al., 2004).

Risk in agriculture causes wide volatility in farmers' income and wellbeing and in turn it influences the decision-making process. Experiencing negative events reduces farmers' willingness to invest and innovate (Sckokai and Moro, 2009). This, in turn, may negatively affect farms' productivity and

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competitiveness (Vigani and Kathage, 2019) and push farms out of the business. The negative consequences may also be reflected in the value chain (Cafiero, 2008) and transferred to all stakeholders of the agro-food system. Major and unexpected events such as the COVID-19 pandemic and the food/energy crises induced by the war in Ukraine have unrevealed the vulnerability of the global food supply. By threatening the status of global food security, these major shocks have induced unprecedented policy responses in all advanced economies, as well as in developing countries (European Parliament, 2022; OECD, 2020; Santeramo and Kang, 2022). Over the years, risk in agriculture has been increasing in width and depth, unveiling the need for improving Risk Management (RM), as recognized by the European Commission (2017) "[...] *it is important to set up a robust framework for the farming sector to successfully prevent or deal with risks and crises, with the objective of enhancing its resilience and, at the same time, providing the right incentives to crowd-in private initiatives*". RM refers to the actions taken to manage potential problems induced by risky events, to reduce their detrimental consequences, and to increase the chances of success of the business (Kahan, 2013). In this sense, RM can be a key factor in enhancing the resilience of farms and related farming systems (Spiegel et al., 2020) and several scholars call for improving and enlarging the scope of RM to do so (Finger et al., 2022). Unfortunately, the state of knowledge on RM in agriculture is still incomplete, and the current approaches to RM are too simple, partial, and inappropriate to successfully help cope with multi-faced global challenges: changes in climate, more frequent extreme weather events, unstable and volatile markets, food security and food safety threats. Improving the state of knowledge on RM is important: successfully managing risks helps in finding the right balance among productivity, environmental care, market resilience to climate change, and capability to secure safe and quality food.

This paper reviews the extant literature on the analyses of agricultural RM, highlights progress and gaps, and advices on promising areas of research. This exercise is *per se* a very useful contribution to developing a holistic approach to analysing RM. More generally, we hope this piece will stimulate the debate on this relevant topic. While we are aware that some recent literature reviews exist, especially on specific topics (e.g., Komarek et al., 2020), we believe that our paper makes a twofold contribution to the extant debate. First, our overview of the literature focuses on five research questions: i) why evidence on RM is often controversial; ii) how farmers behave in selecting among available RM instruments; iii) why some of these instruments are underutilised; iv) how to assess the impacts of innovative RM tools to (further) improve their design; v) how agricultural policy measures aimed at increasing the environmental sustainability of the sector could affect risk and, consequently, RM choices. These questions are answered in the subsequent sections. This review also highlights areas where further analyses are needed. Second, we use a holistic approach to the topic. Since RM in agriculture is a complex phenomenon, several RM actions are available, and farmers' decisions are affected by spatially and temporally heterogeneous factors, a holistic approach seems needed (Figure 1). RM decisions are strongly influenced by the context in which farmers operate. Several dimensions are relevant to define the context, including not only farm structural and productive characteristics, but also the markets and the environment in which farmers operate. Regarding the markets, the complexity and interconnection of the global agri-food sector have imported new risks into the sector or emphasized old ones. Regarding the environment, there is a vast literature pointing out the effect of climate change on the risks farmers are facing (e.g., Sorvali et al., 2021). A growing body of literature has also shown that farmer's behavioural factors do affect the farmer's RM choices and therefore such factors cannot be ignored. Furthermore, the farm sector in the EU is heavily affected by policies. On the one hand, EU rural development policies support the adoption of specific RM tools providing subsidies to reduce the cost of adoption. On the other hand, farm production is constrained by pieces of legislation aimed at reducing the use of inputs with a harmful effect on the environment. However, often these inputs (e.g., pesticides in the case of pests, and irrigation in the case of drought) have also an effect on agricultural risk, thus their imposed reduction is likely to influence RM choices. The policy context is evolving in this area: the recently released Farm-to-Fork strategy (F2FS) and the CAP reform (European Commission, 2018) have set very ambitious environmental targets for EU agriculture (reduction of 50% and 20% in the use of pesticides and fertilisers respectively, by 2030). This will have consequences on the risk faced by farmers because the use of chemicals is intimately related to risk in agriculture and its management (Möhring et al., 2020). Studying the impact of policies targeted to environmental objectives on the farmer's risk and the uptake of RM tools is worthy to be addressed. Farmers are the ultimate decision-makers in terms of risk management strategies. As economic agents they can take several actions to manage risk including the adoption of specific RM tools (Santeramo, 2019; Cai, de Janvry and Sadoulet, 2020), changes in production mix and diversification, subscription of

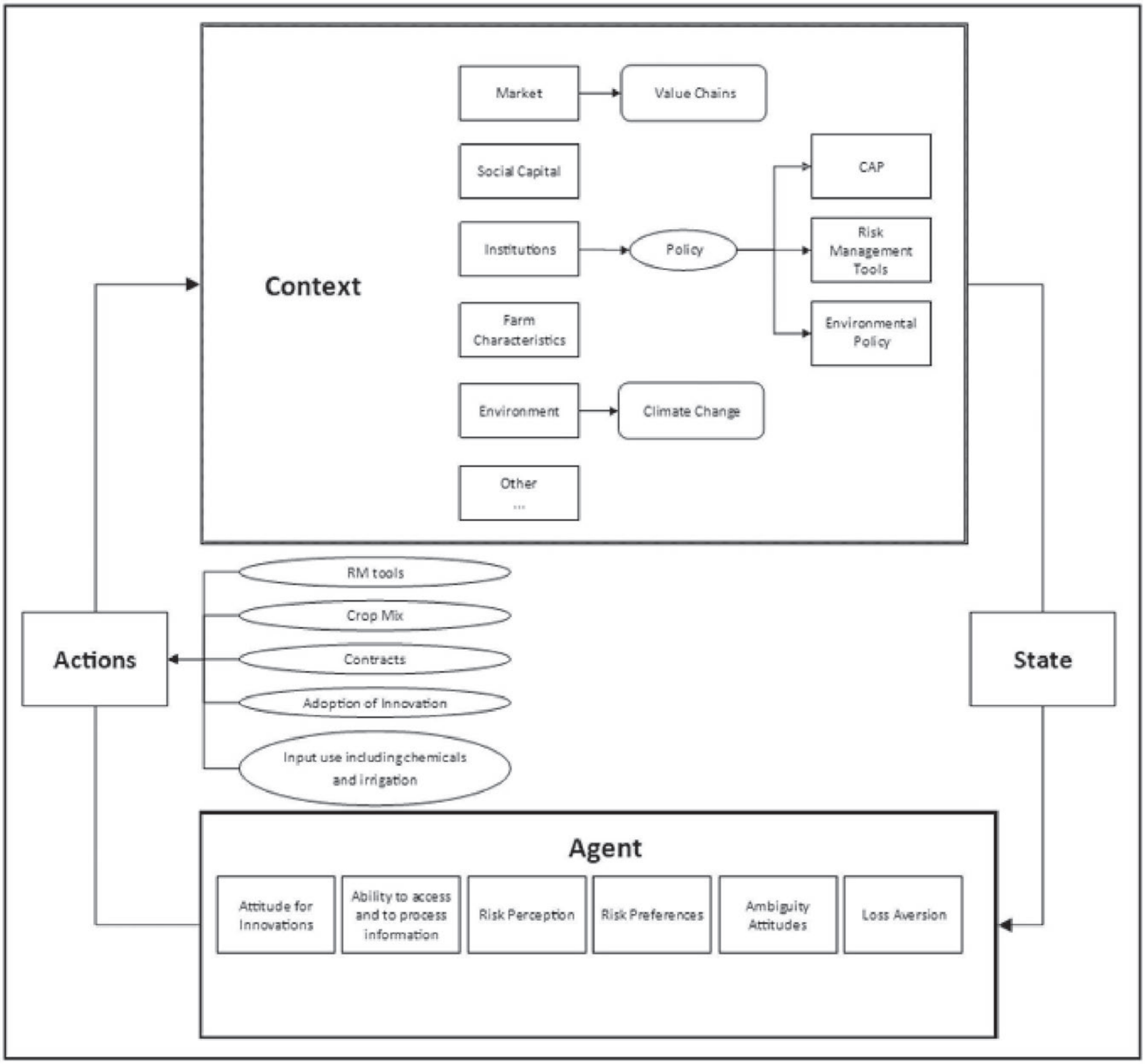

Figure 1. Graphical representation of the environment in which RM takes place. Source: Own elaboration.

production contracts, use of risk decreasing input such as pest control chemicals and irrigation (Cerroni, 2020). Their actions are however influenced by risk preferences (Iyer et al., 2020), and other behavioural factors. The literature on the influence of other behavioural factors (i.e., subjective probabilities, risk perception and preferences, ambiguity attitudes, loss aversion and time preferences) on farmers' decisions to uptake RM tools (Colen et al., 2016) is scant (Coletta et al., 2018; Cerroni, 2020; Čop et al., 2023). Similar considerations apply to the attitude toward innovations and the ability to gather and process information.

In the end, this oversimplified framework (and logical flow) advocates for a holistic approach to the analysis of RM also realizing that the current state of agricultural RM is constantly evolving, and it needs to be adapted to novel challenges. Our literature review is an attempt to approach the study of RM by adopting a holistic view: the methods adopted in the analysis of RM in agriculture, the behavioural factors affecting RM adoption, innovative RM tools, the relationship between agricultural risk and input use and between different policies directly or indirectly affecting risk and RM in agriculture.

These topics were selected because they are important in influencing the choice of RM strategies. Furthermore, on these issues there have been significant advances in the literature but still some aspects require further study. Although the emphasis is on EU RM, the review considers analyses carried out also in non-EU countries. These are included to report approaches of analyses that could be replicated in the EU context and to better position the possible strategic choices of the EU with respect to the international context.

Section 2 gives an overview of the methods available in the literature to study the adoption of RM in agriculture and it also summarises risk types whose frequency is increasing in the agricultural sector. Section 3 focuses on the behavioural factors, specifically the subjective probabilities, risk and uncertainty preferences, affecting the farmer's decision to adopt insurance products (either traditional insurance or weather-based index insurance). Section 4 provides a picture of innovative RM tools, such as the mutual funds for catastrophic events (introduced by the last CAP reform) and the weather-based index, together with their pros and cons compared to traditional insurance products. Section 5 reports on the studies related to the impact of pesticide and fertiliser use on agricultural risk as well as on the effect of insurance product adoption on this use. The section also highlights potential synergies and trade-off among different EU agricultural policies.

The last section concludes by summarizing the main points raised by the literature review. Here, special attention is paid to identify the areas where further improvements in the research on farm risk management are needed.

2. EXPLAINING RISK MANAGEMENT CHOICES

To cope with the large array of risks the farm sector is facing, the European Union (EU) decided to emphasize the role of new RM tools (Meuwissen et al., 2018) by structurally supporting not only crop insurance products, but also mutual funds (MF). These can cover yield losses and, by means of the Income Stabilisation Tool (IST), can help farmers cope with income drops (El Benni et al., 2016), enlarging the type of risks covered by subsidized tools. Despite the pervading exposure to risks for farmers (Trestini et al., 2017), the advantages that these instruments provide to farms (Enjolras et al., 2014; Severini et al., 2019) and the confirmed trend in the reduction of decoupled direct payments, the expenditure foreseen since 2014 in the CAP for the Risk Management Toolkit involves only 12 over 28 Member States (Chartier et al., 2017). Among these, Italy, the leading country in terms of allocated budget, still records a limited uptake of risk management tools (Ismea, 2022). The application of CAP is further pushing in the direction to improve the development and the support for risk management solutions by confirming actual tools and introducing in the Italian Strategic Plan of the CAP, from 2023, the new catastrophic risk coverage called Agricat, built as a mutual fund.

All this offers farmers the opportunity to get access to a wide set of RM solutions. This availability of innovative tools (i.e. mutual funds, IST and Agricat) together with the limited diffusion of traditional ones (i.e. insurance), impose understanding determinants of the diffusion of both traditional and innovative RM tools to allow farmers to maintain and improve their resilience and competitiveness under the new orientations of CAP. Understanding the factors that influence the adoption of RM tools allows, from the point of view of policy maker, to evaluate the effectiveness of RM policies and to guide their design. While, from the perspective of insurance company or mutual fund, it provides a better understanding of farm preferences by driving the development of RM tools that can promote farm resilience.

The review of the research methodologies applied to understanding the adoption of RM tools by farmers allows to identify research gaps and suggest potential future studies. The adoption of risk management tools is extensively investigated in the literature (Harrison and Ng, 2019), yet the behavioural factors of this adoption is often neglected (see Section 3 for a detailed discussion on this point). In the EU, a growing body of studies about yield insurance and mutual fund adoption is observable (Enjolras and Sentis, 2011; Liesivaara and Myyrä, 2017; Meuwissen et al., 2018; Santeramo, 2018; Santeramo et al., 2016; Was and Kobus, 2018). Index-based insurance tools, marginally adopted in the EU, are mainly investigated in developing countries (e.g., Bucheli et al., 2021; Jensen et al., 2018) with some applications in the EU (Vroege et al., 2019).

In order to understand RM behaviour and assess the probability of farmers' adoption of available and innovative tools, it is worth considering different determinants simultaneously within an effective conceptual framework. In fact, the determinants of the adoption of RM tools are widely discussed in the literature, whereas practical application aiming to understand the interaction of different determinants is much less explored (Holt and Laury, 2002; Franken et al., 2017). Indeed, risk and ambiguity preferences may affect risk behaviour directly (Menapace et al., 2013; Čop et al., 2023). Furthermore, risk attitude explains risk behaviour, being indirectly affected by socio-economic and individual characteristics (Dohmen et al., 2011; Donkers et al., 2001). Complex interrelations can be simplified by multivariate statistical analysis such as the so-called Structural Equation Modelling (SEM) (Ullman and Bentler, 2003). SEM allows for testing complex models that imply both direct and indirect effects, allowing to solve limitations of traditional regression models. Furthermore, SEM allows researchers to distinguish between observed and latent variables, testing a wider variety of hypotheses compared with most traditional approaches (Kline, 1998). This approach is quite recent among agricultural economists, with one of the first examples incorporating risk components proposed by Pennings and Leuthold's (2000). In recent applications, risk behaviour has been investigated focusing on risk perception and risk attitude (Van Winsen et al., 2016), and on farm socio-economic and individual characteristics of risk attitude (Franken et al., 2017), also incorporating the role of trust and perceived barriers (Giampietri et al., 2020). A first attempt to apply a defined framework to understand the participation to RM tools has been applied by Rippo and Cerroni (2023) using the Unified Theory of Use and Acceptance (Venkatesh et al., 2003). Beside these attempts to build a framework able to understand and support the diffusion of available and innovative tools, any shared conceptual framework is, to our knowledge, applied in the literature.

Literature proposing the analysis of determinants of diffusion and/or adoption of innovation at SMEs including farms is extensive and well formalized. Many other methodologies should be tested also for the case of RM tools adoption. To do so, we should consider the organisational profile of farms and the role of individuals, especially in family farms. At first glance, when evaluating family farm choices, the theory of planned behaviour (TPB) (Ajzen, 1985; 1991) and technology acceptance model (TAM) (Davis, 1986) appear to be the most appropriate frameworks. This is because the two frameworks include constructs such as "Subjective norms", in the case of the TPB, or the perceived usefulness, in the case of the TAM, which strictly refer to the individual evaluation of the choice or to the perceived social pressure to engage or not to engage in a behaviour. When the farm adopts a structure in which wage labour becomes prevalent by assuming a corporate structure with division and delegation of responsibilities, the process of choice moves from being individual or dependent on family needs and relationships to being the result of an organizational choice. In this case, diffusion of innovation theory (DOI) (Rogers, 1995), and the technology–organization–environment (TOE) framework (Tornatzky and Fleischer, 1990) are suitable. These methodologies analyse the adoption process at the organizational level, including among determinants of specific adoption choice variables like the compatibility with the company, in the case of DOI, and formal/informal organisational link, in the case of TOE.

Besides deterministic approaches, Machine Learning solutions start to be applied to further understand factors affecting the adoption of RM strategies. Few applications can be retrieved from the current literature considering application of insurance contracts in Romania and Italy (Mare et al., 2022; Biagini et al., 2022a) and mutual funds for pest diseases in the North of Italy (Höschle et al., 2023).

At present, there is a growing interest in the management of new and/or growing risks: among these, it is worth to mention the need to manage growing systematic abiotic risks (e.g., drought and frost) and emerging biotic threats (pests and diseases). As regards the latter, the need for better-tailored risk management tools becomes more urgent given the orientation of agricultural policy towards the significant improvement of production environmental standards (e.g., F2F Strategy), often not sufficiently supported by alternative solutions in pest management. In the case of extreme and systematic weather risks, a country-wide event cannot be covered under indemnity insurance schemes because the costs for the physical damage assessment in the field often outweigh the benefit for the insured farm (Vroege et al., 2019) and the systemic nature of the event may expose insurance sector to unsustainable costs. Concerning biotic threats, the availability of insurance is rare as it is often unsuitable for the insurance market, due to both their unpredictable spread, linked to an epidemic dynamic, and agents' behavioural reasons, mainly moral hazard (Norton et al., 2016). To face the limitations of insurance, some pioneering initiatives of mutual funds to manage such risks have been locally developed in Italy, both with private and public support (Giampietri et al., 2020; Höschle et al., 2023), but the availability of such tools is below the expected demand.

To design a better-tailored RM tool offering protection against pests and diseases that are appealing to farmers, the first important step is to investigate farmers' preferences for the characteristics of such innovative tools. Until now, farmers' preferences for insurance contract characteristics remain mostly unaddressed, despite being of utmost importance for designing new insurance contracts, extending them to other crops, and increasing participation rates. To this purpose, the discrete choice experiment (DCE) approach has proved to be useful. Based on the Lancaster's (1966) theory of consumer and the Random Utility Theory, demand is defined over the characteristics of goods, rather than over goods themselves. In DCE respondents are thus asked to choose between different bundles of goods (e.g., RM tools) described in terms of their characteristics (e.g., price, level of maximum indemnity). DCE has been largely employed to elicit consumers' preferences and policy design (Colombo et al., 2005). More recently, this approach has also been used to investigate farmers' preferences for agro-environmental scheme designs (Ruto and Garrod, 2009) and contract farming configurations (Abebe et al., 2013). Furthermore, discrete choice experiments have been used to investigate farmers' preferences for insurance contract characteristics. While there are several DCE carried out in developing countries addressing farmers' preferences for insurance characteristics (Akter at al., 2016; Reynaud, Nguyen, Aubert, 2017; Ward and Makhija, 2018; Ali et al., 2021; Tang et al., 2022), there are only few that concern European farmers (Mercadé et al 2009; Liesivaara and Myyrä, 2017; Möllmann et al., 2019; Doherty et al., 2021; Čop et al., 2023) and there are no applications on Italian farmers. In conclusion, the literature review highlights the lack of a general framework to support the development of effective policies to promote RM solutions in agriculture. A comparison of different frameworks can improve the understanding of farmers' behaviour and evaluate the most suitable approach depending on the organizational profile. These studies should support policy design based on the joint study of farmers' preferences and behaviour towards RM strategies. Furthermore, there is a need to carry out policy impact assessments in terms of farmer uptake of RM innovations and effects in reducing risks and increasing farm resilience. Finally, it may prove useful, as RM solutions for farmers increase, to better understand the interactions and possible trade-offs between the different tools.

3. BEHAVIOURAL FACTORS INFLUENCING FARMERS' ADOPTION OF RISK MANAGEMENT TOOLS

From a behavioural perspective, the economic framework that is generally used to understand and predict farmers' decisions to cope with agricultural risks is rooted in expected utility theory (EUT) (von Neumann and Morgenstern, 1947). However, some fairly recent empirical applications have demonstrated that farmers' decisions to insure their production often depart from standard EUT. Non-standard economic theories, such as prospect theory, explain farmers' choice behaviour more parsimoniously (e.g., Babcock, 2015; Dalhaus et al., 2020; Feng et al., 2021). These empirical findings determined the development of a small but growing research that investigates the extent to which behavioural factors such as farmers' probabilistic beliefs, probability weighting, risk and uncertainty preferences, and loss aversion influence farmers' decisions to purchase an insurance product (e.g., Fezzi et al., 2021) and participate to mutual funds (Rippo and Cerroni, 2023; Čop et al., 2023). These behavioural factors are generally elicited using experimental methods, while their ability to explain and predict farmers' choice behaviour is tested by combining data from economic experiments with primary data obtained using stated preference surveys or available secondary data on actuarial farmers' purchasing decisions (Iyer et al., 2019). In this section, we mainly focus on the literature related to subjective probabilities, risk and uncertainty preferences.

Subjective probabilities are considered to be important predictors of farmers' behaviour because farmers, like any other economic agent, base their decisions on their beliefs or expectations when the decision context is highly uncertain. If expressed in a probabilistic fashion, these beliefs or expectations are defined as subjective probabilities (e.g., Hardaker and Lien, 2010). The literature looking at the role of subjective probabilities in explaining farmers' behaviour is scant, and only a very small number of studies examined how subjective probabilities influence farmers' decision to purchase an insurance product (see Cerroni, 2020; Čop et al., 2023; Cerroni and Rippo, forthcoming for recent reviews). There are a couple of noticeable exceptions. Čop et al. (2023) found that subjective probabilities are important predictors of farmers' decisions to enrol on a sector-specific IST related to grapevine. Fezzi et al. (2021) found that farmers' subjective probabilities regarding production losses due to extreme climatic events are not in line with objective measures of risk. Hence, policy interventions geared to reduce this gap could have important policy implications regarding insurance subsidization. One potential drawback of these studies is the elicitation of subjective probabilities using hypothetical methods that are not incentive-compatible and therefore do not induce farmers to elicit truthful beliefs. However, the literature on decision analysis provides several incentive-compatible methods that are able (in theory) to elicit truthful beliefs under a proper incentive scheme. These methods could be used to elicit more accurate subjective probabilities related to uncertain agricultural outcomes (see Cerroni and Rippo, forthcoming for a review). More accurate probability assessments should have in theory a higher degree of external validity and explain farmers' choice behaviour more parsimoniously.

Risk preferences have been shown to be an important driver of farmers' decision-making processes, especially those related to the adoption of new technology and crops (e.g., Liu, 2013; Barham et al., 2016). However, only a few studies have investigated whether these preferences can play a role in explaining farmers' decision to purchase insurance products. Recent research indicates that risk preferences are poorly correlated with the decision to purchase traditional insurance products (Menapace et al., 2016; Coletta et al., 2018; Rommel et al., 2019; Čop et al., 2023). These results may be driven by some confounding factors that have been recently identified in the related literature. First, risk preferences appear to be highly context-dependent (Finger et al., 2022) and therefore their ability to explain farmers' choice behaviour may be context-dependent too. Second, a wide range of approaches exists to elicit risk preferences (see Cerroni, 2020, and Cerroni et al., forthcoming for recent reviews), and, unfortunately, empirical evidence suggests that different elicitation techniques provide inconsistent measures (e.g., Reynaud and Couture, 2012). Once again, the elicitation technique used may have an impact on the ability of elicited preferences to explain choice behaviour. Some practitioners advocate that adding an agricultural context to standard monetary lotteries can improve the external validity of elicited preferences, thus boosting the predictive power of elicited risk preferences. On the other hand, contextualization may lead farmers to use heuristics that undermine the internal validity of experimental data (see Cerroni, 2020 for an application of contextualized field experiments and a discussion on strengths and limitations).

If farmers' risk preferences are extensively researched in the related literature, uncertainty and ambiguity preferences are not. There are only very few studies eliciting farmers' uncertainty and ambiguity preferences (e.g., Beharam et al., 2014, Bougherara, 2017; Cerroni, 2020). None of these studies attempt to use such preferences to explain farmers' behaviour when purchasing insurance products. In this section, we use the terms uncertainty and ambiguity interchangeably, however, we have to acknowledge that the distinction between risk, uncertainty and ambiguity is far from being clear in the decision analysis literature (see Cerroni and Rippo, forthcoming for a discussion).

The most popular approach to disentangling these concepts is the frequentist. Here, risk refers to situations where definite numerical probabilities are known and can be objectively measured, while uncertainty refers to situations where definite numerical probabilities are unobservable (Knight, 1921). However, other paradigms exist, such as the subjectivist, under which subjective probabilities play a key role under both conditions of risk and uncertainty (Ramsey, 1931; de Finetti, 1931, Savage, 1954). Furthermore, there are other schools of thought that try to differentiate uncertainty from ambiguity. For example, according to Harrison (2011), uncertainty refers to situations when the agent can form a unique and well-defined subjective probability distribution, while ambiguity refers to situations when the agent is not capable of doing so.

This brief discussion on the role that subjective probabilities, risk and uncertainty preferences can have on farmers' decisions to use risk management tools allows to highlight a few key points relevant in the case of the use of insurances. First, the literature exploring the extent to which these behavioural factors affect these decisions is almost non-existent. The literature focusing on standard agricultural insurances and mutualistic solutions is limited. While common sense suggests that subjective probabilities, risk, and uncertainty preferences can affect the uptake of risk management tools, the extent of these impacts and the underlying behavioural mechanisms are unclear and under researched. Second, there is still an open discussion in the decision analysis literature regarding the most appropriate way to elicit these behavioural factors. Many methods are available to elicit subjective probabilities, risk and uncertainty preferences in the literature and empirical evidence suggests different methods lead to different results. This may have an influential impact on the role these behavioural factors play in explaining farmers' insurance decisions. The horse race to truthful probabilistic beliefs, risk and uncertainty preferences is not over yet. Exploring the internal and external validity of results obtained via different elicitation methods appears to be the only strategy to shed light on these issues. Third, behavioural factors can be useful also to predict farmers' choice behaviour. A new stream of research is emerging that seeks to incorporate these behavioural factors into simulation models to enhance their ability to explain and predict choice behaviour (e.g., Huber et al., 2022). This line of research definitively contributes to build a more holistic view about. sustainable risk management in agriculture.

4. INNOVATIVE RISK MANAGEMENT TOOLS

The previous sections have focused on RM behaviour and choices of RM tools mainly referring to already existing tools such as crop insurance schemes that have a long history in Italy, and date back to the early 2000s (Cafiero et al., 2007; Santeramo and Ramsey, 2017). The transition has been motivated by drawbacks associated with the ex-post compensation, such as its financial unsustainability (Goodwin and Smith, 1995; Goodwin and Mahul, 2004; Mahul and Stutley, 2010; Santeramo et al., 2016), as compared to crop insurance and revenue insurance schemes.

Despite this, the public crop insurance scheme has not been a story of success, as testified by low and heterogeneous participation and retention (Santeramo et al., 2016). This has been motivated by the lack of tradition with subsidized schemes, as well due to the necessity to serve a relatively little market, with many (highly differentiated) crops and a majority of small-size firms (Santeramo et al, 2016) and has suggested to implement ameliorative reforms to overcome the complexity of the policy environment (Severini et al., 2017). Two major reforms were implemented in 2013 and 2015; the former removed subsidies to the mono-risk insurance contracts; the latter replaced the multi- and pluri-risks contract schemes with "packages" covering a set of adversities (Santeramo et al., 2022). Both reforms had negligible effects on insured acreage (as high as three percent) and insured values (estimated to be lower than one percent), casting doubts on their effectiveness. Finally, farmers are often coping with risks which are not covered by traditional insurance schemes, or that are extraordinary in terms of expected damages (i.e., due to so called catastrophic events).

Because of these reasons, it seems relevant to consider innovative RM tools because these may overcome the issues encountered by the traditional insurance products. Indeed, the new Common Agricultural Policy is continuing to reform by enlarging the support for innovative risk management interventions and strategies. Here we focus on two of themes: mutual funds for the so-called catastrophic events and the index-based insurance schemes. These options are precisely meant to complement traditional insurance schemes but are not the only innovative instruments[1]. While the ex-post approach tries to limit the potential additional damages that may occur after a catastrophic event, and to promote the restoration of the damaged structures, alternative mechanisms may help share the costs associated with extreme events and catastrophes. The use of insurance tools to cope with extreme and catastrophic events is dated (Michel-Kerjan, 2010) but still very debated, especially in agriculture (Bucheli et al., 2020). The rationale is simple: due to the increasing amount of available data on weather conditions and the higher frequency of extreme events and natural disasters (both systemic in nature and with high impacts on the sector), coping more directly with these events is not only possible, but also necessary to avoid the default of many farms. The catastrophic bonds and the catastrophic reinsurance may help cope with disasters as they are bet on the occurrence of a disaster, in which case an indemnity is paid. Another possibility, being explored in Italy, is the use of a mutual fund to cover losses from high impactful events.

In Italy the new risk management interventions have been defined by the National Strategic Plan (NSP) 2023-2027 of the CAP. Besides confirming support to (production) insurance schemes, (production) mutual funds (for plants, animal production, farm structures and livestock farms), and (income) mutual funds (for selected sectors such as poultry, sugar beet, durum wheat, cow and sheep milk, olive, fruit and vegetable, rice, and pig), it also establishes a mutual fund (the Agricat) for catastrophic event. The latter covers farmers against specific weather events (frost, drought, and flood) defined as potentially catastrophic. The indemnities are triggered by production losses due to one of the three events, as certified by randomly executed expert reports. The economic sustainability of the newly established fund is unclear, and depends on the design of the fund, on the rating of the premia, and on the effectiveness of the damage reports. In 2022 the Ministry of Agriculture has started a pilot study in thirteen provinces (both in the North and in South), for twelve products (apples, pears, durum wheat, corn, almonds, oranges, apricots, actinidia, wine grapes, oil olives, peaches, and industrial tomatoes). ISMEA has released preliminary results on peaches, concluding that about sixty percent of insured farms have incurred in losses below the (20%) damage or (30%) deductible thresholds, whereas the remaining share of farms has incurred in losses as high as fifty percent in one out of four cases. The findings are of undoubted interest, but also worrisome compared to the US system, in which indemnities worth 14.9% of insured liability are considered to be excessively high in that the median value is as low as 2% of crop insurance liabilities (DeLay et al., 2022). Such a high level of indemnities points at precise future goals, which can be summarised in four priorities: i) improve the accuracy of existing data to map and monitor high-impacts weather events; ii) increase the penetration of the program, and farm retention; iii) mitigate and reduce repetitive losses to lower operating expenses; iv) strengthen the financial sustainability of the program by designing optimal participation rates. These points translate into research questions worth investigation.

Another innovation, barely adopted in developed countries, is the use of index-based insurances: the

[1] For sake of brevity, we do not discuss other innovative instruments such as, for instance, the Income Stabilization Tool (cfr. Giampietri et al., 2020, and Zinnanti et al., 2022, for recent assessments).

scheme indemnifies farmers, who have likely incurred losses, when the index exceeds a threshold (Abdi et al., 2022). A practical example may help in understanding the rationale behind this scheme. Assume a set of farms are exposed to potentially detrimental events (e.g., excessive rain): when the event occurs with a certain magnitude (e.g., the daily volume of precipitation is three times larger than the average precipitation) the likelihood that the farm experiences a loss is high. In this situation, while collecting data on precipitation for each single farm may be costly and inappropriate to determine the incurred losses, relying on the index may be a second-best solution. The operation of an index-based insurance consists of indemnifying all farms when the index exceeds a threshold. The scheme of an index-based insurance has *pros* and *cons*, and is not the ultimate solution (Carter et al., 2017): on one hand it may reduce (or eliminate) moral hazard and adverse selection issues; on the other hand, it may be ineffective if the correlation between triggered pay-outs and the occurrence of loss events is rather low. This potential fallacy is referred to as "basis risk" and defined as "the risk that a protection buyer's own losses exceed the payments under a risk transfer mechanism structured to hedge against these losses." (Ross and Williams, 2009). The basis risk has serious impacts on the functioning of index insurance (Clement at el., 2020) and calls for a deep understanding of the phenomena aimed to be coped against.

The basis risk is a three-dimensional concept, defined by time, space and design of the index. The three dimensions correspond to the temporal, spatial and design basis risks, which are inversely correlated with the informative content of the information being used. For instance, an index-insurance built on hourly data for weather events provides lower temporal basis risks with respect to the same index built on annual data. Similarly, an index built on state level data will have higher spatial basis risk than a similar index relying on municipality level data. As for the design basis risk, the lower the flexibility (and complexity) of the index, the higher the design basis is likely to be. Differently, highly informative datasets allow good performance, in terms of correlation between agricultural data and weather statistics (e.g., Cheng et al., 2017). In a recent paper, Stigler and Lobell (2023) decompose, from a theoretical point of view, the basis risk of the index insurance schemes. Their empirical analysis uses linear and quantile regressions, coupled with richly informative datasets, to derive effective indexes.

Index-based insurance is still underutilized in developed countries, whereas there are several applications in developing countries: "more than fifteen developing countries have offered individual-level index insurance schemes […], and some twenty have offered it at the institutional or geographical level." (Carter et al., 2017, p. 423). The low uptake of index-based insurance calls for a better understanding of the challenges that prevent participation. In particular, Carter et al. (2017) indicate four areas of improvement on (a) the design of the contract; (b) the measurement of risks; (c) the quality of insurance schemes, and (d) the use of other risk coping interventions.

These areas of improvement should be approached by promoting empirical studies that explore the informative content of the large datasets, through a holistic lens capable of merging knowledge from different disciplines (e.g. climatology, agronomy, statistics, economics, management) . For instance, promising research may be conducted by analysing the correlation in the tails of the yield and weather data distribution[2] (e.g., copula-based models, quantile regressions) as well as using quantitative methods capable of synthesising large sets of variables[3] (e.g., machine learning, shrinkage estimators). However, none of those techniques would be sufficient without a better understanding of the fundamentals of the economics and management of risks, topics that should remain a priority in the research agenda.

5. AGRICULTURAL RISK, INPUT USE AND RELATED POLICIES

The previous sections have considered the potential role of RM strategies and tools without accounting for the fact that other policies exist and affect farmers' behaviour. Indeed, some policies not targeted to risk in agriculture may have an unintended effect on RM behaviour and choices. A holistic view to the risk analysis cannot ignore the synergies and trade-off across policies directly or indirectly affecting the agricultural risk. This section refers to the literature that has shown that there exists a relation between the farmer's use of fertilisers and pesticides and the risk farmer faces. Thus, any policy aimed at constraining the use of chemicals in agriculture has an indirect effect on the risk the farmers must cope with.

This branch of analysis fits with the EU F2F Strategy, which has defined a set of objectives and guidelines to drive the European agri-food system toward a fair,

[2] See for instance applications by Goodwin and Hungerford (2015), Conradt et al. (2015), Bokusheva (2018), among others.
[3] A good discussion on recent methodological advances to model insurance is provided by Ali et al. (2020) who discuss the potentiality of machine learning, as well as of artificial intelligence.

healthy, and environmental-friendly transition. Among the targets of the Strategy, two are specifically addressed to fertilisers and pesticide use. The Strategy aims at reducing the overall application of chemical pesticides in agriculture by 50% as well as of the more hazardous ones by 50% by 2030. The Strategy also envisages a reduction in fertiliser application of 20% by 2030 and a reduction of the nutrient losses in the soil of 50% over the same time horizon. Along this line, in June 2022 the Commission made a proposal (European Commission, 2022) to revise the directive on the sustainable use of pesticides (2009/128/EC) and to switch the legal framework from a directive to a regulation. The proposal aims at meeting the F2F Strategy targets in terms of pesticides and has received criticism from many Member States which particularly blame the "flat rate" pesticide cut proposed by the Commission. In order to implement the fertiliser goal of the Strategy, a new digital tool is being developed, the Farm Sustainability Tool for Nutrients (FaST). FaST will combine data from different sources and will provide detailed *ad hoc* recommendations on the application of crop fertilisation and plant protection products. This should improve the efficiency in fertiliser use and, consequently, should help to comply with the target on the fertiliser use reduction and losses. Finally, measures related to the pesticides and fertilisers targets are contained in the National Strategic Plans of the Common Agricultural Policy (CAP) 2023-2027, specifically in the eco-schemes and in the enhanced conditionality of the first CAP pillar as well as in the agri-environmental-climate measures of the second CAP pillar. The effect of a policy targeted at the reduction of chemicals is likely to affect farm input decisions and the corresponding farmers' expected utility in two ways. First, it would directly constrain the amount of chemical application in the farmer's decision process. Second, as literature has shown that pesticides and fertilisers use often changes the level of agricultural risk and farmers are usually risk-averse, the policy imposed on these inputs alters the level of risk the farmers face and, as a consequence, is likely to affect farmer's decision on the use of other inputs related to the chemicals (may they be substitutes or complementary inputs).

The use of agricultural inputs, including pesticides and fertilisers, is affected by the degree of risk aversion of the farmer (Bontemps et al., 2021). For example, according to the model adopted (either the Expected Utility or the Cumulative Prospect Theory (Tversky and Kahneman, 1992)) it has been shown that from 4% to 19% of the pesticide expenditure on farms is explained by farmer risk aversion behaviour (Bontemps et al., 2021). Therefore, the higher the risk aversion of the farmers the higher will be the impact on farmer's decisions and, in turn, on the effectiveness of a policy that restricts chemicals use. The estimation of the farm risk aversion behaviour is partially dependent on the theoretical model adopted. For instance, Rommel et al. (2022) in a study on farmer's risk preferences in 11 EU countries have shown that the Cumulative Prospect Theory explains the preferences better compared to the Expected Utility framework.

Möhring et al. (2020a) provide a deep literature review on the relationship between pesticide use and farm risk. They show that around half of the papers that so far have assessed this issue find a risk-increasing effect of the pesticides (e.g., Serra et al., 2006 and 2008), around half report a risk-decreasing effect (e.g., Koundouri et al., 2009; Antle, 2010; Gardebroek et al., 2010) and only one paper finds no effect (Hurd, 1994). Besides the heterogeneity of the agricultural products and of the countries analysed in the papers, another reason to explain such opposite effects found in the literature is the heterogeneity of the indicators used to measure pesticide application across papers. Möhring et al. (2020a) show that the impact of pesticide use on farm risk depends on the pesticide indicators and on the pesticide type considered. Unfortunately, in most of the countries the national FADN datasets contain data of poor quality related to pesticide quantity and this prevents from using that type of information in this type of research. If no better-quality data are available, the only option is to use pesticide expenditure as a proxy for pesticide quantity. Indeed, most of the studies cited above use pesticide expenditure. Improving the data quality concerning pesticides in the EU is of paramount importance to inform evidence-based policy making. The F2F Strategy also acknowledges the need to overcome the data gaps by changing the 2009 Regulation concerning statistics on pesticides. In addition, the Commission announced its intention to convert the FADN dataset into the FSDN (Farm Sustainability Data Network) which would include more detailed information on the environmental practices of the farms and would introduce data on their social practices (European Commission, 2021).

When it comes to fertilisers, literature (Paulson and Babcock, 2010; SriRamaratnam et al., 1987) agrees that fertilisers are risk-increasing and it highlights the "fertilisers paradox". Indeed, although fertilisers are risk-increasing, risk averse farmers oversupply them. This happens because, under production uncertainty, due to for example unpredictable weather conditions or uncertainty in the amount of nutrients available to the crops, the overapplication of fertilisers is used by farmers as a form of self-protection (Babcock, 2001; Paulson and Babcock, 2010). Therefore, when modelling farmer fertiliser use it is important to account for the uncertain conditions the agricultural production faces which affect farmer's decisions about fertilisers.

When analysing the relationship between chemical use and agricultural risk some issues must be addressed from a methodological viewpoint. First, there may be some simultaneity in the chemical use decision and agricultural risk. Indeed, usually chemicals are applied multiple times in the cropping seasons and the number of applications as well as the amount of chemicals applied in each application are decided by the farmers based on how the season is going in terms of weather and pests and how the crop is growing. If throughout the cropping season, the farmer observes an increase in agricultural risk compared to his initial expectation, he may adjust the planned fertiliser and pesticide application consequently. In addition, the past year agricultural risk is likely to affect the current year input decisions. This consideration makes relevant the use of a sequential decision-making production model as proposed by Antle (1983a) to account for the possible feedback effect, i.e., the farmer adjusts his decision on variable input use based on the output observed or on the adjustment in the output expectations. Second, the analysis of risk in agriculture needs to account not only for the mean and variance of the crop yields and of farmer's revenue, but also for higher moments of the yield and revenue distribution (Finger et al., 2018) as farmers are often downside risk averse (Di Falco and Chavas, 2006). Indeed, it is likely that farmer decisions are more affected by variations of crop yield and farm revenue below the average than by variations above the average. Specific econometrics approaches exist to address higher moments of the distribution such as the moment-based approach (Antle, 1983b) recently applied to Italian farm data by Biagini et al. (2022b) and its updated version that uses partial moments (Antle, 2010).

Another important topic only partially addressed in the literature is the relationship between RM tools adoption and chemical application. RM tools change the agricultural risk faced by farmers and consequently, they may impact the use of risk-increasing and risk-decreasing input when the farmer is not risk-neutral. For example, the adoption of insurance may induce farmers to adopt moral hazard behaviour which in turn influences the pesticide and fertiliser use decisions (Mishra, 2005). As stated earlier, pesticides are risk-increasing or risk-decreasing according to the type of crop, the country and the pesticide indicator considered, and therefore the direction of the relationship between pesticides and farm insurance remains an empirical question. Second, insurance may induce farmers to change land allocation among crops, e.g. by growing more risky crops, and this also affects chemical use. Analysing whether insurance and chemicals are substitutes, complements or independent goods from the producer's perspective is a worthy issue. Indeed, this assessment would outline the interaction and the spillover effects among two policies: the one pointing at reducing chemicals application in agriculture and the one pointing at increasing the adoption of RM tools among farmers. Although this research branch is rather explored in the US where studies reveal a positive, a negative and a zero effect of insurance uptake on input use, Möhring et al. (2020b) is one of the few examples applied to European agriculture. The study is focused on two countries (France and Switzerland) and it shows that the adoption of insurances increases the application of pesticides.

6. CONCLUSIONS

The agricultural sector is, by its nature, exposed to several risks, and farmers have a long-lasting tradition in coping with them. Yet the rising complexity and interconnection of the global agri-food sector have introduced new risks into the sector, calling for more and more frequent policy interventions. In the European Union, the interventions on risk management have been fragmented and managed at the national level and slow is the introduction of innovative tools. In the context of a CAP with a declining budget, oriented toward environmentally-friendly and sustainable production models, risk management becomes a relevant strategy to lower income uncertainty and favour the resilience of the agri-food system. Given the low uptake rate of RM tools in the European Union, studying the determinants of the uptake referring to both the farm and farmer's characteristics as well as to the RM tool design is crucial to set up effective innovative RM tools and to refine the traditional ones. Studies on the determinants of farmers' behaviour towards risk management tools are rather limited in number. Equally, literature on innovative tools, such as index-based and the catastrophic insurance schemes is scant.

The role of behavioural factors in explaining farmers' risk management decisions is often neglected in the literature. However recent studies suggest that behavioural factors should be incorporated into models to explain and predict farmers' adoption and use of risk management tools (e.g., Babcock, 2015; Dalhaus et al., 2020; Feng et al., 2020; Tack and Yu, 2021). Those studies have stimulated a growing stream of research that has mainly focused on the elicitation of farmers' risk preferences using experimental methods. Empirical results show that further research is needed in several dimensions. First, preference elicitation methods appear to have an important impact on the magnitude of elicited preferences, therefore further research is needed to identify the methods that provide more robust measures in terms of internal and external validity. Second, empirical evidence indicates that risk preferences are context-dependent. Hence, it is still unclear whether risk preferences elicited using monetary lotteries are fully able to explain farmers' choice behaviour, or whether practitioners should move to the use of contextualized lotteries that may improve the external validity of elicited preferences. Third, while farmers' risk preferences have been widely investigated in the literature, there are only a few studies focusing on the role that subjective beliefs, ambiguity attitudes and time preferences may have on farmers' decisions in general, and more specifically, regarding the uptake of different RM tools. Finally, a holistic approach to the study of risk management cannot ignore the interrelation between farmer's input not specifically targeted to risk management and the agricultural risk. This is key to discover possible synergies and trade-offs among different policies. The policies aiming at reducing the fertiliser and pesticide use in agriculture indirectly affect the agricultural risk because fertilisers and pesticide impact the risk level. Results reported by the literature on this impact are controversial and depend on the crop, country and indicator considered and there is often the issue of poor data quality. A more sustainable use of chemicals in agriculture and a better management of risk in the sector are two forefront topics in agricultural economics. Hence, efforts towards gathering better quality data are required. In addition, given the importance of framing consistent and effective EU policies, the investigation of the relationship between the RM tools adoption and the farm application of chemicals needs to be addressed. This investigation would shed light on whether two apparently independent policies, namely the policy restricting the use of chemicals in agriculture and the one promoting the adoption of RM tools, have the same or opposite direction.

Besides briefly mentioning what the literature has already provided and which methods have been investigated, we conclude this paper with a few priorities to orient future research: efforts should be devoted to improve the use of the large amount of available data, to improve the financial mechanisms that may ensure the financial stability of the RM schemes, and to increase the interconnection (and complementarity) of the RM instruments. In short, the search for innovation in RM should be not only oriented toward a sophistication of the strategies, but also (and mainly) toward a better exploitation of the informative content of the existing data, as well as of the holistic nature of the approaches. In addition, the results of this literature review suggests that the theoretical framework used so far in the literature for understanding farmer behaviour in terms of RM is not unique: different models have been applied sparsely, and often without accounting for the complex nature of the issue at stake. Therefore, it seems necessary to commit research efforts to carrying out a comparative evaluation of methods and hypotheses used in empirical analyses, also including behavioural variables towards risk. This latter calls for developing new tools to investigate farmers' preferences, with particular attention to the characteristics of the tools and their interaction with other strategies. Similarly, because farmers' behaviour is affected by several policies, including those aimed at reducing the use of potentially harmful inputs, it seems important to analyse RM choices under a more articulated policy scenario. Fostering the analyses in these directions is expected to better understand how farmers select among available RM instruments including the most innovative ones on which they have not a large experience. The results of these analyses could provide insights that could be used to increase the uptake of already existing RM tools, facilitate the design and introduction of the new ones and, indirectly, allow the EU farm sector to become more resilient.

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Modelling technical efficiency of horticulture farming in Kosovo: An application of data envelopment analysis

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Abstract. With a view to integration into the European Union, the efficiency and competitiveness of the Kosovo' different sectors (including agriculture) must be improved. This paper assesses the technical efficiency (TE) of horticultural farms through Data Envelopment Analysis (DEA) applying output orientation. It was founded that the TE of these farms is positively affected by their size, with large-size farms presenting overall higher technical efficiency. The research findings indicate that the degree of agricultural education does not have a significant impact on TE, whereas public assistance through subsidies and grants has a substantial and negative impact on TE, as confirmed by statistical analysis.

Keywords: technichal efficiency, horticultural farming, data envelopment analysis.
JEL codes: Q10, Q18, C14.

HIGHLIGHTS

- With a view to integration into the European Union, the efficiency and competitiveness of the Kosovo' different sectors (including agriculture) must be improved
- We use a model of Technical Efficiency of Horticulture Farming in Kosovo with application of DEA.
- FADN data used on this study are from the years 2015 to 2019, in total 5 years in a row making the total observation 779.
- The study's findings reveals that the majority of farms in the sample show a technical efficiency level below 50%.
- It was found that the TE of these farms is positively affected by their size, with large-size farms presenting overall higher technical efficiency.

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1. INTRODUCTION

A future integration for Kosovo to the European Union (EU) raises significant opportunities but also challenges for the country's economy. One challenge is to improve the competitiveness of several sectors, including agriculture.

According to latest agriculture census, Kosovo has 1.1 million hectares of land, out of which 53% is agricultural land (from which 54.3% belongs to permanent grasslands, 43.6% arable land, 1.9% permanent crops and 0.3% kitchen garden), 41% is forest, and 6% belongs to other land uses (KAS, Agriculture Census, 2015). Kosovo has traditionally supported with direct payment (subsidies) and through investment grants three main agricultural sectors: cereals, horticulture, and livestock, which are divided into 21 subsectors: 11 annual and perennial crops (cereals and horticulture), wine, and organic products, and 10 livestock sectors and milk (Kostov et al. 2020).

In Kosovo, the agriculture sector employs the highest number of people, accounting for 34% of the total employment. This sector also makes a significant contribution to the country's Gross Domestic Product, which was around 8% in 2019. Additionally, agricultural products constitute 17% of the total export value (MAFRD, 2020). Although, 60% of the population lives in rural areas in Kosovo, they do not contribute much to economic growth. According to the Kosovo Ministry of Agriculture, Forestry and Rural Development (MAFRD), "*only a limited number of farms are currently able to compete and grab a greater share of the EU and foreign market*". The low competitiveness of farms can be attributed to several key structural factors, including the small size of most farms, land fragmentation, outdated building and equipment design, and limited access to financial resources (MAFRD, 2014). Furthemore, Kosovo continues to have a relatively high volume of imported agricultural products, which make up approximately 10% of all imports. In Europe, Kosovo ranks among the highest importers of food per capita (ERP, 2018).

In this context and to attain the European standards, improving the competitiveness of the agricultural sector becomes paramount. One way to help agriculture go towards competitiveness in domestic and foreign markets is to improve the technical efficiency (TE) of each agricultural sub-sector. Technical Efficiency refers to the ability to achieve the highest possible output level from a given set of inputs or resources. It measures how effectively inputs are utilized to produce desired outputs within a production process or system. It is a fundamental concept in economics and plays a crucial role in various fields, including agriculture, manufacturing, healthcare, and public services. According to Koopmans (1951, as cited in Farrell, 1957, p. 255; Charnes & Cooper, 1985, p. 72) provided a definition of what we refer to as technical efficiency, stating that an input-output vector is technically efficient if increasing any output or decreasing any input can only be achieved by decreasing some other output or increasing some other input.

In the context of agriculture, Technical Efficiency is particularly significant as it directly impacts food production, resource utilization, and sustainability. By measuring and improving Technical Efficiency, policymakers, farmers, and stakeholders can make informed decisions, allocate resources effectively, and drive agricultural development.

In this study we focus on the horticultural farms from FADN data, which includes TE for vegetables cultivated indoor in greenhouses and vegetables cultivated outdoor. In comparing the 2019 total share of agricultural crops's production to 2018, 2019's vegetables lead with the highest percentage 33.4%, followed by fodder crops, cereals, fruits and others (MAFRD 2020). According to the green report from MAFRD (2020) the total area cultivated with vegetable during 2019 was 18,911 ha. The crops that dominate the largest area in 2019 were potato (20%), pepper (16%), beans (15%), pumpkin (13%), onion (7%) and watermelon (6%). From the total area with vegetables, the different forms of horticulture in Kosovo, with the largest part are produced in open field. In percentage, the main area used for horticulture is in the open field with 83.5% followed by garden with 11.3% and vegetables cultivated in greenhouses with 5.2% (MAFRD, 2020).

Following the introduction, section two presents a comprehensive review of the existing literature. Section three provides a detailed explanation of the research methods employed, while section four elaborates on the data utilized for estimating efficiency. Moving forward, the fifth section presents the results of the technical efficiency analysis and identifies the factors that influence it. Finally, in the sixth section, the paper concludes with a summary of the analysis and discusses the policy implications derived from the findings.

2. LITERATURE REVIEW

Despite the fact that there is limited literature that demonstrates the significance of measuring technical efficiency in Kosovo's horticultural sector, there are numerous global studies that explore efficiency in this area, Iráizoz et al. (2003) measured the TE of horticultural production in a sample of Spanish farms. They discovered a significant resemblance between the two technical efficiency estimates. Other authors, Bozoglu and Ceyhan (2007) assessed the technical efficiency of 75 vegetable farms involved in vegetable production and investigated the factors that contribute to technical inefficiency in the Samsun region of Turkey. This study's findings indicate that the technical efficiency of the sample vegetable farms ranged from 56% to 95% (82% in average) and was affected by schooling, experience, credit use, participation by women, and that information score negatively affected technical inefficiency. On the other hand, factors such as age, family size, off-farm income, and farm size were positively related to inefficiency. Another study conducted by Clemente et al. (2015) focused on assessing the technical efficiency of citrus-producing properties in Sao Paulo State during the years 2009 and 2010. Their investigation involved conducting interviews with producers and employing both non-parametric data envelopment analysis (DEA) and econometric methods to determine the levels of technical efficiency and identify factors that influenced efficiency. The study's findings demonstrated that a significant proportion of citrus-producing properties in Sao Paulo operated below optimal efficiency levels. Notably, the factors of "producer schooling" and "experience as a rural producer" emerged as the primary drivers of increased efficiency. The mean technical efficiency score obtained from the study was 0.79, indicating the potential for production growth while maintaining the current input proportions based on the product-oriented model. In a similar vein, a study conducted by Irz and Stevenson (2012) investigated the potential inverse relationship (IR) between farm size and technical efficiency in Philippine brackishwater pond aquaculture. This paper employs a stochastic ray production function to examine the potential inverse relationship in Philippine brackishwater aquaculture, utilizing a cross-sectional sample of 127 farms. The distribution of efficiency scores spans the entire range, with an exceptionally low average value of 0.37. Farm size explains only 13% of the variability in outputs that are not accounted for by physical inputs, while 73% is attributed to unidentified factors and 14% to random shocks. Although the findings of this study are significant for policy formulation, they present a rather negative outcome, as they indicate that variations in efficiency are influenced by unexplained factors. Consequently, further investigation and speculation are necessary to uncover the underlying reasons for the subpar average technical performance of farms.

Previous studies about the technical efficiency in Kosovo mainly focused on livestock and the dairy sector. For example, Sauer et al. (2015) analysed the effect of migration on farm TE and found migration a decreasing effect. More recently, Alishani (2019) investigated the effects of public support policies on technical efficiency in Kosovo, with 394 farms from FADN year 2014.

To the best of our knowledge, few research deals with technical efficiency of horticultural farms in Kosovo. Frangu et al., (2018) assessed the input efficiency of 136 greenhouse farms growing tomatoes and peppers at both the farm and regional levels. The research utilized a combination of linear regression and DEA methods to identify any external factors that impacted efficiency. The study concluded that technical efficiency scores varied between regions, and based on the structural and operational characteristics of the greenhouse farms growing tomatoes and peppers, it was found that there was a possibility for farms and regions with low technical efficiency to enhance their input usage.

While larger farm size is essential for achieving sustained higher productivity in the long term, technical efficiency presents the most promising solution for enhancing productivity in the short to medium term and promoting the growth of Kosovo's agricultural sector. Vegetable production offers the best opportunity for producing viable incomes on small farms while adding significant value to the national economy. According to statistical data from MAFRD, total area for cereals is decreasing, while for vegetables, the area of cultivation is increasing. Kosovo has the quality of land to achieve this but experience shows that when the products are grown by large numbers of small farmers acting independently, without irrigation, greenhouses, cool storage, grading and packaging facilities, and sufficient processing capacity there will be a considerable amount of dumping on oversupplied markets at peak supply.

This study not only measures efficiency, but it also examines the factors that influence efficiency, and uses this analysis to provide additional recommendations for policy. In order to achieve this objective, we employ a two-step method suggested by Simar and Wilson (2007). In the first step, we estimate the relative efficiencies using inputs and outputs and then analyse the effects of the exogenous variables on efficiency. As several authors (Iráizoz et al. 2003; Sauer et al. 2015; Wilson, 2001; Karimov, 2014; Latruffe, 2004; Theodoris et al., 2014; Gaviglio 2021; Morrais, 2021; Alishani 2019), the exogenous variables are age, agricultural training of the manager/holder, gender, irrigation system, altitude, area constrains, total subsidies on crops, rented area (Iráizoz et al. 2003; Sauer et al. 2015; Wilson, 2001; Karimov, 2014; Latruffe, 2004; Theodoris et al., 2014; Gaviglio 2021; Morrais, 2021; Alishani 2019).

Finally, the paper contributes to fill the research gap on efficiency in the horticulture sector in Kosovo. We focus on the farms from FADN data, which includes TE for vegetables cultivated indoor in greenhouses, and vegetables cultivated outdoor.

3. METHODOLOGY

Methodologically, we employ Data Envelopment Analysis (DEA) to assess the performance of a group of units. Based on the pioneering work of Farrell (1957), Charnes et al. (1978) developed the DEA model under the constant return to scale (CRS) assumption, and Banker et al. (1984) extended it under the variable returns to scale (VRS) assumption. DEA involves creating a production frontier that illustrates the highest attainable output from inputs, and subsequently measuring the distance between each unit and the efficient frontier (Blancard and Hoarau, 2013). The best performers' group provides practical observations for constructing this frontier. The most efficient units are those closest to the frontier, and so the furthest from the frontier, the highest is the units' inefficiency.

Two approaches can be used to estimate technical efficiency (TE): parametric, which includes both stochastic and deterministic methods, and non-parametric, such as DEA. In agriculture and farming, each approach has its own advantages and disadvantages when it comes to measuring farm performance. Studies comparing parametric and non-parametric methods have revealed disagreements regarding these approaches, particularly in agriculture. Coelli (1995) reviewed literature on frontier function estimation and efficiency measurement and suggested potential applications of these methods in agricultural economics. Further to this debate Sharma (1999) compared two approaches in measuring efficiency of the swine industry in Hawaii and the study revealed the DEA method is a more robust approach for measuring efficiencies compared to the parametric approach, based on the obtained results. DEA is particularly suitable for agriculture because it allows for the assessment of relative efficiencies among multiple decision-making units (DMUs) without requiring explicit functional form assumptions or knowledge about the underlying stochastic production function. It considers the best-practice frontier defined by the most efficient units, providing a benchmark for comparing and evaluating the efficiencies of other units. This is beneficial in the agriculture sector, which encompasses a wide range of production systems and practices, where the assumptions of a specific functional form may not hold universally (Fare et al. 1994).

In our study, we utilized an output-oriented model to estimate TE, which was based on both on (variable returns to scale) and (constant returns to scale).

The term "Decision-Making Unit" (DMU) is used to refer to any entity that is evaluated based on its ability to transform inputs into outputs. In our study, we use this term to refer horticultural farms. Our primary goal is to evaluate efficiency based on the assumption that a DMU can produce a greater amount of output by using the same level of inputs. To achieve this, we use an output-oriented model. We chose output orientation based on the challenges that the horticulture sector in Kosovo faces, as described in the first part of the paper. Moreover, as following numerous studies, we decomposed technical efficiency (TE) into pure technical and scale efficiencies from CCR (Charnes et al., 1978) and BCC (Banker et al.,1984) models to identify the sources of inefficiencies.

Let us consider n farms producing s output from m inputs. For the evaluated farm o, the output-oriented DEA linear programming is written as follow:

$$\max \phi$$

Subject to

$$\begin{aligned} &\textstyle\sum_{j=1}^{n} \lambda_j x_{ij} \le x_{io} && i=1,2\ldots,m \\ &\textstyle\sum_{j=1}^{n} \lambda_j y_{rj} \ge \phi y_{ro} && r=1,2\ldots,s \\ &\textstyle\sum_{j=1}^{n} \lambda_j = 1 (\text{DEA–BCC}) && \\ &\lambda_j \ge 0 \ \ (\text{DEA-CCR}) && j=1,2,\ldots n \end{aligned} \tag{1}$$

where n, m and s are number of DMUs, inputs and outputs, respectively. DMU_j consumes x_{ij} of input i and produces y_{rj} of output r; λ_j are the weights assigned by the linear program, ϕ is the calculated efficiency.

The summary of the results obtained from the envelopment model interpretation is as follows: if $\phi^* = 1$, then the DMU under evaluation is a frontier point. i.e., there are no other DMUs that are operating more efficiently than this DMU. The DMU under evaluation is inefficient. i.e., this DMU can either increase its output levels or decrease its input levels (Zhu, 2014).

The results of DEA TE_{VRS} model represent pure technical efficiency (PTE). Alternatively, DEA TE_{CRS} model represents the overall technical efficiency (OTE), which consists of two components: scale efficiency and pure technical efficiency. While comparing scores from both DEA TE_{CRS} and DEA TE_{VRS} model, if a DMU has a different efficiency score that means that the particular DMU has scale inefficiency. Scale efficiency can be obtained by:

$$SE = \frac{TE^{CRS}}{TE^{VRS}} = OTE/PTE \tag{2}$$

After obtaining the results from the two models, we employed bootstrapping in the nonparametric model to address potential scepticism regarding the use of DEA in agriculture. Non-parametric efficiency measures are often criticized for lacking a statistical basis. However, Simar and Wilson (1998) argued that nonparametric efficiency measures do indeed have a statistical basis, and used bootstrapping to analyze the sensitivity of non-parametric efficiency scores to sampling variation. To generate the bootstrap estimates, we utilized the algorithm proposed by Simar and Wilson (1998) in R studio, which is a statistical computing software. We used B = 2,000 bootstrap replications, and set the bandwidth at h=0.014 based on empirical evidence from Simar and Wilson (1998) that suggests small values of h provide smooth density estimates that follow the empirical density function, while large values of h yield over-smooth density estimates.

4. DATA

4.1. Data source

The study uses data from farms covering the entire Kosovo. Kosovo has 7 administrative regions, but a nomenclature of territorial units for statistics has not yet been introduced. It is divided into two territorial levels: municipal and settlement level; it currently has 38 municipalities and 1,469 settlements (MAFRD 2014). In hydrographic terms, Kosovo is divided into river basins: The Drini i Bardhë, Ibri, Morava Binqës and Lepeneci (KAS, 2019). This sector of vegetable production in Kosovo is one of the main branches of agricultural production whilst in some regions of the Dukagjini Plain, it represents the main economic activity (MAFRD 2014). The predominant approach to horticultural cultivation involves cultivating crops in open fields for the purpose of commercial production. Among the various types of crops, vegetable production is typically the most labor-intensive.

Data employed in this study are extracted from the farm accountancy data network (FADN). The development of a sustainable FADN system in Kosovo has been a focus of effort over recent years. Funded by the European Agency for Reconstruction-EU, a FADN pilot project was launched in 2004 involving 50 farms. This network expanded to 159 farms in 2005, increasing the number of farms to 300 in 2008 and 402 in 2013 and 2014. In order to make an adequate selection of the sample, the FADN team applied the stratified simple random sampling. Sampling is carried out by following three fundamental criteria, which include economic size, farm type, and region. These criteria conform to the standardized FADN methodology in line with the European Commission's guidelines.[1], even though it was simplified to suit the specific situation of the country. The decision was made to include around 1,250 farms, which is roughly 2% of all agricultural holdings, in the FADN survey in order to ensure that the sample is as representative as possible (MAFRD, 2020). To account for the possibility of some farms declining to participate in the survey, each entity involved included approximately two additional reserve farms.

In order to assess the technical efficiency (TE) of the horticultural sector of Kosovo, FADN data used are from the years 2015 to 2019, in total 5 years in a row making the total observation 779 (table 2 in appendix). The number of farms is different from year to year, the reason is that some farmers refused to participate in the upcoming years, so there was a number of reserved farms of the same typology which was used in case of refusal, besides this some farms change the category during the five years' period.

4.2. Inputs and output selection

To measure the technical efficiency, we retained four inputs and one output. The chosen inputs are widely employed in the literature for measuring technical efficiency.

The term "total labor" refers to the amount of work completed in a year, equivalent to a full-time job. This is measured in annual work units (AWUs), which represent the amount of work performed by a person who is employed full-time on a farm. In Kosovo, the minimum annual working hours are considered to be 1,800, which is equivalent to 225 workdays of eight hours each. The second input is land or the utilized agricultural area expressed in hectares. It consists of the land in owner-occupation, rented land and land in share-cropping.

The third input is total intermediate consumption, which includes total specific costs (including inputs produced on the farm) and overheads arising from production in the accounting year. The total specific costs included specific crop costs (fertilizers and soil improvers, purchased manure, crop protection products) and other specifics costs (labour and machinery costs and inputs, contract work, and machinery hire, current upkeep of machinery and equipment, motor fuels and lubricants, car expenses). Farming overheads include land improvements and buildings, electricity, heating

[1] Council Regulation (EC) No 1217/2009 of 30 November 2009 setting up a network for the collection of accountancy data on the incomes and business operation of agricultural holdings in the European Community

fuels, water, farm insurance, other farming overheads expressed in the euro.

Finally, we consider one more input which is the average farm capital includes cash & equivalents, receivables, other current assets, inventories, plants, land improvements, farm buildings, machinery and equipment, and intangible assets.

Output is the total value of the crop products, and of other output expressed in Euros, including that of other gainful activities (OGA) of the farms.

The table 2 (appendix) presents the descriptive statistics of variables for farms together indoor and outdoor in the open fields[2]. On average, they produced output in value of 29,319 € for the year 2015 with 139 farms in the sample for this year. In 2016 with 150 farms the total output value was 28,404 € while in 2017, 162 farms produced on average 29,678 €. In 2018, 143 farms produced total output on average of 26,516 € while in the year 2019, 185 farms produced total output in value of 25,550 €.

5. RESULTS AND DISCUSSIONS

5.1. Efficiency results

In our study VRS, CRS and SE were evaluated for horticultural farms. The number of farms is different from year to year, the reason is that some farmers refused to participate in the upcoming years, so there was a number from the list of a reserved farm of the same typology which was used in case of refusal, and besides this some farms change the category during the five years' period.

The summary of results is presented in the table 1. The year 2017 showed the highest efficiency score with a pure technical efficiency level of 0.72 for farms horticulture indoor, which means that 28% can increase the output to reach the efficiency frontier. The majority of farms in the sample show a technical efficiency level of above 50%, besides the year 2018, which is with the level of efficiency of 45%. On the contrary, farms operated in the open field have a lower efficiency score, with the largest efficiency level of 0.56 in the year 2017, while similar to horticulture indoor, also at the open field, the year 2018 has the lower efficiency score below the 50%. For the farms, horticulture indoor the highest average score on scale efficiency (0.92) was in the year 2017 while the lowest score (0.77) was in 2019. While for the farms in the open field the highest average score on scale efficiency (0.91) in the year 2017 and the lowest in the year 2015 and the lowest score of SE (0.74). From the average aggregate results for farms (Indoor and open fields together), most of the farms in the sample show a technical efficiency level that is less than 50%. The highest efficiency score with a pure technical efficiency level of 0.50, which means that 50% can increase the output to reach the efficiency frontier. The lowest pure technical efficiency score (0.36) is in the year 2018. The highest average score on scale efficiency (0.94) was in the years 2017 and 2018 while the lowest score (0.87) was in 2015.

Table 1. Descriptive results of efficiency estimate for horticultural open field farm.

2015	Mean	SD	Min	max	no of farms
PTE	0.52	0.28	0.11	1.00	
OTE	0.36	0.24	0.10	1.00	121
SE	0.74	0.21	0.10	1.00	
2016					
PTE	0.49	0.27	0.13	1.00	
OTE	0.36	0.23	0.12	1.00	130
SE	0.77	0.21	0.28	1.00	
2017					
PTE	0.56	0.26	0.13	1.00	
OTE	0.51	0.24	0.12	1.00	144
SE	0.91	0.14	0.31	1.00	
2018					
PTE	0.46	0.28	0.13	1.00	
OTE	0.39	0.24	0.10	1.00	124
SE	0.87	0.19	0.21	1.00	
2019					
PTE	0.48	0.28	0.14	1.00	
OTE	0.42	0.24	0.12	1.00	164
SE	0.89	0.16	0.17	1.00	

Source: Author's composition.

From the FADN methodology, farms are defined as being commercial only when they pass the Standard Output of 2,000 Euros. This implies that a commercial farm is able to provide the farmer with a sufficient level of income to support the welfare of his family. Thus, based on this classification the table 5 in appendices present the technical efficiency score categorized by economic sizes of farms. The large-size farms had overall higher technical efficiency under the category 6 (100,000 - < 500,000).

5.2. Biased corrected efficiency scores

Figure 1 to 10 present a graphical illustration of the distribution of farms (in appendices), using box plots to

[2] Descriptive statistics for each of inputs and output variables for the three categories horticultural farms indoor, outdoor in open field are presented in table 3 and 4 in appendices.

facilitate the comparison among farms efficiency score in addition to the bias corrected. For each group of farms, the box represents the 50% mid-range values of efficiency scores and biases corrected. The interquartile range (IQR) is depicted by the length of each box, and the natural limits of the distributions are defined by the whiskers (which correspond to the mean ±1.5 (IQR)). Any outliers that fall beyond the natural limits are represented by round circles. Each group of farms are determined based on the bias corrected scores, the allocation of farms is different than the groups obtained based on the efficiency scores. Due to this different scope of the groups, we get these differences that appeared in the charts with red colors. Groups of farms are determined based on bias-corrected scores, for example group of farms with bias corrected scores from [0-0.10[belong to group 1, while [0.10-0.20[belong to group 2 and the rest until group 10. From the graph its clear the homogeneity of farms in respect to efficiency scores within each group and those to be noted are in group 7 the differences within group in each year under VRS and CRS. In addition, there are substantial differences between the two measures.

On average, under this determination, in the year 2019 the efficiency score is 0,46, while under the bootstrap PTE model, it is only 0.39. Further for the same year, the OTE average score of TE is 0.39, while under the bootstrap OTE the score is 0.34. For instance, none of farms found entirely efficient under the PTE model and OTE model in each year (2015-2019) do not remain so after accounting bias-corrected scores through the bootstrap procedure. In this case, farmers should consider increasing the output while maintaining the same inputs. The results show there is a lot of space for using efficiently the inputs, area, labour, total intermediate consumption and average farm capital.

5.3. Determinants used to explain efficiency

This section explains the second stage of technical efficiency study. The objective of this stage is to identify shared common characteristics among the most efficient farms. Two step procedures are used in the same scenario as Irazoz et al. (2003), so OLS and analyses of variance are used to determine the link between efficiency and exogenous variables. Although the one-stochastic frontier method has a clear technical advantage over the two-step procedures, the two-step procedures may be more logically appealing for policy analysis and decision making because they directly relate the exogenous variables to the observed efficiency performance of the firms. Furthermore, identifying the sources of inefficiency may aid in the development of policy recommendations (Yu 1998; Theodoris 2014). In this case we want to show the effects of exogenous variables in technical efficiency of horticultural production for further policy analysis in national level.

Running DEA and creating a regression model with the DEA efficiency scores as the dependent variable and other possible factors as explanatory factors. This is a well-known two-stage technique that has been widely criticized for producing skewed results. However, it is frequently utilized, at the very least, to figure out which determinants are relevant. Contrary to a number of authors using Tobit, in second stage data envelopment analysis (DEA), McDonald (2003), is not a fan of using this model. In the two articles written by McDonald (2009, 2010), he describes OLS as a better replacement and a sufficient second stage DEA model. As he mentioned for many applied researchers, familiar and easy to compute, OLS may be the best option. Throughout the paper when referring to DEA, he dealt with the single output, output-oriented case. After comparing, in a stage 2 analysis, OLS, 2LT and 1LT marginal effects were similar.

Output oriented frontiers are constructed under both the assumptions of variable returns to scale (VRS) and constant Return to Scale (CRS). The effect of the determinants is investigated with Ordinary Least Squares (OLS) regressions on each of the three TE scores for the period of 2015 to 2019 with total of 779 observations specialized in horticultural farming. This methodology is used by Latruffe (2017) to measure effect of subsidies on technical efficiency, contrary to us he used only variable return to scale (VRS) as our purpose is not only to measure the effect of subsidies on technical efficiency, in addition to that also we tend to measure other determinants which effect on technical efficiency on horticultural farming.

Regarding the determinants that affect the efficiency scores, the most common variable used are farm size, the age of holder, qualifications, experience and specialization of the farmer and combination of inputs (Iráizoz et al., 2003). In this study they found limitations to get this information in their sample data, while in our case, we could have accesses to raw data from FADN and get this information. We classified farm level data based on specialization of farms in horticultural (open field and indoor), match them with farm code and efficiency results of each farm. These similar determinants mentioned above were used also from Sauer et al., (2015) who investigated the effect of migration on farm technical efficiency in Kosovo. Another important study is to analyse the managerial drivers and practices due to business planning in farm and relation to the technical efficiency. Results from the research by Wilson on influence of management characteristic on technical efficiency of wheat farmers in eastern England shows that, those farmers who seek information, have more years of managerial experience, and have a large farm are also associated with higher levels of technical efficiency (Wilson, 2001).

Age and education are commonly cited as factors that may impact technical efficiency (Karimov, 2014). He stressed the important role formal education (university degree and educational background in agriculture) and informal education such as participating in workshops and seminars of farmers are associated with efficiency-improving results (Karimov, 2014). Other authors stressed that farmers that are more educated are considered more likely to be efficient farms associated with higher scores of TE (Latruffe, 2004). And there is a strong significance between agricultural trainings and efficiency (Theodoris et al., 2014). Farmers who are younger may have a greater tendency to adopt innovative technologies aimed at reducing input usage. In contrast, older farmers may have greater efficiency due to their extensive experience in addressing efficiency-related issues (Hadley, 2006). Exceptionally to these authors, Gaviglio (2021) found in his research that in fact, the level of education does not significantly improve the level of efficiency (Gaviglio, 2021).

In terms of the socio managerial aspect, we involved the variables age of owner/manager of farm, level of education in agriculture with only practical agricultural experience, basic agricultural training, full agricultural training, with the aim of seeing if the level and type of experience in agriculture affects the inefficiency. Other variables were: specialization of farm that produce vegetables indoor and in open field, form of irrigation, irrigation system used on the farm, not applicable (when no irrigation on the farm), surface, sprinkler or drip. In similar research on effects of irrigation in technical efficiency Morrais, (2021) results indicated that farms with irrigation had higher average technical efficiency compared to non-irrigators, which implies that irrigation technology has a significant effect on the efficiency gain for those groups. We also included variables on altitude of farms and the location, areas facing natural and other specific constraints. Also, we divided regions in two main plains of Kosovo, Dukagjini Plain and Kosovo Plain, to see which farms are more efficient based on their location, although the plain of Dukagjini is well known for cultivating vegetables due to weather conditions, farm experience and tradition etc. However, the other part (mainly, the east part of the Kosovo plains) in recent years has benefited from increased investment in this sector based on data from Agency for Agricultural Development of Kosovo.

Following other determinants, we included size to measure this we used the total output expressed in physical units (kg) of vegetables produced by farms. Alike Iraizoz et al. (2003), they explain that they expected to obtain a positive coefficient for size, because horticultural production could present scale economies, in our case we follow this conclusion. We included the same determinants involving the combination of inputs.

Additionally, we considered the total output coming from other gainful activities (OGA) directly related to the farm such as processing of farm products. We measured this by the share of total OGA in total Output (%). We want to see if there is higher technical efficiency on farms that diversify their activities, and if large farms operate more efficient with higher share of OGA.

Furthermore, we included as other determinants the share of subsidies to total output. Various studies have investigated the effect of subsidies on farms' technical efficiency, and in general the effect reported is negative. According to Minviel and Latruffe (2017) direct payments are common negatively associated with farm technical efficiency. In another study of the impact of support policies on technical efficiency of farms in Kosovo, subsidies had negative effect on technical efficiency (Alishani, 2019). Drawing from these related studies, Latruffe (2017) conducted a study on the impact of subsidies on technical efficiency with respect to environmental outputs. The study highlights that the policy implications are important, as a farm utilizing subsidies to increase environmental good outputs or reduce environmental bad outputs may have a lower traditional technical efficiency as compared to a farm receiving the same level of subsidies but using them solely for producing marketed outputs. Therefore, the effect of subsidies on traditional technical efficiency could be negative for the former farm and positive for the latter farm. However, this case doesn't necessarily fully apply to for Kosovo's scenario because cross-compliance subsidies are still not introduced in national level support, but it still remains a recommendation from EU commission to Kosovo for initiating this form of subsidies.

Moreover, other determinates we used are the share of paid labour to total AWU (annual working unit), and the share of rented land to total UAA (Utilized agriculture area). For these two variables results, a study by Alishani (2019) found out the paid labour to total AWU affects negatively the technical efficiency score, while the determinant of rented land to total UAA was insignificant.

Finally, we incorporated the factor of machinery and equipment into the analysis, which encompasses various items such as tractors, motor cultivators, lorries, vans, cars, and other farming equipment that are valued in euros. In the study by Sauer et al., (2015) results show that physical capital (machinery and farm equipment) decreases technical inefficiency, but this stands mainly because of outdated machinery and equipment.

Our model with all determinates of inefficiency is presented on the table 8 (appendices). The adjustment shows corrected R squared coefficients of 0.38 for VRS, 0.44 for CRS and 0.26 for SE. Similar results are found by different author, Iraizoz et al. (2003) obtained coefficients of 0.31 and 0.68, and in addition, they found similarities to different authors as cited in (Parikh ,1995) who obtain a coefficient of 0.214, (Sharma, 1999,) with a coefficient of 0.23, and (Wadud and White, 2000) with a coefficient of 0.66.

Concerning the socio managerial aspect in our results, the determinant age of the holder does not have significance with TE scores. Under the VRS and CRS, full agricultural training significantly does not affect the TE scores, while under the scale efficiency, there is a strong positive significance of full agricultural training to TE scores. These results have relation to different reports that shows either formal or informal education in the field of agriculture remains insufficient compare to EU and neighbouring countries. According to the report from (National Research Programme of the Republic of Kosovo from 2010), research and technological development (RTD) in agriculture is still a marginal undertaking in Kosovo, despite the fact that agriculture is an important economic sector. Compared to other countries in EU and the region, Kosovo has the lowest budget allocated for research per GDP, amounting to 0.1%. Only 0.19% of budget was allocated (0.05% of GDP), while in 2016, around 0.33% of budget (0.1% of GDP) (Kaçaniku, 2018).

Considering the differences of horticultural farms if they operate more efficiently in open field or indoors in greenhouses, results show not any significance. In terms of irrigation system used on the farm, drip system shows significance on 10% under VRS and CRS. This system of irrigation is the most recommended to use in crops, as drip irrigation reduces deep percolation, evaporation and controls soil water status more precisely within the crop root zone (Singandhupe, 2003). Furthermore, Lattrufe and Desjeux (2014) indicate that farm size in Kosovo increases integration into the output market and that irrigated crop output is more marketable than livestock output.

With respect to demographic contents in term of altitude, there is no particular significance. There is strong significance in scale efficiency to altitude below 300m and above 600m. For specific vegetables there are different requirements to produce yields, for example potato according to Haverkort (1990) it is shown that is adapted to a wide range of environments and hints are given on further exploitation of its potential in the various ecosystems. For the regional determinant, there is a negative significance under the scale efficiency in Dukagjini Plain, although it is well known for cultivating vegetables, this confirms our supposition that investment is being increased in the recent years in the east part of the Kosovo plain and the area covered by vegetables.

As regard to farm size measured as total production in kg, the study shows a positive relationship with technical efficiency under VRS, CRS and SE, with a strongly significance of 1%, in this case, the most efficient farms produce more in physical units. These results were also found by Iraizoz et al. (2003) in horticulture production in Spain.

With respect to cultivation costs per hectare of land as a determinant relating to a combination of inputs, results show statistically no significant correlation with technical efficiency, contrary to Iraizoz et al. (2003) who found negative correlation indicating that higher cultivation costs do not guarantee better results, in terms of efficiency.

Following other determinants, the partial productivity indices (output per unit of land and output per unit of labour), and the outcome are as expected, because the farms with higher productivity is an indicator for obtaining higher levels of technical efficiency. There is strong statistically significant under VRS, CRS and SE.

With respect to subsidies, as we expected there, is a negative and statistically strong significant correlation between this determinant and technical efficiency under VRS and CRS. Public expenditure on Kosovo's agriculture and rural development is based on two pillars; Grant aid to encourage investments in the means of production (the Rural Development Measures) and payments for quantities of horticulture and livestock produced (Direct Payments).

In term of commercialization, direct payments have positive effects for horticultural and fruits farms (Kostov et al. 2020). Regarding size, the authors suggest that the impact on commercialization will be more significant if a larger number of semi-subsistence farms receive payments based on their size. In Kosovo, eligibility requirements for direct payments related to fruits and vegetables (open field) have lower size thresholds compared to most other payments, making them more attainable for semi-subsistence farmers (Kostov et al. 2020). In every year, expenditure on direct payments has exceeded the amount contracted for investment grants, and overall accounts for 56% of the total public expenditure in the agricultural sector. At the outset, it should be recognized direct income support has a vital role to play in the management of the transition from a production-oriented to a market-oriented food production sector. Last but not least, the lack of producer organization in the fruit and vegetable sector, lack of specialist advice and training, and lack of support for innovation, are not being addressed. Continuing the following determinants, utilized agricultural areas rented by the holder does not have any significance on TE scores, while paid labour to total annual working unit is statistically significant under VRS only at 10%, contrary to Alishani (2019), this determinant affected negatively the technical efficiency score.

With respect to other gainful activities in farms concerning the diversification of economic activities, and contrary to what we expected, the results shows this determinant presents negative and statistically significant correlation with TE scores, indicating that higher time spending on processing horticultural products does not guarantee a better TE score. While as we expected based on results, large farms operate more efficient under VRS and SE with higher share of OGA.

Lastly, machinery and equipment's decrease technical inefficiency on farms, there is a negative and statistically strong significant correlation with TE scores under CRS and SE. This finding are is similar as Sauer et al. (2015) on migration and farm technical efficiency evidence from Kosovo. This is consistent with our study's observations regarding the continued use of old technology and machinery by farmers in Kosovo.

With regards to five years of research data, from the results we can show that the year 2017 is strongly positive correlation with TE scores under CRS, VRS and SE, and it has the highest average TE score compare to other year. This mean that farms in horticulture operated more efficiently in the year 2017.

5.3. Implications (limitations of our study)

A limitation of using the FADN (Farm Accountancy Data Network) for measuring technical efficiency is the potential for selection bias. The FADN database collects data from a sample of farms that voluntarily participate in the program. This self-selection process can introduce bias if participating farms differ systematically from non-participating farms in terms of their characteristics or behavior. Therefore, the findings based on the FADN data may not be representative of the entire agricultural sector, potentially limiting the generalizability of the results. To address these limitations, we employed appropriate statistical techniques, consider conducted robustness checks. The future research idea is to compare nonparametric methods with parametric methods for measuring technical efficiency scores in the agriculture sector in Kosovo. This study will offer valuable scientific insights for researchers and provide assistance to policymakers in addressing the issue of inefficiency.

6. CONCLUSION AND POLICY IMPLICATION

The study's findings reveals that the majority of farms in the sample show a technical efficiency level below 50%. The insufficient level of sore of TE implies that the remaining potential output could not be realized due to technical inefficiency. This means that 50% can increase the output to reach the efficiency frontier. The highest efficiency scores are in the region of Prizren and Prishtina, the biggest regions in Kosovo. Concerning the exogenous factors affecting the efficiency scores with respect to subsidies, there is a negative and statistically strong significant correlation between this determinant and technical efficiency under VRS and CRS. Time spending on processing horticultural products does not guarantee a better TE score, although large farms operate more efficient under VRS and SE with higher share of OGA. The results suggest that farmers should consider increasing the output while maintaining the same inputs. The findings indicate that there is considerable room for improvement for using efficiently the inputs, area, labour, total intermediate consumption and average farm capital. In this respect, policy makers MAFRD[3] should consider these low results of technical efficiency of farms to focus on a better program for extension services in order to promote better use of inputs.

Vegetables are produced often in rather small areas and is very labour intensive; this fact fits the current situation with plenty of underemployed family labour and unemployed. However, it seems that sooner than later, the abundance in the workforce will be gone, mainly because young people do not see agriculture as a business but just as an unwanted heritage. The mechanization is again low due to the small parcel sizes, but also due to missing financial means. Tractors, ploughs, trailers are old and just bigger farmers can afford machines like good sprayers or e.g., carrot-harvesting machines. The situation is improving when dealing with bigger farmers with modern orchards of 5 ha and more. Small farms struggle to access the market and to be commercialized, in this case considering the results from our

[3] Ministry of Agriculture, Forestry and Rural Development.

study it was found that the TE of these farms is positively affected by their size with large-size farms presenting overall higher technical efficiency. For instance, small farms in horticultural sector should consider gathering in cooperatives.

Kosovo's agricultural policy is focused on semi-commercial and commercial farmers; the difference is that commercial farmers bring all their products to the market whereas the semi-commercial ones keep a substantial part of their harvest for on-farm consumption. There seems to be a shortage in modern storage facilities for all kinds of vegetables; storage, cold storage (4°C) and cooling rooms (-15°C), and warehouses under a controlled atmosphere. Nonetheless, there is sufficient support in various forms such as investment grants for the processing industry, as well as subsidies for primary production. Furthermore, there is a larger group of donors like the European Commission (as funds cannot be used for IPARD because the ADA is not accredited yet), USAID, GIZ, SDC, and others. However, the performance of the vegetable processing sector is not yielding satisfactory results, eventually as there was too much support and in an uncoordinated form. Investments should be focused on the direction of strengthening the primary production by indirect support through processing companies, and improvement of hygiene conditions and certifications with food safety standards in order to have easy access to the EU market.

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Incorporating expert knowledge in the estimate of farmers' opportunity cost of supplying environmental services in rural Cameroon

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Abstract. This paper applies a Bayesian approach to incorporate non-data information in estimating the opportunity cost for farmers in rural Cameroon to engage in biodiversity conservation and carbon sequestration efforts. Findings from our field survey reveal that only a small percentage of farmers are willing to participate in environmental protection programmes without compensation. A multidimensional preferences analysis indicates that this behavior may be attributed to a disconnection between environmental values and socioeconomic values. Bayesian analysis of the Tobit model, examining Willingness to Accept (WTA) compensation for agroforestry participation, highlights that factors such as aging, higher educational attainment, and higher socioeconomic status are highly likely to promote pro-environmental behaviors. The estimated opportunity cost of supplying environmental services is 10,775 CFA francs with a standard deviation of 333.6 CFA francs per farmer. These results differ qualitatively from the existing literature, underscoring the relative significance of considering expert knowledge in the interpretation of environmental policies.

Keywords: Bayesian analysis, environmental services, stated preferences, opportunity cost, rural Cameroon.
JEL codes: Q57, C34, C11.

1. INTRODUCTION

Nature plays a crucial role in supporting human development; however, the increasing demand for the Earth's resources is leading to accelerated extinction rates and a decline in global biodiversity and ecosystem services. According to the International Panel on Biodiversity and Ecosystem Services (IPBES, 2019), the average abundance of native species in major land-based habitats has decreased by at least 20%, primarily since 1900. Additionally, more than 40% of amphibian species, nearly 33% of reef-forming corals, and over one-third of marine mammal species are currently facing threats. Recognizing this global challenge, governments worldwide are taking action to incorporate biodiversity and ecosystem services into their development plans, policies, and strategies (IPBES, 2019). These initiatives include targets

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such as regenerating vegetative cover in the agricultural sector, enhancing agricultural productivity, and reducing the amount of land used for agriculture through the implementation of intensive agricultural systems.

Farmers, being at the forefront of environmental conservation in agriculture, play a crucial role. The effectiveness and efficiency of government incentive mechanisms depend not only on the specific design of the schemes (Bareille et al., 2023) but also on the values farmers associate with ecosystem services and the opportunity costs associated with adopting sustainable agricultural practices (Karsenty et al., 2010; Bessie et al., 2014; Kernecker et al., 2021). By taking into account farmer preferences and expectations in the design of government incentive schemes, we can identify the factors that determine the social acceptability and economic efficiency of these schemes. Conducting research to assess farmer preferences and expectations, as well as estimating farmers' willingness to accept compensation (WTA) for providing environmental services, is essential in this context. Farmers' WTA to participate in environmental protection programmes reflects the opportunity cost of supplying environmental services. In other words, farmers express their preferences by assigning selling prices to environmental services, which can be used for their valuation (Brown and Gregory, 1999; Hanley and Czajkowski, 2019).

The economic literature on the adoption of payment for ecosystem services (PES) schemes using a Stated Preference (SP) approach is extensive (Carson, 2012; Villanueva et al., 2017; Johnston et al., 2017; Hanley and Czajkowski, 2019; Wang and Nuppenau, 2021; Raina et al., 2021; Viaggi et al., 2022). However, most SP studies rely on respondents' hypothetical choices as data to infer their preferences and, consequently, their WTA for changes in environmental services. As noted by Haghani et al. (2021), the hypothetical nature of SP choice settings introduces a hypothetical bias, leading people to systematically over or understate their WTA values in SP exercises. This bias arises because no actual payment is made or received in exchange for a change in the quantity or quality of environmental services. Current research on hypothetical bias in SP approaches focuses on understanding its causes and developing methods to mitigate it. One approach to mitigate

hypothetical bias is the use of "cheap talk" scripts, which aim to improve the realism of hypothetical scenarios and reduce the influence of social desirability biases. However, the effectiveness of cheap talk as a bias mitigation tool varies depending on the context and the specific script used, as highlighted by Bosworth and Taylor (2012) and Doyon et al. (2015).

Another approach to mitigating hypothetical bias is to use "non-hypothetical" or "real" choice experiments (Menapace and Raffaelli, 2020; Fang et al., 2021; Cerroni et al., 2023). These experiments involve asking participants to make actual choices rather than hypothetical ones, and they can be conducted in laboratory or field settings. Real-choice experiments have been found to reduce hypothetical bias in some contexts, although they can be more expensive and logistically challenging to implement compared to hypothetical choice experiments. In addition to these methodological approaches, researchers are exploring the use of behavioral interventions to reduce hypothetical bias. Vossler and Holladay (2016, 2018) suggests that framing survey questions in a way that emphasizes the importance of the decision or providing feedback on the accuracy of participants' responses may encourage more truthful and accurate responses. However, it is important to note that survey-based welfare measures for public environmental goods are often sensitive to elicitation methods, such as whether the elicitation is framed as an up-or-down vote or an open-ended willingness-to-pay question. Controlling for economic incentives, Vossler and Zawojska (2020) show that most survey response formats, including single binary choice, double-bounded binary choice, payment card, and open-ended formats, elicit statistically identical WTP distributions. This finding highlights that behavioral factors may not be the primary drivers of elicitation effects.

Overall, research on hypothetical bias in SP approaches is an active and evolving field, with ongoing efforts to understand its causes and develop effective mitigation strategies. Reducing hypothetical bias in choice experiments requires not only careful survey design but also the integration of non-survey data information and expert knowledge. Non-data information refers to prior knowledge or assumptions derived from sources other than observed or survey data, such as expert opinions, previous studies, or theoretical considerations (Knuiman and Speed, 1988; Gelman et al., 2013; Mahmoud et al., 2020; Awwad et al., 2021; Hegazy et al., 2021). Incorporating non-data information in SP studies is particularly valuable when survey data is limited, noisy, biased, or when complex problems demand additional information for accurate analysis. By accounting for non-data information, we can improve analysis accuracy, mitigate the impact of outliers or measurement errors, and enhance understanding of economic agent preferences and behaviors (Kadane and Lazar, 2004; Gelman et al., 2013; Kruschke, 2013). However, it should be noted that incorporating non-data information poses challenges compared to analyzing survey data alone. Despite its potential, there have been limited studies explicitly considering expert knowledge or non-data information to address hypothetical bias in choice experiments. This is partly explained by the difficulty to capture expert knowledge in current WTA modelling frameworks, which usually rely exclusively

on survey data to estimate the unknown parameters of agent preferences. This paper explores an approach that utilizes non-data information to constrain the range of unknown parameters of agent preferences and aims to reduce hypothetical bias in estimating WTA values.

To achieve our objective, we start by conducting a field survey in Barombi Mbo, a rural area in Cameroon, to gather data on the socio-economic and environmental conditions of farmers. The survey includes information on farmers' willingness to accept (WTA) compensation for participating in agroforestry and afforestation programmes. Additionally, we employ a Multidimensional Preferences Analysis (MPA), a technique used to develop spatial representations of proximities among psychological stimuli or other entities (Carroll and Chang, 1970; Wish and Carroll, 1982; Davison, 1983), to gain insights into the contextual socio-economic and environmental values of the farmers in Barombi Mbo. This analysis helps us understand the various factors influencing farmers' decision-making processes. We then extend a Tobit model, originally proposed by Tobin in 1958, to estimate the WTA values. The Tobit model accounts for the presence of censoring or truncation in the WTA data. Furthermore, we incorporate stochastic constraints in the model's parameters using prior distributions. These prior distributions capture our expert knowledge or expectations regarding agent preferences when engaging in environmental protection programmes. By adopting a Bayesian approach, we update our knowledge based on the data and obtain posterior estimates of the model parameters. The results of our analysis indicate that a significant majority of farmers in Barombi Mbo are willing to participate in agroforestry and afforestation programmes if their financial constraints are alleviated. Furthermore, we find that a higher socio-economic status is likely to promote pro-environmental behaviors among farmers, while increased knowledge on environmental protection strategies alone does not necessarily lead to eco-friendly behaviors. Based on our Bayesian estimation, the distribution of farmers' WTA is found to be normally distributed with a mean of 10,775CFA franc and a standard deviation of 323.59CFA franc. Moreover, we estimate the opportunity cost of providing environmental services for farmers in our study area to be approximately 3,290,448CFA fanc per year.

Our research findings demonstrate qualitative differences from the existing literature (Moukam, 2021; Gou et al., 2021; P´erez-S´anchez et al., 2021). While previous studies have acknowledged the potential of employing a Bayesian approach for modeling ecosystem services (Landuyt et al., 2013; Ban et al., 2014; Uusitalo et al., 2015; Hofer et al., 2020), a review of these studies reveals that the technique is not yet fully utilized. It has been highlighted in Hofer et al. (2020); Moukam (2021); Gou et al. (2021); P´erez-S´anchez et al. (2021) that the standard approach for modeling ecosystem service delivery relies solely on data, without incorporating expert knowledge, which can lead to controversial results regarding the drivers of economic agent behavior for environmental protection. In contrast to the aforementioned studies, our approach incorporates expert knowledge through the utilization of prior distributions for the model parameters. By doing so, we not only provide mean-

ingful insights into the determinants of economic agent preferences but also significantly improve the estimation of WTA compensation for participation in environmental conservation efforts. This allows us to account for situations where the available data may not adequately capture the tangible and intangible benefits of the environment. Our results suggest that the conditional probability of the parameters provides the best summary of the knowledge we can gain from the data.

The remaining sections of the paper are structured as follows. Section 2 provides a description of the study area, emphasizing its agroecological characteristics and the availability of agricultural extension services. In Section 3, we outline the research methodology, including details on the survey design, data collection process, and analytical methods employed. The obtained descriptive statistics, research findings, and their discussions are presented in Section 4. Finally, Section 5 serves as the conclusion of the paper, summarizing the key points and providing policy implications based on the findings.

2. BAROMBI MBO AREA IN CAMEROON

2.1. Agro-ecological characteristics

The rural area Barombi Mbo is located in the Meme Division of the Southwest region of Cameroon and is one of the villages near the periphery of Lake Barombi Mbo, just after the Forest Reserve (indicated by a black line in Figure 1). It was created in 1940 by the colonial government to protect the Lake, and the local inhabitants (natives) were granted the rights to fish in the Lake and harvest cocoa in existing farms within the Reserve (RIS, 2008). However, over the years, the resources attracted an increasing number of people, leading to the exploitation of illegal farming, hunting, timber, and non-timber forest products (NTFPs), coupled with uncontrolled fishing (Agbor, 2008; Sounders and Kimengsi, 2011; Tchouto et al., 2015).

The major food crops grown in the region include cassava (Manihot esculenta), plantain (Musa paradisiaca), Egusi melon (Cucumis sativus), maize, cocoyams, and taro (Colocasia antiquorum). Cocoa, palm oil, and rubber are the major cash crops in the zone, which is characteristic of the humid forest agro-ecological zone of the Southwest region of Cameroon. Barombi Mbo experiences a typical equatorial climate with a long rainy season from March to November and a short dry season from December to February. The village is known for its hot weather, with an average annual temperature ranging from 20°C to 30°C, as reported by the Delegation of Agriculture of Kumba. However, according to the most recent survey (RIS, 2008), the mean annual temperature is approximately 18°C or even lower at higher altitudes, with annual precipitation ranging from 1825 to 3000mm. The area has undergone significant climate change, with rains sometimes starting earlier in March and unexpected rainfall occurring during the dry seasons. In 2010, the rainy season extended until December, disrupting the planting and production of cash and food crops, as well as other economic activities, which typically end in October-November in previous years (Sounders and Kimengsi, 2011; Lebamba et al., 2012; Tchouto et al., 2015).

Furthermore, the area consists of steep slopes that are prone to erosion, and it is characterized by a mixture of soils, including limon, laterite, sandy, clay, and volcanic soils. These soils, which have a high content of andosols, are predominantly composed of dark volcanic materials. They are generally fertile and suitable for cultivating both food and cash crops. However, in deforested and degraded areas, soils are gradually losing fertility due to increased slash and burn practices, soil exposure, pollution, and overcropping (Sounders and Kimengsi, 2011; Tchouto et al., 2015). Agriculture is increasingly encroaching on the area, leading to the reduction of forested areas. As a result, the intensified use of fertilizers in agriculture has led to the pollution of the lake.

2.2. *Agricultural extension services*

Several types of sustainable agricultural practices have been promoted among farmers in the Meme Division by the Ministry of Agriculture and Rural Development (MINADER), including farmer field school and farmer business school. Through farmer field school, MINADER trains farmers on good agricultural practices in collaboration with cooperatives, while farmer business school focus on promoting agroforestry as a source of income. MINADER provides farmers with improved corn seedlings, maize seeds, cassava cuttings, as well as some pesticides and fertilizers. However, farmers face difficulties in adopting agroforestry practices due to the scarcity of improved agroforestry species or nurseries and limited access to productive agricultural land for planting. It is important to note that Barombi Mbo village is not one of the communities targeted by MINADER due to its proximity to the forest reserve, which is managed by the Ministry of Forestry and Wildlife (MINFOF). Due to the lack of collaboration between these two government institutions at the field level, Barombi Mbo farmers are unable to learn about or benefit from agroforestry practices supported by MINADER.

3. METHODOLOGY

This section outlines the methodology employed to estimate the opportunity cost for farmers in the Barombi Mbo area of Cameroon to adopt agroforestry and afforestation practices. We present the conceptual framework, survey design and data collection methods, modeling framework, and the integration of expert knowledge.

3.1. *Conceptual framework – Contingent valuation*

Sustainable agricultural systems, such as agroforestry, deliver and maintain a range of valuable positive environmental externalities, including wildlife habitat and climate mitigation. They have been proven to be less vulnerable to shocks and stresses (VERMA et al., 2016; Gama-Rodrigues et al., 2021). Since these environmental benefits are typically considered public goods, private ranches are often less motivated to supply them at their optimal levels. Additionally, a standing forest typically represents a potential source of income that can be accessed through logging or farming in the case of sudden need (Bacon et al., 2012; Gama-Rodrigues et al., 2021). Farmers may thus be unwilling to introduce changes in their production systems that involve a loss of these potential income sources. Therefore, a valuable approach to promoting biodiversity conservation and carbon sequestration is the PES, which provides financial transfers to landowners, farmers, and communities whose land-use decisions may affect the biodiversity values and climate change. PES creates incentives for the conservation of plant and animal species, as well as the soil quality (Engel et al., 2008; Ito, 2022).

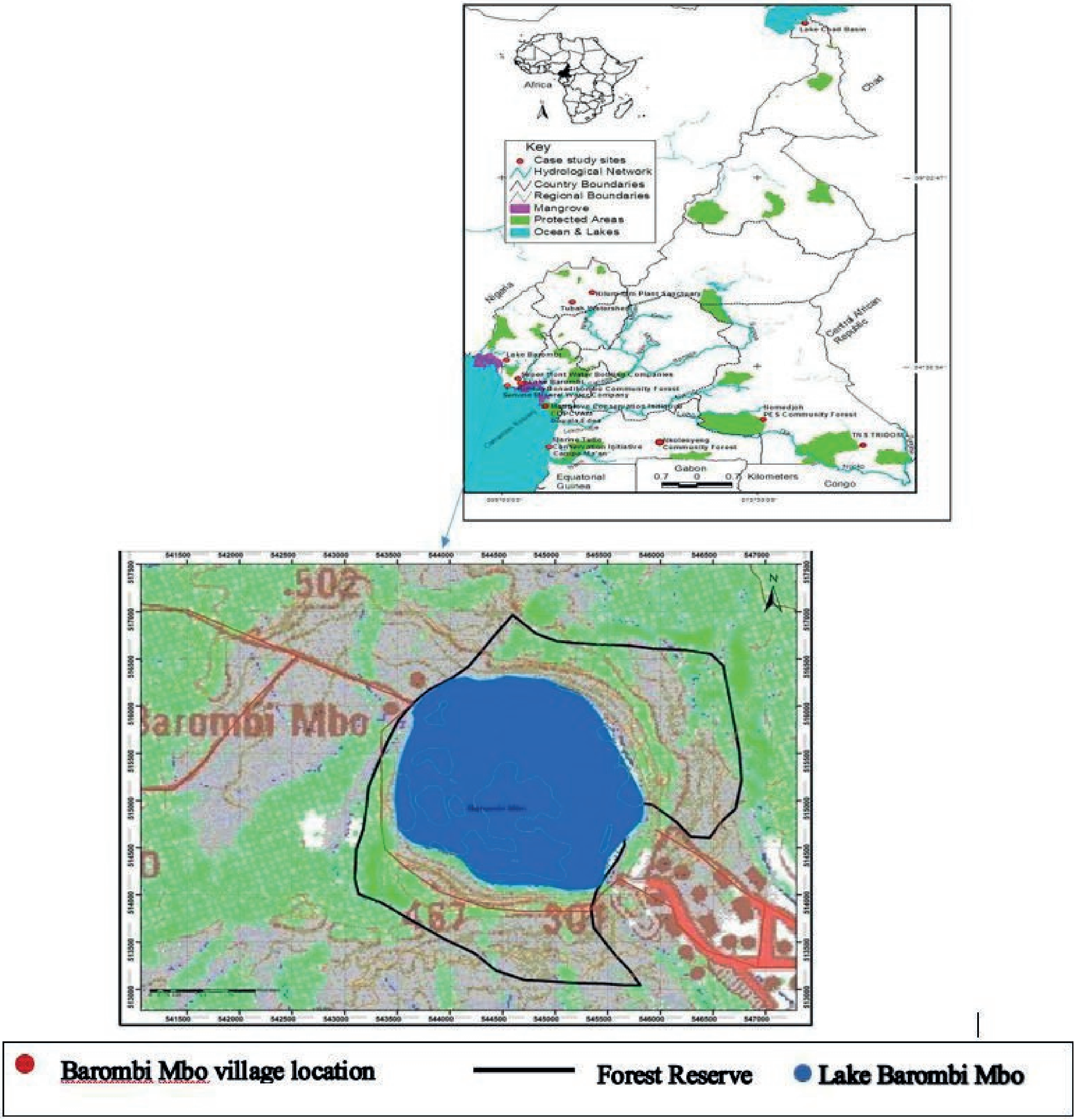

Figure 1. Location of the study area in South West region of Cameroon.

Although PES is an economic incentive mechanism for the provision of environmental services, the effectiveness and efficiency of its implementation, especially in the agricultural sector, largely depend on their social acceptability (Todorova, 2019; Viaggi et al., 2021). In addition, it is relatively difficult, and even impossible, to value environmental services through market mechanisms due to their public goods nature. Therefore, the compensation for supplying environmental services is

usually based on the opportunity cost of changing practices or restricting use rights. In other words, an economic agent may seek a monetary amount to ensure that their activities protect or deliver a range of environmental services (Divinski et al., 2018; Sheng et al., 2019). The contingent valuation methodology helps reveal the monetary amount an economic agent would like to receive to secure the value of goods or services when prices are not available (Carson, 2012; Johnston et al., 2017). If an economic agent, such as a farmer, has exclusive property or user rights over a good, such as a standing forest, and is being asked to give up or restrict that entitlement in terms of exclusivity or transfer of user rights, then the correct measurement within a contingent valuation framework is the WTA (Brown and Gregory, 1999; Carson et al., 2001; McFadden and Train, 2017).

There is evidence suggesting that farmers, through their exposure to agri-environmental schemes, have become familiar with the tradeoff between agricultural production and the provision of environmental public goods (Buckley et al., 2012; McGurk et al., 2020). According to McFadden and Train (2017), the SP methodology involves conducting surveys to elicit economic agents' preferences and their WTA for the provision of public goods, such as environmental services. The development of SP surveys aims to maximize the validity and reliability of the resulting value estimates. Validity refers to minimizing bias in estimates, while reliability pertains to reducing variability (Mitchell and Carson, 1989; Bateman et al., 2002; Bishop and Boyle, 2019). Therefore, as emphasized by Johnston et al. (2017), well-designed surveys and proper implementation procedures are crucial for achieving these goals and are necessary when extrapolating model estimates from a survey sample to an intended population.

3.2. Survey design and data collection

We design a survey instrument that clearly explains the current conditions and presents a consequential valuation question. Additionally, we select a random sample from the potentially affected population and choose a survey mode that ensures complete questionnaire responses.

Scenario description

We define a hypothetical scenario to assess agroforestry development in Barombi Mbo, capturing the impacts of current agricultural practices and potential changes. We present both the baseline or status quo conditions and the proposed changes relative to the baseline to the farmers. This approach ensures that farmers understand and accept the valuation scenario (Schultz et al., 2012; Johnston et al., 2017). Our hypothetical scenario, along with its consequential value question, is as follows: "Studies conducted in the Barombi Mbo forest reserve have observed that approximately 90% of the forest reserve, particularly the forest near the lake, has been destroyed. If the current level of activities in the reserve continues, there will be no trees left to provide fuelwood, wood, climate stabilization, wildlife habitat, and water quality and quantity for future generations, as well as for eco-tourism in the watershed. To restore the forest reserve, the government plans to implement an afforestation programme. Your participation in this programme will assist the government in estimating the cost of afforestation."

Questionnaire testing

As recommended by Johnston et al. (2017), we conducted a focus group discussion with 28 farmers from Barombi Mbo to test our questionnaire. This allowed us to assess the impacts of the information provided on farmers' responses to the valuation questions, the framing of the valuation questions, as well as the respondents' prior experience and knowledge. The testing of the questionnaire helped us clarify the questions and information with the farmers, and also enabled us to determine the monetary amounts (bids) that farmers are willing to accept for adopting agroforestry. This process is crucial not only for ensuring the validity and reliability of our estimates but also for avoiding respondent fatigue caused by the provision of unnecessary details (Mitchell and Carson, 1989; Bateman et al., 2002; Champ et al., 2017).

Value elicitation

We utilize an open-ended elicitation format to gather pilot data during the survey pretesting phase. This format enables us to collect point estimates of different monetary amounts that farmers are willing to accept for agroforestry adoption (Vossler and Zawojska, 2020). Following the presentation of the hypothetical scenario for agroforestry development, our open-ended valuation question is as follows: "What annual compensation would you expect to plant trees in or out of the Reserve?" The responses obtained from the participants provide us with a range of monetary amounts, allowing us to determine the distribution of the WTA and select a finite set of monetary amounts to be proposed to farmers in the final survey.

Instead of choosing monetary amounts between the 15th and 85th percentiles or from the tail of the distribution, as recommended by Kanninen (1995) for WTP, we retain the first two lowest monetary amounts, specifically 10,000CFA franc and 15,000CFA franc. This approach helps to reduce hypothetical bias, as economic agents often tend to overstate their WTA, as highlighted by Kahneman and Tversky' (1979). Alberini (1995) and Terra (2010) suggest that including approximately two monetary amounts for estimating WTA is theoretically optimal. Having a small number of bids is preferred over a large number as it increases estimation efficiency and the power of statistical tests. After conducting the field pilot survey, we revise the questionnaire to incorporate the monetary amounts/WTA for the provision of environmental services, as well as farmers' suggestions regarding the types and levels of activities carried out in the farm and forest reserve, as presented in Section 4.1.

The final survey employs a dichotomous-choice elicitation format. Specifically, we use a WTA question to determine the minimum amount of cash a farmer is willing to accept as compensation for changing their current land-use practices to more productive and environmentally friendly ones. This question is presented to farmers using a single binary choice format (Carson and Groves, 2007; Carson et al., 2014; Vossler and Holladay, 2018). Our single binary choice question is as follows: "Would you be willing to receive 'X amount' per year for your participation in the afforestation programme?" The 'X amount' represents either 10,000CFA franc or 15,000CFA franc. The farmer is asked to respond with either "yes" or "no."

Population and sampling procedure

The population of Barombi Mbo was estimated to be 595 inhabitants in March 2015, with 349 males and females above 15 years old (Tchouto, 2015). Limiting the age of respondents to 15 years and older allows us to account for farms owned or managed by youths when one or both of their parents are still alive or have passed away.

To obtain a sample size that represents the population of Barombi Mbo, we use the following formula (Yamane, 1967):

$$n = \frac{N}{1 + Nc^2} \quad (1)$$

In this formula, N = 349 represents the number of individuals older than 15 years old, and c = 4.6% is the margin of error. By plugging these values into the formula, we calculate a sample size of 200 farmers.

The selection of farmers for face-to-face interviews is done randomly within the village.

Data collection

For data collection, we assign 50% of the sample to each of the two monetary amounts to ensure an equal distribution of bids. The responses to the single binary choice question mentioned earlier are obtained through face-to-face or in-person interviews.

Our questionnaire includes auxiliary or supporting questions to aid in understanding responses to value elicitation questions and ensure construct validity (Krupnick and Adamowicz, 2006; Mitchell and Carson, 1989; Bateman et al., 2002; Champ et al., 2017; Johnston et al., 2017; Vossler and Holladay, 2018). These auxiliary questions serve multiple purposes, such as identifying demographic, household, or other relevant characteristics of the respondents. Additionally, a subset of these questions may provide covariates, which are used in valuation models to explain the variation in responses to the value elicitation questions (Johnston et al., 2017; Vossler and Holladay, 2018). To account for factors that may influence the WTA, our questionnaire collects information on the socioeconomic characteristics of farmers, farm characteristics, and environmental variables. This information helps deconstruct farmer preferences and identify factors that affect the WTA. Previous studies, such as Chatterjee et al. (2021), have shown that the adoption of conservation agriculture is related not only to ecological factors but also to adopters' characteristics, their perceptions, and the decision-making process. Specifically, our questionnaire includes questions regarding the age, gender, education level, family size, and origin of farmers. We also inquire about the location and size of farms because the ownership of large and strategically positioned agricultural land may influence farmers' participation in environmental protection programmes (Ajayi et al., 2012). Furthermore, we include questions about the current agricultural income and the use of fertilizers and pesticides to examine how the land opportunity cost or on-farm income could make compensation or payments more attractive within a PES scheme. Existing evidence suggests that farmers with higher profit levels from their existing activities generally demand higher levels of compensation to participate in a conservation scheme (Bateman, 1996; Ajayi et al., 2012).

Furthermore, our questionnaire includes questions to capture farmers' perceptions of the potential development outcomes associated with unsustainable agricultural practices, such as the heavy use of chemical fertilizers and slash and burn techniques. The poor performance of these unsustainable practices may motivate farmers to seek sustainable alternatives, such as agroforestry. As highlighted by Gama-Rodrigues et al.

(2021), agroforestry has positive effects on both income and the environment. In agroforestry systems, habitats are provided for species that can tolerate a certain level of disturbance, and the rate of natural habitat conversion is reduced compared to traditional agricultural systems (Jose, 2009). Agroforestry also contributes to biodiversity conservation as trees, crops, and/or animals enhance soil fertility, improve water quality, increase aesthetics, and sequester carbon. For instance, multi-strata cocoa agroforestry systems that incorporate timber, fruit, and native forest species create improved wildlife habitats by increasing plant diversity, enhancing landscape connectivity, and reducing edge effects between forests and agricultural land (Jose, 2009; Gama-Rodrigues et al., 2021; Bareille et al., 2023). However, it is important to acknowledge that seeking more sustainable alternatives also involves costs and potential income losses for farmers. Therefore, they may require compensation for implementing agri-environmental protection solutions (Raina et al., 2021).

Moreover, our questionnaire includes questions aimed at capturing the social, environmental, and cultural values associated with agroforestry. These values encompass the importance of non-timber forest products (NTFPs), environmental sensitivity, access to information and knowledge about agroforestry and biofertilizer technologies, as well as awareness of the PES mechanism. Recognizing and understanding these cultural and environmental values is crucial for promoting biodiversity

conservation through agroforestry in the long term. These values provide justification for farmers to conserve native forest habitat within cocoa production landscapes, maintain or restore diverse and structurally complex shade canopies within cocoa agroforestry systems, and retain other forms of on-farm tree cover to enhance landscape connectivity and habitat availability (Schroth and Harvey, 2007; Gama-Rodrigues et al., 2021; Bareille et al., 2023; Ito, 2022). However, our field survey reveals a lack of knowledge about the benefits of agroforestry in the Barombi zone. This issue will be discussed further in Section 4.1.

Non-data information or expert knowledge

In situations where the available data are limited, noisy, or biased, or when the empirical problem is complex and requires additional information to determine the WTA, non-data information can be particularly valuable. Non-data information refers to any prior knowledge or assumptions about the WTA that are not derived from observed or survey data (Knuiman and Speed, 1988; Gelman et al., 2013; Mahmoud et al., 2020; Awwad et al., 2021; Hegazy et al., 2021). Such information can be obtained from various sources, including:

- Expert opinion: Prior knowledge can be informed by the insights and expertise of professionals in the field who possess relevant experience and knowledge.
- Previous studies: Prior knowledge can be based on the findings of previous research that has investigated similar or related problems.
- Empirical data: Prior knowledge can be derived from data collected from sources other than the current study, such as pilot studies or surveys.
- Theoretical considerations: Prior knowledge can be based on theoretical frameworks and considerations regarding the relationships between the variables of interest.

Accounting for non-data information can indeed enhance the accuracy and precision of WTA estimates and mitigate the influence of outliers or measurement errors (Kadane and Lazar, 2004; Gelman et al., 2013; Kruschke, 2013). However, it is crucial to approach the use of non-data information with caution and provide adequate justification, as it introduces subjectivity into the analysis. In our study, we rely on prior knowledge derived from theoretical considerations regarding the relationship between WTA and psychological stimuli experienced by farmers. Further details on this aspect are discussed in Section 3.4.

3.3. Modeling farmer's willingness to accept

The use of a Tobit model is appropriate in our study to model farmers' WTA compensation. The Tobit model is a regression model commonly employed when the dependent variable is censored within a certain range. In our case, the WTA lies within the interval $[0, \infty[$ since there is no negative compensation observed in our experiment (as discussed in Section 3.2). Therefore, the Tobit model can effectively capture the behavior of the WTA.

In the context of the Tobit model, the choice of a farmer to participate in the agroforestry programme with compensation can be represented as a dichotomous outcome. A farmer either agrees to participate (indicating $WTA > 0$) or does not agree to participate (indicating $WTA = 0$). The Tobit model has been widely used in studies investigating technology adoption and participation in conservation programmes, as mentioned in prior research (e.g., (Buckley et al., 2012; Thompson et al., 2021)).

The conceptual model can be described in terms of a latent variable WTA^* and an observed variable WTA as follows:

$$WTA_i^* = X_i\beta + \varepsilon_i, \quad (2)$$

$$WTA_i = \begin{cases} WTA_i^* & if \quad WTA_i^* > 0 \\ 0 & if \quad WTA_i^* \leq 0 \end{cases} \quad (3)$$

where, X_i is a row vector of explanatory variables that determine the respondent i's WTA_i or participation in a sustainable agriculture or conservation programme, β is a column vector of parameters to be estimated, and ε_i is an error term with a normal distribution N (0, σ^2).

The Tobit model consists of two parts: a continuous part, represented by the linear regression equation 2, and a discrete part, represented by the censored point equation 3. The continuous part, equation 2, models the underlying relationship between the latent variable WTA_i^* and the explanatory variables X_i. It assumes a linear relationship, where the value of WTA_i^* is determined by the values of X_i multiplied by the parameter vector β, along with the error term ε_i. The censored point equation 3 introduces the censoring mechanism. It states that the observed WTA value WTA_i is determined based on the value of WTA_i^*. If WTA_i^* is greater than zero, indicating that the respondent agrees to participate, the observed WTA value equals WTA_i^*. However, if WTA_i^* is less than or equal to zero, indicating that the respondent does not agree to participate, the observed WTA value is censored at zero.

The Tobit model combines these two parts to estimate the parameters β that determine the relationship between the explanatory variables and the WTA, taking into account the censoring mechanism. The estimation procedure accounts for both the continuous and censored parts simultaneously, providing insights into the factors influencing farmers' WTA and their decision to participate in the agroforestry programme with compensation.

From (2), we derive that WTA_i^* follows a normal distribution; and the probability to reject an offer to participate in a sustainable agriculture programme is given by:

$$Prob(WTA_i^* \leq 0) = \phi\left(-\frac{X_i\beta}{\sigma}\right) = 1 - \phi\left(\frac{X_i\beta}{\sigma}\right), \quad (4)$$

where φ is the standard normal density function. It follows that the probability for WTA_i^* to take on positive values is given by:

$$Prob(WTA_i^* > 0) = 1 - Prob(WTA_i^* \leq 0) = \phi\left(\frac{X_i\beta}{\sigma}\right) \quad (5)$$

We derive the log-likelihood function of WTA from (3), (4) and (5) as follows:

$$LogL = -\frac{1}{2}\sum_{WTA_i>0}\left(Log2\pi + Log\sigma^2 + \frac{1}{\sigma^2}(WTA_i - X_i\beta)^2\right) + \sum_{WTA_i=0} Log\left(1 - \phi\left(\frac{X_i\beta}{\sigma}\right)\right) \quad (6)$$

To determine the components of the explanatory variables X_i, we draw insights from existing literature on empirical research on farmers' valuation of environmental services, adoption of agricultural technologies, and participation in conservation programmes in both developed and developing countries. These studies include research by Adesina et al. (2000); Jose (2009); Scognamillo and Sitko (2021), Chatterjee et al. (2021) and Raina et al. (2021), among others. These studies provide valuable information on the factors influencing farmers' WTA. Additionally, some of these studies offer guidance on designing a relevant questionnaire to explore the key determinants of farmers' WTA (refer to Table 1).

From (2) and (3), it can be shown that:

$$E(WTA_i/X_i) = (1 - \Phi(\alpha))(\mu - \sigma\lambda(\alpha)) \quad (7)$$

where $\alpha = -\mu/\sigma$, $\lambda(\alpha) = \phi(\alpha)/(1-\Phi(\alpha))$, ϕ and Φ are the standard normal density and distribution functions respectively, and $\mu = X_i\beta$, with

$$X_i\beta = \beta_1 + \beta_2 AGE + \beta_3 GEND + \beta_4 ORIGIN + \beta_5 EDU + \beta_6 FHSIZE + \beta_7 ONFINC + \beta_8 LOFARM + \beta_9 FASIZE + \beta_{10} ENVSTY + \beta_{11} AWPES + \beta_{12} BIOFERT + \beta_{13} OUTCPRA + \beta_{14} NTFPs \quad (8)$$

Denote by $\theta = (\beta, \sigma)$ the parameter of the empirical model (2). Using data to estimate θ, we can predict the WTA from (7). In this paper, we are interested in predicting the WTA of a representative farmer characterized by $\bar{X} = E(X_i)$. In the following section, we propose an approach to estimate θ.

3.4. Incorporating expert knowledge into farmer's willingness to accept

In most SP studies, data on farmers' hypothetical choices of the WTA are utilized to deduce their preferences for various levels of environmental services (Johnston et al., 2017; Hanley and Czajkowski, 2019; Wang

Table 1. Description of explanatory variables and their expected signs.

Variables	Description	Expected signs
AGE	Age of farmer (CONTINUOUS)	(±)
GEND	Sex of farmer (DUMMY): 1 if male and 0 if female	(±)
ORIGIN	Origin of farmers (DUMMY): 1 if native and 0 if non-native	(+)
EDU	Education level of farmers (CATEGORICAL): 0 if None (never been to school), 1 if primary and 2 if high level (secondary, high school)	(−)
FHSIZE	Size of farm households (CONTINUOUS)	(±)
ONFINC	Average yearly on-farm income (CONTINUOUS)	(+)
LOFARM	Location of the farm (DUMMY): 1 if out of the reserve and 0 if otherwise	(+)
FASIZE	Size of the farm (DUMMY): 1 if more than 5ha and 0 if not	(−)
ENVSTY	Environmental sensitivity of farmers (DUMMY): 1 if sensitive to the role of forest to protect the environment and 0 if not	(−)
AWPES	Awareness of PES scheme (DUMMY): 1 if yes and 0 otherwise	(±)
OUTCPRA	Perception of the output of current practices by farmers (DUMMY): 1 if average (average, bad) and 0 if good (good, very good)	(±)
BIOFERT	Knowledge of Bio-fertilizers (DUMMY): 1 if farmers have knowledge and 0 otherwise	(±)
NTFPs	Importance of NTFPs to the farmer: 1 if important and 0 otherwise	(−)

Source: Authors' definitions

and Nuppenau, 2021). However, the hypothetical nature of the WTA choices introduces a bias, as individuals tend to systematically overstate or understate their WTA values. This bias arises because no actual payment is made or received in exchange for an actual change in the quantity or quality of environmental services (Haghani et al., 2021).

As suggested in Section 3.2, one way to correct the bias and improve the accuracy and precision of the WTA estimates is to incorporate expert knowledge. Expert knowledge can be utilized to constrain the range of possible values for the unknown parameters, θ, related to agent preferences.

The most commonly employed statistical methods for estimating the parameter θ are referred to as frequentist (or classical) methods. Specifically, the maximum likelihood method is often utilized, making use of the log-likelihood function (6) (Xu and Lee, 2015; Xu and fei Lee, 2018; Toker et al., 2021). These methods assume that the unknown parameter θ is a fixed constant and determine the probability of its estimator through limiting relative frequencies. As a result of these assumptions, it is not possible to provide a probabilistic statement regarding the unknown parameter θ since it is considered fixed. Consequently, the frequentist approach is not suitable for incorporating expert knowledge in the estimation of the unknown parameter θ.

Bayesian estimation provides an alternative approach, treating θ as a random variable and allowing for the expression of uncertainty through probability statements and distributions known as priors (Mahmoud et al., 2020; Awwad et al., 2021; Hegazy et al., 2021). Priors are designed to incorporate any relevant information the researcher possesses before observing the data. Therefore, priors can take various forms, accommodating the inclusion of expert knowledge in the estimation of the unknown parameter θ. By leveraging our expert knowledge of farmer preferences, as captured by the prior distribution of θ, Bayesian analysis enables us to learn from data and update our knowledge accordingly. It emphasizes that the conditional probability of the unknown parameter θ serves as the optimal means of summarizing the information derived from the data (Chan et al., 2019).

The Bayesian approach provides a comprehensive probabilistic framework for empirical modeling. It enables us to address hypothetical bias in the estimates of sample characteristics such as $E(WTA_i/X_i)$ by leveraging our prior knowledge of the unknown parameters (Kadane and Lazar, 2004; Gelman et al., 2013; Kruschke, 2013).

As stated by Chan et al. (2019), Bayesian analysis involves the calculation of the posterior distribution of the parameter θ, denoted as $p(\theta/WTA)$. It can be expressed, up to an arbitrary constant, in a proportional form as:

$$p(\theta/WTA) \propto \text{Log } L \times \pi(\theta) \qquad (9)$$

Here, Log L represents the log-likelihood function of the censored regression model for WTA (refer to (6)), and $\pi(\theta)$ is referred to as the prior distribution of θ, or simply the prior. As mentioned earlier, the prior distribution reflects our expert knowledge about the parameter θ before examining the data. It can assume various forms, such as uniform, normal, gamma, or other distributions, depending on the problem's nature and the available prior information. In equation (9), the prior knowledge is incorporated into the posterior distribution using Bayes' theorem. As more data is collected, the influence of the prior distribution diminishes, and the posterior distribution becomes increasingly shaped by the likelihood function. This process is known as updating the prior distribution.

As discussed in Section 3.2, there are various sources of prior knowledge. When expert opinions, previous studies, or empirical data about the parameters are lacking, theoretical considerations can be employed to generate prior knowledge. Theoretical considerations are particularly valuable for specifying uninformative priors. Chan et al. (2019) defines an uninformative, flat, or diffuse prior as any distribution that expresses vague or general information about a parameter. The use of non-informative priors in Bayesian analysis offers several advantages, including:

- **Objectivity:** Non-informative priors aim to minimize the influence of prior knowledge on posterior results by expressing ”objective” information, such as ”the parameter is positive” or ”the parameter is less than a certain limit.” They strive to be as objective as possible, allowing the data to exert the greatest influence on the final inference. This can help address concerns about subjectivity or bias in the analysis.
- **Robustness:** Non-informative priors can be valuable when prior knowledge or information is limited or unreliable. They provide a default assumption that avoids strong assumptions or bias based on incomplete or uncertain information. This is particularly beneficial in situations where there is a lack of prior knowledge or when multiple analysts with different perspectives are involved.
- **Simplicity:** Non-informative priors are often simple and unrestrictive, facilitating a more straightforward analysis. They simplify the modeling process and reduce the computational burden associated with estimating complex prior distributions.
- **Sensitivity analysis:** Non-informative priors are useful for conducting sensitivity analyses. By comparing the results obtained with non-informative priors to those obtained with informative priors, researchers can assess the impact of prior assumptions on the final inference. This helps identify the extent to which the results depend on prior specifications.
- **Communicating uncertainty:** Non-informative priors offer a means to quantify and communicate uncertainty when little or no prior knowledge is available. They enable the estimation of credible intervals or posterior distributions that reflect the uncertainty in the parameters of interest based solely on the observed data.

However, it's important to acknowledge that non-informative priors have their limitations. In certain cases, they may not fully capture all available information, resulting in less efficient inference or potentially misleading results. Table 1 outlines the expected signs for the parameters in our model based on theoretical considerations, representing the necessary prior knowledge for specifying noninformative priors. However, for robustness, we assume that all explanatory variables may have both positive and negative effects on *WTA*.

The principle of indifference, which assigns equal probabilities to all possibilities, is the simplest and oldest rule for determining a non-informative prior. In this study, we adopt a non-informative prior for β, specifically a uniform prior distribution, $\pi(\beta) \propto 1$. Additionally, it is common in the literature to use a gamma distribution as a prior for the standard deviation of a normal distribution (Chan et al., 2019). Therefore, we assume that σ follows a gamma distribution, $\pi(\sigma) \propto G(a, b)$, where a = 0.01 represents the shape parameter and b = 0.01 denotes the inverse-scale parameter. The choice of hyper-parameters a and b ensures convergence of the posterior distribution sampling. Furthermore, we assume that β and σ are independently distributed, giving $\pi(\theta) = \pi(\beta)\pi(\sigma)$.

To perform a Bayesian analysis of the Tobit model (2) and (3), we can utilize the LIFEREG procedure in the Statistical Analysis Software (SAS). This procedure incorporates an Adaptive Rejection Metropolis Sampling (ARMS) algorithm based on the programme provided by Gilks (2003) to draw a sample $\theta_k = (\beta_k, \sigma_k) k=1...m$ from the full-conditional distribution (9). The Bayesian estimate of the mean WTA of agent i, denoted as $E(WTA_i/X_i)$, is then calculated as:

$$(E(WTA_i/X_i)/Y) \approx \frac{1}{m}\sum_{k=1}^{m}(1 - \Phi(\alpha_k))(\mu_k - \sigma_k\lambda_k(\alpha_k)), \quad (10)$$

as m approaches infinity,

where, $Y = \{WTA_i, X_i\}_{i=1,..,n}$ represents the data, $\alpha_k = -\mu_k/\sigma_k$, $\lambda_k(\alpha_k) = \phi(\alpha_k)/(1 - \Phi(\alpha_k))$, ϕ and Φ denote the standard normal density and distribution functions, respectively, and $\mu_k = X_i\beta_k$.

4. RESULTS AND DISCUSSION

In this section, we provide the results of implementing the methodology outlined in the previous section. Firstly, we provide a brief overview of the descriptive statistics pertaining to both traditional and eco-innovative farming practices in the study area. Subsequently, we employ a multidimensional preferences analysis to examine contextual behavior patterns that could elucidate farmer preferences. Finally, we analyze the empirical estimates of farmer willingness to accept compensation for environmental services.

4.1. Descriptive statistics of traditional and eco-innovative farming practices

Throughout generations, farmers have continuously strived to enhance agricultural land productivity through the utilization of available technologies. Table 2 provides an overview of the traditional and eco-innovative farming practices employed by farmers in the study area. It is observed that approximately 85 percent of farmers utilize chemical inputs, such as fertilizers and pesticides, to improve soil fertility and manage cocoa farms. Among the pesticides used, fungicides and insecticides are the most commonly employed, both within and outside the reserve. Regarding soil preparation techniques, 53.5% of farmers employ crop rotation, followed by a slash and burn method (34%). Despite facing challenges related to limited land availability for crop cultivation, a majority (50.5%) of farmers employ various durations of bush fallow systems to enhance land productivity. While 24.5% of farmers have their farms located within the reserve, a significant proportion of respondents (70.5%) attribute most of the observed deforestation in the reserve to the exploitation of fuelwood, timber, and NTFPs.

To mitigate the adverse impacts of deforestation, chemical fertilizers, and pesticides in the vicinity of the lake, farmers have adopted various eco-innovative practices to protect the environment. A significant number of farmers prioritize conservation by preserving old and large trees within their own farms. For example, approximately 52% of farmers have planted fruit trees, NTFPs, and other species on their land. These seedlings are typically sourced from their own nurseries or purchased from external suppliers. The planting of trees serves the dual purpose of preventing soil erosion and safeguarding the environment. However, agroforestry practices are not widely implemented, primarily due to limited awareness regarding their significance. Only a small proportion of farmers (16%) have heard about agroforestry or bio-agriculture, with information dissemination occurring through various channels, including schools, village meetings, and the farmers field school initiative of MINADER (Ministry of Agriculture and Rural Development). It is worth noting that the majority of farmers believe that chemical fertilizers are the most effective solution to combat declining soil fertility. This inclination can be attributed to the lack of awareness regarding indigenous knowledge pertaining to soil erosion prevention, soil demineralization, and the production and application of organic manure. In fact, when asked to explain their understanding of bio-fertilizers, only 30.5% of farmers demonstrated some knowledge on the subject.

Table 2. Traditional and eco-innovation farming practices.

Description	Frequency of "yes"	% of the respondents
Chemical use		
Overall	170	85
Fungicides	94	55.29
Insecticides	22	12.94
Soil preparation techniques		
Slash and burn	68	34
Rotation	107	53.50
Bush fallow practice	101	50.50
Tree conservation		
NTFPs	47	43.12
Timber	31	28.44
Fruit trees	21	19.27
Reforestation		
Fruit trees	70	67.31
NTFPs	27	27.96
Origin of seedlings		
From own nursery	48	46.15
Buy	29	27.88
Donation	22	21.15
Forest cover destroyed in the reserve		
More than 75% of forest destroyed	141	70.50
Agro-forestry knowledge	32	16
Bio-fertilizers knowledge	61	30.50

Source: Authors' calculations from survey data.

Moreover, it is noteworthy that only 48% of farmers consider the outputs from their current farming practices to be good or satisfactory (see Table 2). Almost all farmers (95.5%) acknowledge the significance of forests in providing vital ecosystem services, including climate regulation, flood control, erosion control, wildlife habitat, landscape beauty, and cultural/spiritual value. Concerning watershed protection, the majority of farmers (97.5%) recognize the positive correlation between for-

Table 3. Distribution of the willingness to accept.

Response	FCFA10,000	FCFA15,000	Total
No	14	11	25
Yes	86	89	175
Total	100	100	200
Percentage of yes	86%	89%	87.5%

Source: Authors' calculations from survey data.

est cover and water quality. However, only 27% of farmers are familiar with the PES mechanism (see Table 2). Nonetheless, considering the farmers' willingness to plant diverse tree species on their own land, it is reasonable to expect their active participation in the PES scheme if they are provided with incentives to plant and preserve trees.

4.2. Adoption of agro-forestry and multidimensional preferences analysis

According to the data presented in Table 3, a significant proportion of farmers (87.5%) are willing to accept compensation in order to participate in an afforestation programme both within and outside the reserve, as well as along the border of the lake. While the benefits of agroforestry are discussed with farmers during the survey, only a small percentage (8.5%) of farmers residing near the lake express their willingness to adopt agroforestry practices. However, among those who are willing to adopt agroforestry, a majority also demonstrate their commitment to refrain from using chemicals within an 8-meter distance from the lake, provided that they receive seedlings for agroforestry and receive training on best agroforestry practices.

In conducting a multidimensional preferences analysis (MPA), we aim to identify the primary dimensions of farmer preferences that can explain their willingness to adopt agroforestry practices. While Principal Component Analysis (PCA) focuses on reducing complexity and identifying patterns in large datasets, MPA delves into understanding individual or group preferences and priorities. It can be seen as a PCA of a data matrix, with columns representing individuals and rows representing variables or objects.

As depicted in Figure 2, the determinants of farmers' willingness to participate in an afforestation programme are classified into three groups:

- The first group comprises variables such as awareness of PES schemes (AWPES), knowledge of bio-fertilizers (BIOFERT), the importance of non-timber forest products (NTFPs), and education level (EDU). This group reflects the extent to which farmers possess knowledge about environmental management. It is reasonable to assume that farmers with higher levels of education are more likely to be aware of PES programmes, have knowledge of bio-fertilizers, and understand the importance of NTFPs.
- The second group consists of variables related to environmental sensitivity (ENVSTY), the origin of the farmer (ORIGIN) (whether native or non-native to the study area), and the location of the farm (LOFARM) (whether inside or outside the reserve). This group captures the farmers' connection (sensitivity, origin, and location) to the study area and the local community. It is evident that farmers who are native to the study area and have farms within the reserve exhibit a higher sensitivity to the role of forests in environmental protection.
- The third group includes variables such as age (AGE), gender (GEND), farm size (FASIZE), farm household size (FHSIZE), and yearly on-farm income (ONFINC). This group reflects farmers' socioeconomic status and demographic characteristics. The strong correlation between on-farm income and farm size suggests the existence of an extensive agricultural system, which often exerts significant pressure on the environment.

By analyzing these three groups of variables, multidimensional preferences analysis helps uncover the underlying dimensions driving farmers' preferences and their willingness to adopt agroforestry practices.

The perfect negative correlation between the first group of variables (related to knowledge and awareness of environmental management) and the second group of variables (related to connections with the local community) reveals an interesting pattern. It suggests that farmers who have weak connections with the local community tend to be more knowledgeable about environmental management, while those with strong connections are less informed in this regard. This finding has important implications as it may help explain why rural areas are more susceptible to environmental degradation.

In rural areas, where strong community ties and social networks are prevalent, farmers who have close connections with the local community may rely on traditional practices and knowledge passed down through generations. However, these practices may not always align with sustainable agricultural practices or modern environmental management strategies. On the other hand, farmers who have weaker connections with the local community, such as migrants or individuals with limited social integration, may have more exposure to

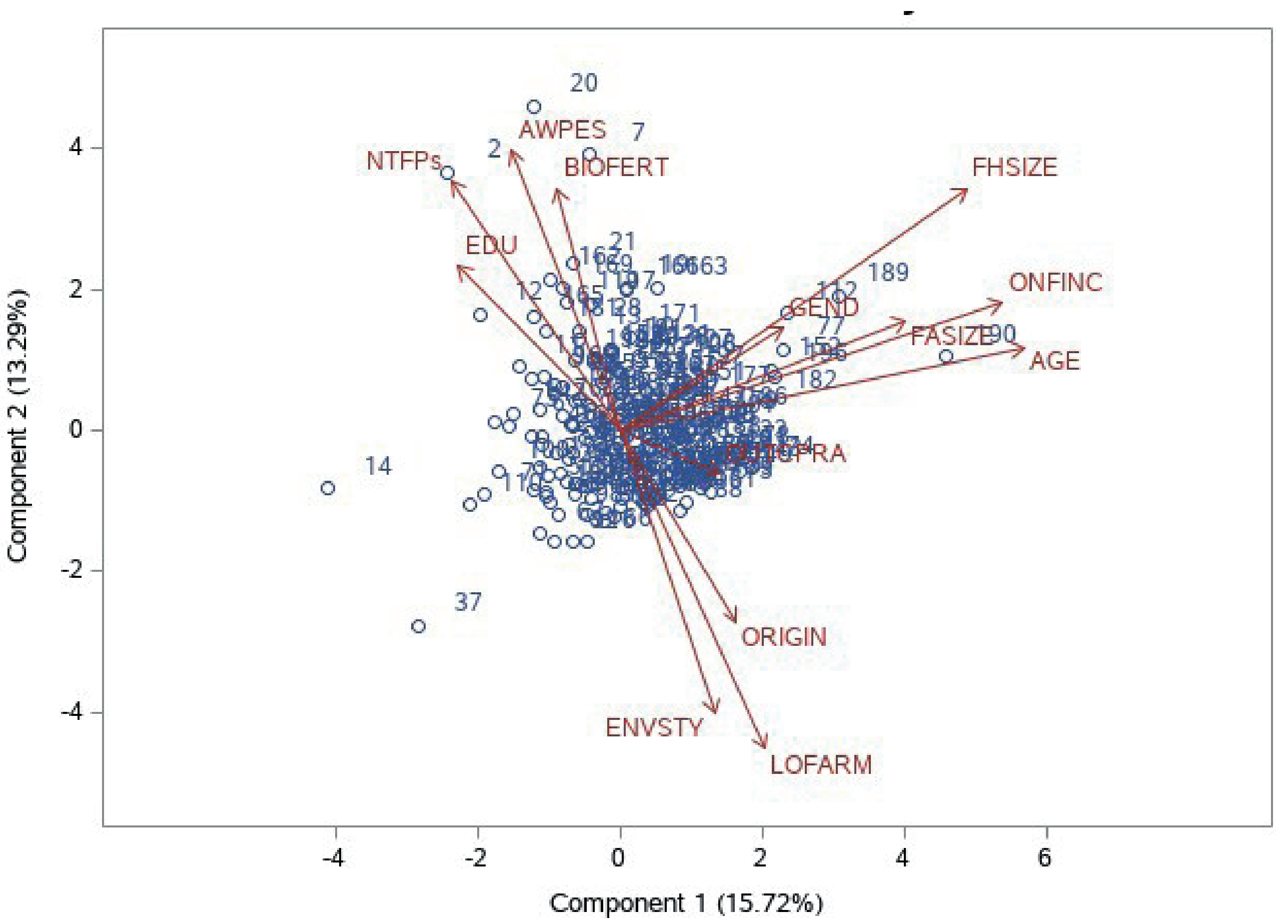

Figure 2. Multidimensional Preferences Analysis.

external information and knowledge regarding sustainable agriculture and environmental management. This finding highlights the need for capacity building and training initiatives targeting local and indigenous communities, as well as natural resources owners in rural areas like Barombi Mbo. By providing them with appropriate knowledge and skills related to sustainable agricultural practices and environmental management, we can promote behavior change and the adoption of more sustainable practices. Recognizing the ownership of natural resources, coupled with empowering individuals with the necessary knowledge, can serve as a catalyst for positive changes and contribute to the reduction of environmental degradation in the area.

The non-correlation between the third group of variables (related to socio-economic status and demographic characteristics) and both the first and second groups of variables suggests that farmers' knowledge of environmental management practices and their connections with the local community are independent of their socio-economic and demographic conditions. In other words, farmers can enhance their understanding of environmental management or improve their community connections regardless of their socio-economic status or demographic characteristics. This finding implies that efforts to build farmers' capacity in environmental management will not significantly impact their socio-economic and demographic conditions. While farmers may possess knowledge about sustainable agricultural practices, they may lack the socio-economic incentives or motivations to translate that knowledge into concrete actions that protect the environment. This may explain why farmers, despite having knowledge of sustainable practices, appear to be less sensitive to environmental degradation.

To address this gap between knowledge and action, it becomes imperative to introduce economic incentive schemes such as PES programmes. These programmes create an enabling business environment where farmers can be rewarded for their efforts in reducing environmental deterioration. By providing economic incentives, farmers are more likely to be motivated to adopt and implement sustainable agricultural practices that contribute to environmental protection. Integrating economic incentives with farmers' existing knowledge of sustainable practices, we can bridge the gap between awareness and action, ensuring that farmers are actively engaged in protecting the environment. This approach recognizes the need to align environmental goals with socio-economic conditions and provides a practical mechanism for incentivizing sustainable practices among farmers.

Overall, combining knowledge-building initiatives with economic incentive schemes can effectively encourage farmers to apply their knowledge and contribute to environmental conservation while considering their socio-economic and demographic realities.

4.3. Determinants of the WTA for the provision of environmental services

Geweke diagnostics are commonly used to assess the convergence of parameters drawn from the posterior distribution in Bayesian analysis. The fact that Geweke diagnostics (Table 4) indicate no evidence to reject the convergence suggests that the estimation process has been successful and the sample of parameters obtained from the posterior distribution (9) is representative. By using this sample of parameters, statistical inferences can be made about the effects of farmers' socio-economic, environmental, and demographic values on their WTA for environmental services.

The probabilities $Pr(\theta_i \leq 0)$ provide a basis for determining the likely direction of influence of each variable on WTA. The influence is likely negative if $Pr(\theta_i <= 0) \geq 0.5$, whereas it is positive if $Pr(\theta_i <= 0) < 0.5$. Based on the given information, it appears that variables such as the sex of farmers (GEND), origin of farmers (ORIGIN), location of farms (LOFARM), output of current practices (OUTCPRA), awareness of PES scheme (AWPES), and knowledge of bio-fertilizers (BIOFERT) have a positive influence on WTA. This means that these factors are likely to increase farmers' WTA for environmental services.

On the other hand, variables such as the age of farmers (AGE), education level of farmers (EDU), size of farm households (FHSIZE), size of the farm (FASIZE), yearly on-farm income (ONFINC), and importance of non-timber forest products (NTFPs) are likely to have a negative effect on WTA. This suggests that these variables are expected to decrease farmers' WTA for environmental services.

These findings provide valuable insights into the factors that shape farmers' preferences and willingness to accept compensation for environmental services. Understanding these determinants can inform policy and decision-making processes related to the design and implementation of effective incentive schemes, such as payment for environmental services, to promote sustainable agricultural practices and environmental conservation.

The negative effect of farmers' age (AGE) on their WTA participation in an afforestation programme can

Table 4. Bayesian Parameter Estimates.

Parameters (θ_i)	Estimates	Std. Dev.	Equal-Tail Interval		$Pr(\theta_i \leq 0)$	Geweke Diagnostics	
			Lower	Upper		z	$Pr \geq \|z\|$
Intercept	12060.4	1843.8	8529.4	15674.5	0	-1,237	0.216
AGE (age of farmer)	-79.680	36.286	-151.5	-9.6776	0.987	0.171	0.865
GEND (sex of farmer)	1276.7	732.4	-172.5	2691.3	0.043	1,422	0.155
EDU (education level of farmer)	-871.7	549.2	-1942.4	211.5	0.944	-0.101	0.920
ORIGIN (origin of farmer)	1546.9	967.3	-344.2	3469.9	0.054	0.880	0.379
FHSIZE (size of farm household)	-109.7	163.4	-436.2	206.4	0.748	-0.124	0.901
LOFARM (location of farm)	346.9	820.5	-1251.8	11973.7	0.336	-0.235	0.814
FASIZE (size of farm)	-255.3	772.2	-1749.9	1272.6	0.630	-1,505	0.133
ONFINC (yearly on-farm income)	-0.00013	0.000208	0.000281	0.000273	0.736	0.678	0.498
OUTCPRA (output of current practices)	444.7	675.8	-875.5	1770.6	0.254	-0.154	0.877
AWPES (awareness of PES scheme)	1751.6	782.2	218.3	3271.9	0.012	-0.852	0.394
BIOFERT (knowledge of bio-fertilizers)	2923.6	765.1	1416.1	4434.5	0.000	0.766	0.443
NTFPs (importance of non-timber forest products)	-538.0	746.3	-2025.3	912.9	0.763	0.236	0.814
Scale	4595.2	222.5	4182.7	5054.6	0	1,202	0.229

be explained by several factors. As individuals grow older, they tend to prioritize existential values over economic values. Existential values encompass fundamental questions regarding human existence, such as "To be or not to be?", as well as practical concerns related to protecting human life and avoiding threats to existence (Lipiec, 2000). This shift in focus towards existential values may lead older farmers to be less inclined to accept compensation in exchange for adopting eco-innovations that protect the environment and, consequently, human existence.

Additionally, the aging process often fosters a greater concern for the well-being of others, beyond one's own self-interest. As individuals age, they become more attuned to the collective and the welfare of the broader community. Older individuals may view the realization of environmental values as a means to establish the foundational basis for other values. Consequently, elderly farmers are less likely to be receptive to compensation offers aimed at incentivizing their adoption of agroforestry practices, especially when the central question revolves around human existence.

Overall, the negative relationship between age and WTA for participation in an afforestation programme can be attributed to the prioritization of existential values over economic values among older individuals. Aging prompts individuals to care not only for themselves but also for the collective well-being. Elderly farmers may view the pursuit of environmental values as crucial for establishing the existential foundation necessary to support other values. Consequently, they may be less inclined to accept compensation to adopt agroforestry practices, given the overarching importance they place on human existence.

The positive effect of farmers' origin (ORIGIN) on their WTA compensation to participate in an afforestation programme may seem counterintuitive at first. One would expect that native farmers, who have a stronger connection to the local area and a better understanding of the importance of protecting their natural heritage, would be more inclined to adopt agroforestry practices voluntarily, without requiring compensation. However, to interpret this unexpected result, we need to consider the relationship between farmers' origin and the location of their farms.

As illustrated in Figure 2 and Table 4, native farmers tend to have farms located outside the reserve. It is important to note that farmers with farms outside the reserve are more likely to demand higher compensation to participate in an afforestation programme. This can be attributed to the fact that farms located outside the reserve generally have fewer trees compared to those within the reserve. Consequently, the opportunity cost of adopting agroforestry practices on farms outside the reserve is likely to be higher than on farms within the reserve. Native farmers, therefore, may be requesting compensation to offset the higher opportunity cost associated with implementing agroforestry on their farms.

Additionally, the observed behavior of native farmers could be influenced by their lower level of education and their limited valuation of NTFPs, as indicated in Figure 2. Farmers with lower levels of education or those who do not recognize the importance of NTFPs are more likely to demand higher compensation to adopt agroforestry practices, as demonstrated in Table 4. This finding aligns with the well-established understanding that higher educational attainment promotes pro-environmental behavior (Tianyu and Meng, 2020; Zhou et al., 2021).

In summary, the positive effect of farmers' origin on their WTA for participation in an afforestation programme can be explained by several factors. Native farmers, despite their stronger connection to the local area, may request compensation due to the higher opportunity cost associated with adopting agroforestry on farms located outside the reserve. Furthermore, their lower level of education and limited recognition of the importance of NTFPs may contribute to their demand for higher compensation. These findings emphasize the complex interplay between farmers' origin, farm location, education, and value orientations in shaping their willingness to accept compensation for agroforestry adoption.

The variables representing farmers' socio-economic status, namely the size of farm households (FHSIZE), size of the farm (FASIZE), and yearly on-farm income (ONFINC), are found to have a negative effect on farmers' WTA compensation for participating in an afforestation programme, as indicated in Table 4. This implies that higher socio-economic status is associated with a greater propensity for pro-environmental behavior. Two theoretical perspectives in the literature can help explain this important finding.

The first perspective revolves around the concept of post-materialism, which suggests that individuals with higher socio-economic status are more likely to adopt values that prioritize self-expression, subjective well-being, and quality of life. As highlighted by Pampel (2014), post-materialist values are associated with concerns for issues such as environmentalism, feminism, and equality. In our context, the size of farm households, which serves as an indicator of farmers' social status, can be seen as reflecting their adherence to post-materialist values. Farmers who value self-expression and quality of life are more inclined to prioritize environmental protection and are thus more willing to participate in afforestation programmes.

The second perspective is based on the notion of affluence, suggesting that environmental quality is considered an amenity that high-income individuals can more readily afford (Franzen and Meyer, 2010). In this view, the size of the farm and yearly on-farm income, as indicators of prosperity, can positively influence farmers' inclination to protect the environment, particularly when the associated economic costs are perceived as insignificant. Higher-income farmers may be more willing to invest in environmental conservation measures because they have the financial means to do so without compromising their livelihoods. This affluence argument aligns with the observation that higher socio-economic status promotes pro-environmental attitudes and behaviors.

Both theories, post-materialism and affluence, can be applied in our context to explain why farmers with higher socio-economic status exhibit a greater willingness for participating in afforestation programmes. The size of farm households reflects post-materialist values related to self-expression, while the size of the farm and yearly on-farm income capture the affluence aspect, indicating that farmers with greater financial resources are more likely to prioritize environmental protection when the associated costs are perceived as manageable.

Overall, these findings highlight the role of socio-economic status in shaping farmers' pro-environmental behavior and suggest that individuals with higher socio-economic status are more inclined to support environmental initiatives.

The variables representing farmers' knowledge of environmental management, namely the awareness of PES scheme (AWPES) and knowledge of bio-fertilizers (BIOFERT), are found to have a positive influence on farmers' WTA compensation for participating in an afforestation programme, as shown in Table 4. This indicates that having greater knowledge about environmental management does not necessarily translate into eco-friendly behavior among farmers. There seems to be a significant gap between farmers' knowledge of environmental risk management and their actual on-the-ground actions in dealing with environmental issues.

This disparity between knowledge and behavior highlights the need to understand the factors that contribute to the "knowledge-behavior gap" in the context of sustainability. Merely providing additional information to farmers is unlikely to lead to significant improvements in environmental conditions unless certain key factors are addressed. As emphasized by Knutti (2019), securing political will and implementing simple solutions that provide immediate and local co-benefits are crucial. It is not enough for farmers to possess knowledge; they also require support, incentives, and clear pathways for action.

While environmental management strategies exist, their implementation is often hindered by various factors, including attitudes towards environmental protection, short-term and medium-term implementation costs, and doubts about the effectiveness and efficiency of proposed policy instruments. Farmers who have a positive attitude towards environmental management may perceive compensation for participating in an afforestation programme as a means to bridge the gap between their knowledge and their behavior in the context of sustainability. Offering financial incentives can serve as a motivating factor for farmers to align their behavior with their environmental knowledge.

Overall, the presence of a "knowledge-behavior gap" among farmers indicates that simply increasing their knowledge of environmental management strategies is insufficient to drive eco-friendly behavior. Addressing this gap requires a comprehensive approach that goes beyond information provision and tackles other barriers such as attitudes, costs, and doubts about the effectiveness of policy instruments. Offering compensation as a reward for participating in environmental programmes can incentivize farmers and help bridge the gap between their knowledge and their actions in a sustainability context.

4.4. The opportunity cost of environmental services

Bayesian estimation provides us with a sample of parameters $\{\theta_k = (\beta_k, \sigma_k)\}_{k=1 \dots m}$ from the full conditional distribution (9), where θ_k represents the parameters of farmer preferences. Using this sample, we can derive a distribution of the mean WTA using equation (7) for a representative farmer.[1]

The resulting distribution of the mean WTA, as depicted in Figure 3, exhibits a normal shape. To formally test the normality of the distribution, we use the Anderson-Darling statistic, which confirms that the mean WTA follows a normal distribution with a mean of 10,775CFA franc and a standard deviation of 333.6CFA franc, as shown in Table 5.

To estimate the mean WTA using a Bayesian approach, we apply formula (10). The Bayesian estimate of the mean WTA is calculated to be 10,775CFA franc, with a 95% confidence interval of 10,769-10,781CFA franc, as presented in Table 5. The narrow confidence

[1] The characteristics of the representative farmer are obtained by taking the mean of each explanatory variable.

interval indicates that the estimate of the mean WTA has low volatility or high precision, suggesting a more reliable estimate.

Overall, the Bayesian estimation allows us to obtain a distribution of the mean WTA, which is found to follow a normal distribution. The Bayesian estimate of the mean WTA, along with its confidence interval, provides a precise estimation of the mean WTA value, contributing to a better understanding of farmers' preferences in the context of willingness to accept compensation for participating in an afforestation programme.

Based on the survey design outlined in Section 3.2, we can deduce that the probability for a farmer in the Barombi Mbo community to accept compensation and participate in an afforestation programme is $P = 175/200$. To estimate the total willingness to accept (WTA) or the community opportunity cost to participate in the afforestation programme using a Bayesian approach, we can use the following formula:

$$E(Total\ WTA/Y) \approx N \times P \times \frac{1}{m} \sum_{k=1}^{m} Mean\_WTA_k, \quad (11)$$

where $Y = \{WTA_i, X_i\}_{i=1,\ldots,n}$ represents the observed data, $N = 349$ denotes the size of the eligible population in Barombi Mbo, and $\{Mean\text{–}WTA_k\}_k^m$ represents the sample of the mean WTA obtained from the Bayesian estimation. In this formula, m represents the number of samples drawn from the Bayesian estimation. As m approaches infinity, the estimate becomes more accurate.

By multiplying the probability P with the population size N and the average of the sample mean WTA values, we can estimate the total WTA or the community opportunity cost to participate in the afforestation programme. It is important to note that this estimation assumes that the sample of farmers in the survey is representative of the entire eligible population in Barombi Mbo.

The results reported in Table 5 indicate that the Bayesian estimate of the total WTA or the community opportunity cost to participate in the afforestation programme is 3,290,448CFA franc with a 95% confidence interval of 3,288,511-3,292,385CFA franc. The small confidence interval suggests that the estimate of the total WTA exhibits low volatility or high precision.

We can also derive a sample of the distribution of the community opportunity cost of providing environmental services from the sample distribution of the mean WTA using the relationship $Total\ WTA = N \times P \times Mean\ WTA$. Furthermore, a test of normality using the Anderson-Darling statistic confirms that the community opportunity cost of providing environmental services follows a normal distribution with a mean of 3,290,448CFA franc and a standard deviation of 98,818CFA franc.

Comparing these results with those obtained by Moukam (2021) using a Maximum Likelihood method to estimate the Tobit model, it can be observed that the estimated values of the mean and total WTA obtained from the Bayesian approach are almost three times higher. Specifically, the Bayesian estimate of the mean WTA is 10,775CFA franc, whereas the estimate obtained using the Maximum Likelihood method is 4,488CFA franc. Similarly, the Bayesian estimate of the total WTA is 3,290,448CFA franc, while the Maximum Likelihood estimate is 1,370,491CFA franc. This difference highlights the potential of the Bayesian approach to account for both tangible and intangible values of ecosystem services.

Overall, the results suggest that the Bayesian approach provides a more comprehensive and precise estimation of the WTA and community opportunity cost, incorporating both economic and noneconomic factors associated with environmental services.

In Bayesian analysis, sensitivity analysis is usually recommended to assess the impact of prior assumptions on the final inference using non-informative priors as the counterfactual. However, in our case, since our results are primarily based on non-informative priors, conducting a sensitivity analysis is not feasible. Consequently, our results can be interpreted as a quantification of the uncertainty in the parameters of interest based solely on the observed data.

Table 5. Opportunity Cost of Supplying Environmental Services (Fcfa).

Parameter	Estimate	Std. Dev.	95% Confidence Limits		Anderson-Darling	
			Lower	Upper	Stat.	P. Value
Mean WTA	10,775	323.59	10,769	10,781	0.587	0.131
T otal WTA	3,290,448	98,818	3,288,511	3,292,385	0.587	0.131

Note. Aderson-Darling is a Goodness-of-Fit Test for Normal Distribution.

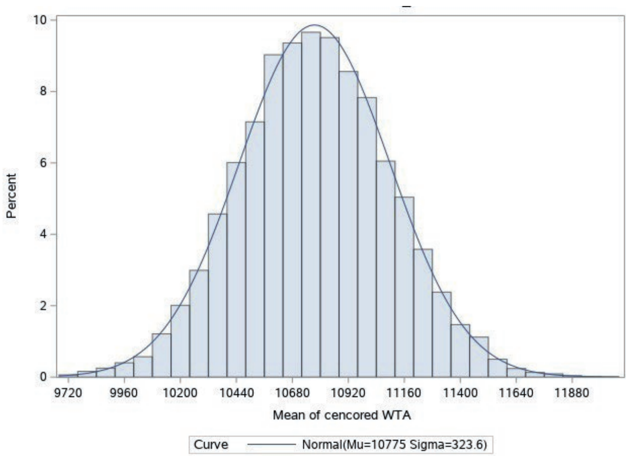

Figure 3. Distribution of *Mean WTA*.

5. CONCLUSION AND IMPLICATIONS

In this paper, we incorporate non-data information and expert knowledge into the estimation of farmers' opportunity cost for providing environmental services through agroforestry and forest regeneration in the rural area of Cameroon. To achieve this, we begin by conducting a survey to gather information on farmers' WTA and factors that may influence their preferences to participate in an environmental protection programme in Barombi Mbo, a rural region in Cameroon. Subsequently, we adjust a Tobit model of the WTA by incorporating expert knowledge through the specification of prior distributions for model parameters. Finally, a Bayesian approach is employed to estimate both the model parameters and the farmers' opportunity cost of supplying environmental services, accounting for both data and non-data information.

The paper contributes to the important economic literature on the valuation of environmental goods and services using a SP approach. Specifically, we propose a two-step survey design to determine a limited number of bids that farmers can choose from, which allows them to highlight their preferences and their WTA for changes in environmental services. Additionally, we conduct a multidimensional preference analysis to identify the primary dimensions of farmer preferences that may explain their willingness to participate in environmental conservation programmes. Furthermore, we expand the well-known Tobit model of WTA by incorporating non-data information or expert knowledge through the specification of parameter distributions. To estimate a comprehensive probabilistic model of WTA for changes in environmental services, we employ a Bayesian approach. Compared to the related literature (Moukam, 2021; Pérez-Sánchez et al., 2021), our approach to WTA modeling has the potential to significantly reduce potential hypothetical bias in data collection and analysis.[2] This reduction in hypothetical bias is achieved through an improved estimate of farmers' opportunity cost of supplying environmental services, resulting in more realistic and interpretable results. Our results align with the findings of previous authors Kadane and Lazar (2004); Gelman et al. (2013); Kruschke (2013) who have demonstrated that Bayesian methods provide more accurate estimates, better model comparison, and improved inferences compared to traditional frequentist methods. However, it is worth noting that conducting a Bayesian analysis requires a careful specification of prior distributions that incorporate our expert knowledge. As more data are collected, the influence of the prior distribution decreases, and the posterior distribution becomes increasingly influenced by the likelihood function (Chan et al., 2019).

An important result of this paper is that the majority of farmers (87.5%) are unlikely to voluntarily engage in environmental management without economic incentives. Our multidimensional preference analysis suggests that farmers' behavior may be attributed to the lack of correlation between environmental and socio-economic dimensions of their preferences. Therefore, it is crucial to implement economic incentive mechanisms, such as PES, to facilitate the alignment of environmental and socio-economic values. The Bayesian analysis reveals that aging is likely to promote pro-environmental behavior, indicating that older individuals are more sensitive to existential values compared to the youth (Lipiec, 2000). Additionally, natives are more inclined to accept compensation for adopting sustainable agricultural practices compared to migrants. This controversial finding can be partly explained by the observation that natives generally have lower educational attainment than migrants. This aligns with the widely accepted understanding that higher levels of education promote pro-environmental behavior (Tianyu and Meng, 2020; Zhou et al., 2021).

A significant finding of this paper is that higher socio-economic status, as indicated by factors such as the size of farm households, farm size, and yearly on-farm income, positively influences proenvironmental behavior. This observation can be explained by the affluence argument (Franzen and Meyer, 2010), which suggests that high-income farmers are more capable of affording environmental quality as an amenity good. Moreover, farmers with higher socio-economic status are more likely to have embraced postmaterialist values, which prioritize self-expression, subjective well-being,

[2] Hypothetical bias arises from the tendency of people to systematically overor understate their WTA in SP studies.

and quality of life, leading to increased concerns for environmental issues (Pampel, 2014). Furthermore, our analysis reveals that an increase in knowledge of environmental management strategies is less likely to promote eco-friendly behavior. This finding aligns with the research by Knutti (2019), who identified several barriers contributing to the observed knowledge-behavior gap. These barriers include attitudes towards environmental protection, implementation costs in the short and medium term, and skepticism regarding the effectiveness of proposed policy instruments.

Another important finding of this paper is that farmers' WTA follows a normal distribution with a mean of 10,775CFA franc and a standard deviation of 333.6CFA franc. Additionally, the community opportunity cost of supplying environmental services also exhibits a normal distribution, with a mean of 3,290,488CFA franc and a standard deviation of 98,818CFA franc. These distributions have significant implications for policy-making, as they enable us to make probabilistic statements about the value of environmental services. For instance, considering the significance of WTA in cost-benefit analysis (CBA), our results provide an effective means to incorporate uncertainty when assessing the welfare effects of regulatory and investment interventions that impact the environment. This allows expected outcomes in CBA, such as financial and economic net present values (NPVs), to incorporate risk and uncertainty associated with environmental management. Furthermore, our estimation of the distribution of WTA plays a crucial role in understanding the intricate financial trade-off involved in the Cameroonian government's engagement in international financial mechanisms for biodiversity conservation and climate change mitigation.

This paper presents a significant empirical framework for estimating the value of environmental services and evaluating the influence of socio-economic and demographic factors on that value. Considering that farmers in developing countries often exhibit comparable socio-economic and

demographic characteristics, along with similar concerns regarding environmental degradation, our estimation of the WTA distribution can serve as valuable prior knowledge or information regarding the value of environmental services in other rural areas of Cameroon or the developing world.

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A. APPENDIX

Figures. 4 and 5 show the draws, the autocorrelation of draws, and the empirical posterior distribution of two parameters: the Intercept and the Biofertilizer (BIOFERT) from the implementation of the Adaptative Rejection Metropolis Sampling (ARMS) algorithm based on a programme provided by Gilks (2003) using the procedure LIFEREG of the Statistical Analysis Software (SAS). We can see that the draws are randomly distributed and exhibit low correlation. This is an indication that the Bayesian estimation has converged for these two parameters. A similar result is obtained for other parameters.

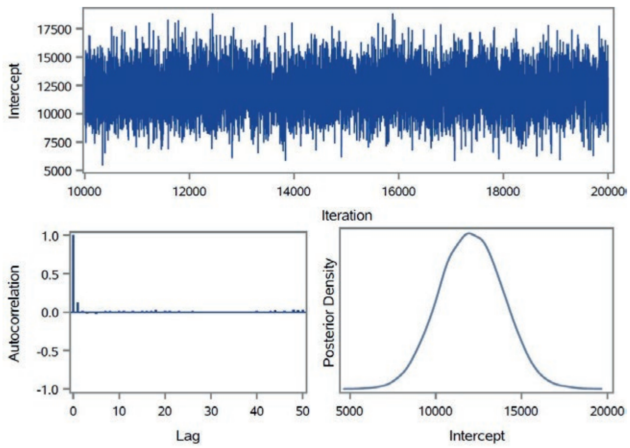

Figure 4. Bayesian diagnostics for Intercept.

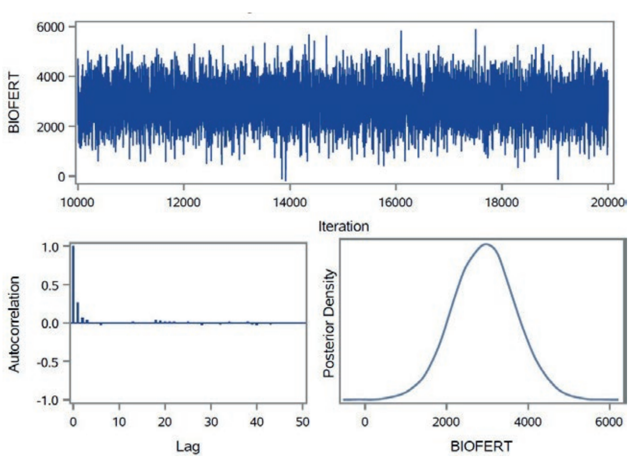

Figure 5. Bayesian diagnostics for Biofertilizer.

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Farmers' acceptance of a micro-irrigation system: A focus group study

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Abstract. Despite water scarcity and the numerous benefits offered by micro-irrigation systems, the implementation of these systems on potato crops in the Bekaa Valley of Lebanon is notably low. This could be related to the local farmers' acceptance to use this technique. The objective of this study is to investigate the factors that may or may not affect the adoption and investment in a new micro-irrigation system. For this purpose, the unified theory of acceptance and use of technology (UTAUT) served as the conceptual framework. A qualitative approach using focus group discussion was applied. A total of six focus groups with 34 farmers were conducted in the three main districts of the Bekaa Valley. From the analysis, performance expectancy, effort expectancy and facilitating conditions emerged as the three most prominent factors which influenced the farmers' acceptance and adoption of micro-irrigation systems. According to the results of the focus groups, potato farmers are willing to adopt a new micro-irrigation system if they are assured that it will result in gains and reduce the amount of time and effort required for farming Barriers included lack of knowledge about the system, financial capabilities and extension services. Participants were enthusiastic about the idea of adopting a micro-irrigation system, but hindered by the unstable socio-economic conditions in Lebanon and the financial situation. It was concluded that age, experience and voluntariness of use exert an effect on the related major determinants. This study will provide recommendations that can be considered while drafting agricultural policies.

Keywords: UTAUT model, Focus group, climate change, Micro-irrigation, Technology acceptance.
JEL codes: Q01, Q2, Q3.

1. INTRODUCTION

Climate change is having a huge detrimental impact on freshwater availability on a worldwide scale, affecting water resources quantitatively and qualitatively (Field & Barros, 2014). Water scarcity is one of the most dangerous threats which has already resulted in catastrophic losses, notably in the arid regions. High temperatures, increased evaporation and fluctuations in precipitation are altering water availability and reducing crop yields (Arbuckle et al., 2013; Niles & Mueller, 2016). These factors affect the management of farms, especially in arid and semi-arid regions (Scoville-Simonds et al., 2020). Moreover, climate change is endangering the agricultural sector presenting risks for developed and developing countries (Field & Barros, 2014; Niles & Mueller, 2016).

Lebanon is a small mountainous country on the Mediterranean Sea's eastern coast, covering a total area of 10,452 Km^2. From a climatic point, Lebanon is characterised by a Mediterranean climate with a cold rainy winter and a semi-hot dry summer. According to the Lebanese Ministry of Agriculture (MoA), Lebanon experiences water shortages during the dry season which goes from July through October, with about 60 percent of the country's territory undermined by desertification (MoA, 2003). This condition is expected to worsen in the future as a result of the effects of climate change. (Bank, 2014). According to the Lebanese Agricultural Research Institute (LARI), water scarcity more than land resources is actually the constraining factor in the country's expansion of agricultural production (LARI, 2019). In Lebanon, groundwater sources are increasingly stressed by climate change as well by the increased demand from agriculture, the inadequate utilisation of underground water, the population growth and the industrial development (UNDP & UNHCR, 2021). Further, recent results (Halwani & Halwani, 2022) showed that from 1930 to 2019, the average temperature in Lebanon increased between 1 to 3 °C and a recent report from USAID (USAID, 2018) expects a 4–11% decrease in precipitation by 2100. Thus, various conditions threatening water balance make adaptation to climate change more difficult in Lebanon. In this situation, the enhancement of irrigation water usage efficiency and the conservation of water resources are turning into strategic priorities. For this to happen, adequate institutional arrangements are required to complement technical interventions in order to achieve effective water usage (Speelman & Veettil, 2013).

According to the Lebanese Ministry of Economy (MoE) and the UNDP, the Bekaa valley of Lebanon, which represents 42% of Lebanon's area, is a very fertile valley in which 60% of Lebanon's agricultural production is concentrated including cereals, potatoes, vegetables and grapevine (MoE & UNDP, 2011; MoE et al., 2015). The production of potatoes typically ranks first among the top 10 commodities produced in Lebanon each year, with a total production of 390,000 tonnes in 2017 (FAOSTAT, 2017). Two-thirds of Lebanon's potato production comes from the Bekaa Plain, which is entirely irrigated (MoA & LARI, 2008). The Bekaa valley is divided into three main zones: North Bekaa, Central Bekaa and West Bekaa. The valley is confronting the consequences of drought and reduced water availability that menace the yield and quality of irrigated crops (Karam & Karaa, 2000; MoE et al., 2015; Jaafar et al., 2016) . This is the case of potato crops which is one of the most sensitive crops to soil moisture stress and requires a systematic irrigation schedule (Ayas, 2013).

Since potato crops are sensitive to water stress, water use efficiency such as water-saving technologies are becoming of high importance. Until now, in the Bekaa region, the high majority of potato farmers are still using the ordinary sprinkler irrigation (MoA & LARI, 2008). Micro-irrigation, particularly mini-sprinklers, could be a solution to the above-mentioned climate-change related problems (Houston et al., 2018). Mini-sprinklers are small sized static sprinklers with a flow varying between 150 and 300 L per hour and a pressure of 1.5 bars inducing a water cooling canopy (Deligios et al., 2019). Micro-irrigation can induce an even application of water resulting in an improved crop quality and yields, in water savings and which also leads to energy and fertilizer savings compared with other irrigation methods (Varma & Namara, 2006; Shah, 2011). Further, micro-irrigation systems allow for a high level of control of chemical applications and weed and disease reduction due to limited wetted area. Previous research executed in the Middle East and North Africa (MENA) region, in Lebanon and beyond indicated that the use of micro-irrigation in potato cultivation could have promoting results in terms of water savings of up to 40% (Darwish et al., 2003; Darwish et al., 2006), and allow for energy savings associated with higher crop quality and yields (Karam & Karaa, 2000; Varma & Namara, 2006; Shah, 2011; Rouzaneh et al., 2021). In this context, it should also be noted that the improvement of the diffusion of innovations such as water saving techniques is a crucial strategy for promoting economic development (Lopolito et al., 2022).

Given the lack of information available on the performances of innovative technologies, farmers may evaluate these new systems through their experience and knowledge. This study aims to analyse the indirect non observed factors such as farmers' motivations, attitudes and socioeconomic factors which may influence the farmers' perceptions and behaviours in their investment in and adoption of a new micro-irrigation system. By disentangling these factors, effective strategies, and support systems for promoting the use of micro-irrigation systems in the area could be designed. To this end, the Unified Theory of Acceptance and Use of Technology (UTAUT) model (Venkatesh et al., 2003) was adopted. The UTAUT model (Venkatesh et al., 2003) is a tool that was mainly used to analyse the acceptance and diffusion of information systems and technology by evaluating the influencing factors. Nowadays, the UTAUT model is commonly used to study individual intention and behaviour to adopt any type of technology (Rippo & Cerroni, 2023). Previous studies utilised the UTAUT model to investigate factors affecting the adoption of pressurised irrigation technology among olive farmer (Nejadrezaei et al., 2018), the acceptance of e-agriculture (Eweoya et al., 2021), farmers' use of communication technologies (Mahamood et al., 2016), the acceptance of water saving technologies (Sabbagh & Gutierrez, 2022) as well as farmers' participation in the apple-Income Stabilisation Tool (IST) (Rippo & Cerroni, 2023).The UTAUT model integrates behavioural factors such as system ease of use, experience, and facilitating conditions , which give valuable insights into individuals' decisions to innovate. Understanding the impact of behavioural variables in innovation adoption could increase the efficacy and success of policies such as agricultural ones (Cerroni, 2020; Streletskaya et al., 2020). This is what makes UTAUT useful to analyse the adoption of other types of technologies other than information systems and technology.

A qualitative study that utilised a focus group discussion (FGD) approach was employed. In this study, FGD could be an appropriate tool because it can allow for drawing upon the respondent's knowledge, views, and experiences about the specific topic of introducing micro-irrigation systems. To the best of our knowledge, this is the first study to use the UTAUT model combined with a Focus Group Discussion approach to shed light on the impact and importance of socio-economic, psychological and behavioural factors in influencing the adoption and use of a micro-irrigation system. Several researchers found that these three factors work simultaneously to understand and obtain a more complete vision of the intention to adopt a new investment (Heller et al., 1988; Konana & Balasubramanian, 2005). To this end, the scope of this paper is to enlarge the literature on technology investment analysing the impacts of socio-economic, psychological and behavioural factors that may affect the intention to adopt and invest in a micro-irrigation system by the potato farmers in the Bekaa Valley of Lebanon.

The remainder of this paper is organised as follows. Section two briefly analyses the UTAUT model. Section three explains the methodological approach employed in this study to explore the acceptance of a new micro-irrigation system. Section four presents the results of focus groups conducted with potato farmers in three main districts of the Bekaa valley. Section five discusses the main findings providing insights about policies that the government could implement to encourage potato farmers to adopt a micro-irrigation system. In section 6, the main conclusions are presented.

2. RESEARCH BEHAVIOURAL MODEL AND RESEARCH QUESTIONS

A number of theories have been put forward to explain an individual's behavioural intention to introduce a new technology. The current study employed the Unified Theory of Acceptance and Use of Technology (UTAUT) (Venkatesh et al., 2003) as a technology adoption model, which integrated previous technology acceptance models. Thus, UTAUT is basically a synthesis through unifying at least eight existing technology acceptance and use models and specifically i) the Theory of Reasoned Action (TRA) (Fishbein & Ajzen, 1975); ii) the Theory of Planned Behaviour (TPB) (Ajzen, 1985); iii) the Technology Acceptance Model (TAM) (Venkatesh & Davis, 2000); iv) the Combined TAM and TPB (C-TAM-TPB) (S. Taylor & P. A. Todd, 1995); v) the Innovation Diffusion Theory (IDT) (Moore & Benbasat, 1991); vi) the Motivation Model (MM) (Davis et al., 1992); vii) the Social Cognitive Theory (SCT) (Bandura, 1994; Compeau & Higgins, 1995; Compeau et al., 1999) and finally viii) the Model of PC Utilization (MPCU) (Thompson et al., 1991). According to UTAUT, an individual's views on technology impact his or her behavioural intent to use and actual use of the technology. Based on the integration of the eight models, UTAUT suggests four major determinants that have an effect on a person's "use behaviour" to adopt a technology: performance expectancy (PE), effort expectancy (EE), social influence (SI), and facilitating conditions (FC). The first three constructs influence use behaviour through a behavioural intention variable, while the fourth construct directly impacts the use behaviour. These constructs can be affected by four moderators a) age, b) gender, c) experience with similar technology, and d) voluntariness of use. Fig. 1 presents the model.

The Performance Expectancy (PE) represents the user's level of belief in how advantageous a system usage will be and how it will help to attain benefits (Venkatesh et al., 2003). PE aggregated all job performance related aspects, like usefulness (adapted from TAM/TAM2 and C-TAM-TBP) (S. Taylor & P. Todd, 1995; Venkatesh & Davis, 2000), job fit (from MPCU) (Thompson et al., 1991), relative advantage (from IDT) (Moore & Benbasat, 1991), extrinsic motivation (from

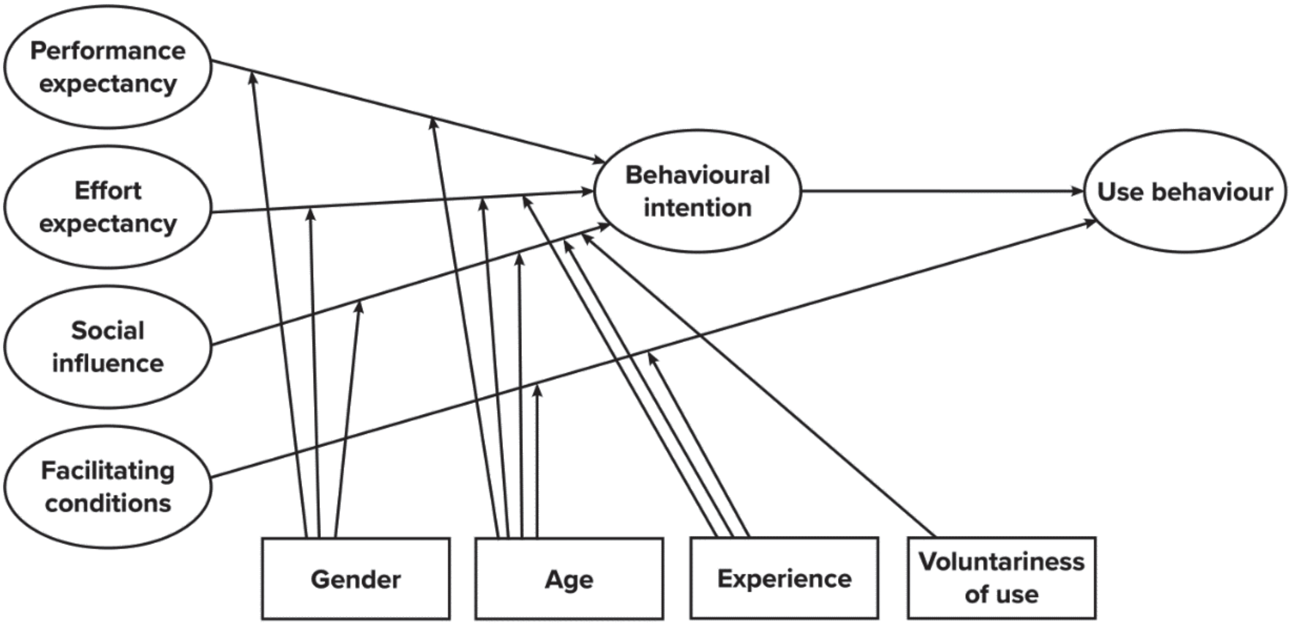

Figure 1. Unified theory of acceptance and use of technology model (UTAUT) (Venkatesh et al., 2003); Adapted with permission from Viswanath Venkatesh, *MIS Quarterly*, 2003. The figure employs terminology, with ovals identifying latent variables and rectangles identifying moderator variables.

MM) (Davis et al., 1992) and outcome expectations which are related to the consequences of the behaviour (from SCT) (Bandura, 1994; Compeau & Higgins, 1995; Compeau et al., 1999). Based on previous findings, PE will significantly and positively influence behavioural intention and technology acceptance (Venkatesh et al., 2003; AbuShanab & Pearson, 2007). People with high PE had high intentions to use a new technology (AbuShanab & Pearson, 2007). Additionally, the influence of performance expectancy on behavioural intention is suggested to be impacted by the moderating effects of gender and age (Venkatesh et al., 2003).

The Effort Expectancy (EE) construct suggests that the level of ease of use affiliated with the user's adoption of a system is an important component in the adoption of a new technology (Venkatesh et al., 2003). In this case, it is composed of three constructs: perceived ease of use (TAM/TAM2) (Venkatesh & Davis, 2000), complexity (MPCU) (Thompson et al., 1991) and ease of use (IDT) (Moore & Benbasat, 1991). Previous research concluded that EE is a positive predictor of behavioural intention so that the higher the perceived ease of use of a new technology, the higher the intention to adopt it (Venkatesh et al., 2003; Bandyopadhyay & Fraccastoro, 2007; Kallaya et al., 2009; Nassuora, 2012). According to Venkatesh et al.(2003), the influence of effort expectancy on behavioural intentions is moderated by gender, age, and experience.

The social influence determinant (SI) refers to the magnitude to which individuals perceive they should adopt a technology based on inputs from people who carry significant positions in their life (Venkatesh et al., 2003). It also consists of "the degree to which peers influence use of the system" (Venkatesh et al., 2003; Slade et al., 2015; Šumak & Šorgo, 2016). Social influence (SI) consists of three variables: a) subjective norms which relate to the person's perception that people who are important to her or him think that they should or should not execute the particular behaviour (Ajzen, 1991; Davis, 1989; Fishbein & Ajzen, 1975; S. Taylor & P. Todd, 1995), b) social factors which connect to the interpersonal arrangements that the individual has made with others as with co-workers (Thompson et al., 1991) and c) image which is the extent to which the use of a new technology is seen to enhance one's image or status in one's social system (Moore & Benbasat, 1991). Based on the review of the literature, it is expected that social influence positively influences the behavioural intention to use a new technology (Bandyopadhyay & Venkatesh et al., 2003; Fraccastoro, 2007; Kallaya et al., 2009; Im et al., 2011; Slade et al., 2015; Šumak & Šorgo, 2016). In addition, Venkatesh et al. (2003) hypothesised that the influence of social influences on behavioural intentions is moderated by gender, age, voluntariness and experience.

Facilitating conditions (FC) represent the organisational and technical conditions or infrastructure that the individual believes would encourage the use of the system and make it simpler for him or her to use it (Venkatesh et al., 2003). The facilitating conditions determinant consists of three distinct constructs: a) perceived behavioural control (Ajzen, 1991; S. Taylor & P. Todd, 1995), which are the possible internal and external limitations on behaviour related to resources, b) facilitating conditions adapted from (Thompson et al., 1991), which relate to objective factors that persons agree make an act easy to realise, and c) compatibility from (Moore & Benbasat, 1991) which indicates the extent to which a new technology is perceived as being consistent with the current needs and capabilities of potential adopters. Each one of these constructs is operationalised to incorporate technological and/or organisational aspects that are intended to eliminate obstacles to use. Facilitating conditions are found to positively influence use behaviour (de Veer et al., 2011). According to Venkatesh et al. (2003), the influence of facilitating conditions on usage is hypothesised to be moderated by age and experience.

As mentioned above, UTAUT hypothesised that gender, age, voluntariness and experience would moderate the relationships depicted in the model. These variables have been shown to moderate the intention to adopt new technologies in several studies (Pearson et al., 2002; Venkatesh et al., 2003; Al-Gahtani, 2004).

In order to expand the literature on technology investment, such as water saving systems, by analysing the impacts of behavioural, psychological and socioeconomic factors, this paper studied the reasons behind using the current irrigation technique on potato fields, farmers' perception of others' opinions as well as the barriers that could hinder adopting a new irrigation system and the policies that could be used to encourage potato farmers to invest in a micro-irrigation system.

3. MATERIALS AND METHODS

The objective of this study was to explore via focus group discussions how socioeconomic, behavioural and psychological factors influence the adoption of a micro-irrigation system as a mean to save water and avert the water scarcity crises among potato farmers in the Bekaa Valley of Lebanon. The focus groups discussed the socio-economic, psychological and behavioural aspects related to the possible shifting from the current irrigation technique (ordinary sprinkler) to micro-irrigation (drip or mini-sprinkler) that saves more water, induces higher production and better quality in the cultivation of potato crops.

3.1. The focus group protocol

The focus group research protocol was divided into three sections. The first section aimed to start the discussion by introducing the research theme and to collect information about gender, age, education, type of land management, farm size and the annual irrigation water used. Participants also received explanations of the role undertaken by the facilitator and that audio recordings would have only been used for the purpose of this study, thus reasserting the significance of privacy of all participants. It was explained that all participants were free to reveal their opinions related to the discussion and that all answers were to be accepted.

Section two aimed to provide information regarding the potato cultivation, the status of underground water in the Bekaa region as well as the differences between the sprinkler irrigation system and the micro- irrigation system thus highlighting the advantages that could be obtained by implementing a micro-irrigation system.

Section three contained open ended questions related to the UTAUT model that the moderator asked participants of the three main districts of the Bekaa Valley. To trigger the discussion around the behavioural elements of the UTAUT model, section three started by asking participants about their knowledge of the micro-irrigation system and the reasons behind using ordinary sprinklers. This allowed the moderator to explore the degree to which each farmer believed that using a micro-irrigation system would help him or her to attain gains, thus exploring the performance expectancy determinant. The moderator then asked about the farmers' perceptions of easiness of tasks related to the implementation and operation of the micro irrigation system and how they perceived the related technical operations. This permitted the moderator to explore the farmers' effort expectancy towards micro-irrigation systems. Further, participants were asked to list people whose judgment is important to them and who would approve or disapprove the adoption of a micro-irrigation system and the effect of personal moral obligation norms to adopt a micro-irrigation system for the sake of protecting the environment by preserving water resources. This revealed the social influence construct. To measure the facilitating conditions, the moderator explored the farmers' opinion of being able or not to access required resources, as well as to obtain training and the necessary support needed to use micro-irrigation systems. Following the UTAUT model variables, questions related to the moderating variables were raised in the focus groups. The moderator asked participants if they believed that the age of the farmers affect their incentive to adopt new irrigation practices. Experience was tested by the familiarity of the farmers with the functioning of the micro-irrigation system either by their own trial on their crops or by observing others using it on potatoes or on other crops. For the voluntariness of use, farmers were asked about their tendency to adopt a micro-irrigation system in the case of the presence of external obligations as well as in the case of subsidies offered by the government.

3.2. Sampling and data analysis

Fig. 2 shows the geographical area in which focus groups were carried out in the months of March and April 2020, among the potato farmers using the ordinary sprinkler irrigation system, in the three main districts of the Bekaa Valley (North, Central, and West Bekaa). The total number of potato growers in the area is approximately 500, and the sample of farmers participating the FG were selected using the information furnished by the President of the syndicate of potato growers in the Bekaa Valley. So, 35%, 20% and 45% of the farms are located in North Bekaa, Central Bekaa and West Bekaa, respectively. There was a total of 34 farmers in six focus groups consisting of five or six farmers each. Two focus groups in each of the three main districts of the Bekaa valley were run/organized/led to help ensure a variety of points of views amongst participants and to test their likeliness or unlikeliness to adopt a micro-irrigation system in their farms.

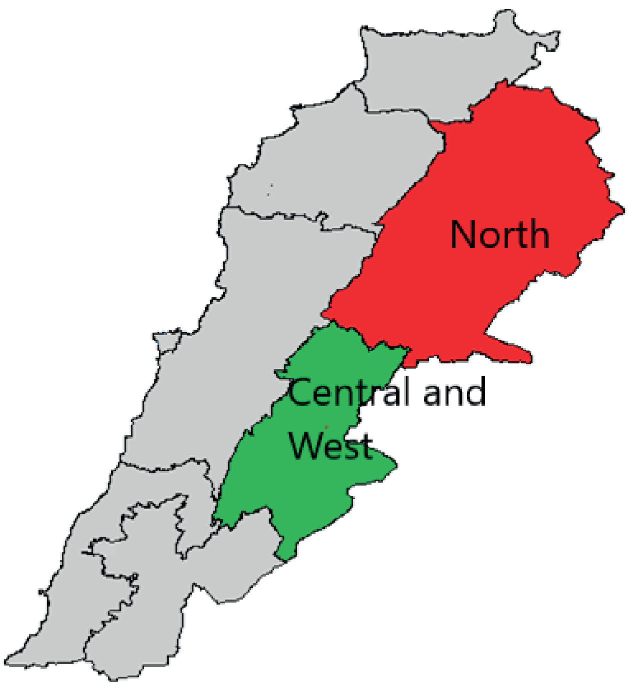

Figure 2. Map of Lebanon map showing the districts of the Bekaa Valley focus group discussions.

Due to COVID-19 restrictions and safety limitations, three focus group meetings were conducted via a virtual "Zoom" meeting platform among farmers having IT resources. After the restrictions were lifted the three remaining focus groups took place, in conference rooms where all required safety measures were taken.

Farmers taking part in the focus groups were engaged in choices regarding agricultural techniques, type of crops, and irrigation strategies to be implemented in their farms; interviewees were chosen from different ranges of age, different educational levels, having different types of land management, and different farm sizes. The proportion of males among the participants was 100% since there were no women running farms in the area given that potato cultivation fields are largely male owned while female participation is higher in the industrial sector (Konishi, 2017).

All focus groups were audio-recorded, manually transcribed, and qualitatively analysed using NVivo12 software.

4. RESULTS

4.1. Characteristics of participants

Table 1 presents the demographic characteristics. The focus groups were held among a total of 34 farmers of which 11 participants came from West Bekaa, 11 others from North of the Bekaa and 12 farmers were from Central Bekaa. In West Bekaa, the average age was 55 years ranging from 45 to 60 years old for most of the N farmers (N=11). In North and Central Bekaa most of the farmers had a mean age of 46 (N=11) and 52 (N=12) years, respectively. In the cited 3 regions, the percentage of farmers who were older than 60 years was more or less equal (36% for both West and North Bekaa while 33% in Central Bekaa). With regard to the educational level, the minority had a primary level (28%) in West Bekaa, while the majority had a university diploma (64%) in North Bekaa. However, in the region of Central Bekaa most of the participants had a secondary educational level (42%).

As also shown in Table 1, in each focus group there was a diversity in the size of the farms in order to gather the maximum points of views possible. In West Bekaa the average farm was 146 hectares (SD=208), whereas in North Bekaa, the mean farm size was 590 hectares (SD=1,55). In the region of Central Bekaa, it was 663 hectares (SD=1,55).

Table 1. The mean and standard deviation results regarding the demographic data of the sample.

Characteristics	West Bekaa (N=11)	North Bekaa (N=11)	Central Bekaa (N=12)
Mean (SD)			
Age (years)	55 (11)	46 (13)	52 (16)
Farm Size (hectares)	146 (208)	590 (1,555)	663 (1,556)
Age Ranges [N (%)]			
<= 45	2 (18%)	6 (55%)	6 (50%)
>45 and <60	5 (45%)	1 (9%)	2 (17%)
>= 60	4 (36%)	4 (36%)	4 (33%)
Educational Level [N (%)]			
Primary	3 (28%)	1 (9%)	3 (25%)
Secondary	4 (36%)	3 (27%)	5 (42%)
University	4 (36%)	7 (64%)	4 (33%)

Unfortunately, almost all of the participants were not aware of the quantity of the water used in the irrigation of their potato crops, which is an alarming problem.

4.2. Results of the focus groups

This section has the aim of presenting the findings from the six focus groups. After being transcribed from Arabic to English, text files were imported into Nvivo12 to first begin with the codings and finding core themes that reflect what participants were discussing to indicate the frequency of each core theme (Allsop et al., 2022). The results are categorised into the investigated determinants affecting the acceptance of the micro-irrigation system in potato farming and three key moderators. To further emphasise and distinguish statements analysis from quotes, all direct quotes given by the participants will be highlighted in italics in the following findings' part.

4.2.1. Major determinants

4.2.1.1. Performance expectancy

Performance expectancy was measured by the perceptions of using a micro-irrigation system in terms of providing benefits. Firstly, participants were asked about their knowledge of the micro-irrigation system and the reasons behind using the ordinary sprinklers. All the participants showed a basic technological knowledge of the micro-irrigation system stating that it incorporates drip irrigation and mini-sprinklers irrigation. Concerning the reasons for the adoption of the current irrigation system, which is the ordinary sprinklers, the most frequent answer was that sprinklers are less expensive (53%), and changing the ordinary sprinkler network that they have had for many years would cost them a fortune. One of the respondents said:

> I have been using sprinklers for a very long time and changing it and buying a micro irrigation network will be very expensive, especially for covering large areas.

Also, in the same context a second participant argued

> I still use sprinklers because I have had my equipment for a long time and in order to change it I will spend a lot of money because micro irrigation is a big investment, so I prefer to stay with sprinklers.

Furthermore, when participants were asked about their opinion about the following statement "adopting micro irrigation can be useful in your farm in terms of increasing potato yield, saving energy, labour, and quantities of pesticides and increasing your benefits", 56% of the respondents totally agreed. Some participants reported:

> Yes, I totally agree with this statement in the sense of that micro irrigation controls water, consumes less fuel, and there is more control of the use of fertilizers. When the quantity of the crop increases, revenues and profits will surely increase.
> The more we irrigate the plant with a small amount, only as much as it needs, and at regular times, the more abundant the production and the better the quality and therefore we use less labour and pesticides. So I agree with this statement.

On the other hand, 26% partially agreed with this statement arguing for example that

> *Micro irrigation definitely saves energy by saving water and because the water pressure is slight through it. It certainly increases the yield and increases profits, but I do not think it saves pesticides, as this amount remains the same as the sprinklers.*

However, one of the respondents asserted:

> Since micro-irrigation uses less pressure, this saves energy. Also, when using this irrigation technique, we don't need a large amount of pesticides, but the yield won't increase, it remains the same as in the case of sprinklers.

Finally, 18% of the participants fully disagreed with the statement, as other reported

In practice, micro irrigation cannot be used on potatoes and cannot be adopted. It does not increase yields, nor save energy, nor reduce the amount of pesticides and it could not increase profits

or

Micro irrigation does not increase the yield and does not save energy, nor does it reduce the amount of pesticides and fertilizers. Micro irrigation does not add anything to sprinkler irrigation".

The most relevant statements that underpin this construct are the ones that relate to the general benefits associated with micro-irrigation use. Therefore, participants were asked about their perceptions about the possible advantages deriving from the adoption of micro irrigation systems. Based on the content analysis, the most important benefit mentioned by the respondents was water saving. This pattern is evident from the word cloud in Fig. 3 which depicts the most frequently occurring words emerging from the focus group discussions.

In Fig. 3, central words with larger fonts are the most frequent, while distant words with smaller fonts are the less frequent. Thus, the most recurrent words (water, distribution, saving, control, etc.) are important advantages according to farmers. Participants highlighted that micro-irrigation is a water saving technique since it supplies water directly to the soil surface close to the plant roots, rather than the land around. In addition, they believe that micro-irrigation ensures uniform distribution of water by delivering water only wherever necessary and evenly over the whole land despite the presence of wind. Moreover, farmers consider that micro-irrigation enhances the financial benefits by increasing yield, productivity, and therefore, farm profits. They also believe that micro-irrigation is a way to reduce operational costs in terms of reducing energy (less energy for water supply/low pumping needs) and saving pesticides and fertilizers.

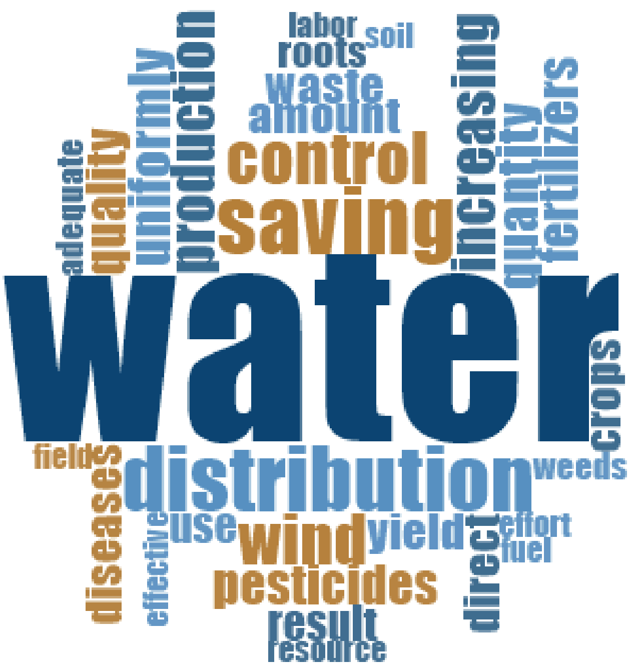

Figure 3. Word cloud of the perceived advantages of micro-irrigation.

Overall, it was revealed that farmers perceived micro-irrigation as a system having many key advantages in potato farming from saving water, labour, and pesticides to increasing profits. Therefore, we expect that "performance expectancy" will be positively associated with the intention of using micro-irrigation technology.

4.2.1.2. Effort expectancy

Regarding the participants' perception of the ease of use of a micro-irrigation system, and whether or not they would be skilled in using it, 62% of them considered micro-irrigation easy to be extended over fields. Half of the 62% said that it saves labour and effort because it is installed once at the beginning of the season and there is no need to worry about moving it. Moreover, the other half believed that micro-irrigation helps to save time. Hence, the farmer can gain more time to take care of other profitable agricultural operations. Accordingly, many participants claimed that

Micro irrigation is easier than sprinkler irrigation, and it is installed only once per season; therefore, the farmer will not worry about moving the network from one place to another as is the case with sprinklers. Thus, micro irrigation saves labour.

Micro irrigation does not require significant time and effort to extend and remove the network. It is easier than sprinklers, because the network is extended once at the beginning of the season and does not need to be moved from one part to another part of the land as in the case of sprinklers.

On the other hand, 38% of the participants perceived a high difficulty in extending the network of the micro-irrigation system on large fields and especially in the case of potato farming. They believed that, once extended, it decreases the efficacy of some agricultural operations.

To highlight this problem some respondents commented

> Micro irrigation is very difficult to install and needs a lot of time since the technical process to extend the network takes about a week and more. There is a difficulty in the tasks related to micro irrigation because we can't apply pesticides and carry out all the mechanical agricultural practices when it is installed.

Aside from that, they also argued that the installation of a micro-irrigation system needs a lot of attention and a specialised work force which induces a huge effort due to the complexity of the network equipment that should be implemented. Additionally, one-third of the respondents who perceived a difficulty in the use of micro-irrigation claimed that micro-irrigation is time consuming. Furthermore, another third considered micro-irrigation as labour consuming because the system needs constant attention in order to prevent damage to the hoses. Some participants said

> Micro irrigation initially requires a lot of effort in order to extend the network. Likewise, if the hoses become clogged and we want to replace them then there is great effort and difficulty during the season.
> When installing the micro irrigation system, it will no longer be possible to operate properly on the field as the presence of the hoses restrains us. The sprinklers are much easier than micro irrigation, so that, just in one day, we can install, remove, and transfer 100 sprays. Sprinklers require less labour because you only need one worker to do this, contrary to micro irrigation , which needs a lot of labour.

Furthermore, the effort expectancy construct is relevant to the question of whether participants believe they would/could become skilled at using micro-irrigation on potato crops. On one hand, 88% claimed that they would be skillful in using micro-irrigation. Approximately one third of respondents believed they would do their best to develop their knowledge in order to improve the yield, and possibly to increase their profits; they would get used on any new agricultural practices that give positive results. One-fifth of the 88% participants described micro-irrigation as an easy technique and not difficult to implement on potatoes. These responses can be summarised with the following comment

> Of course, it can be used in a successful way on potato and personally I will use it in a great way since it's not difficult to manage.

Moreover, another fifth thought they would surely become skillful in micro-irrigation after getting appropriate training and guidance. Further, approximately one-fifth of 88% of the participants assumed that they would improve their skills in every new technique to adopt it properly because it could improve their personal skills, thus their productivity. A respondent said:

> As farmers, we are most interested in developing our agricultural practices and noticing their positive results, and we therefore do our utmost to strengthen our skills in any new agricultural technology we adopt.

On the other hand, 12% of the participants thought they would not become skillful in using micro-irrigation technology on potatoes. Half of those participants were not convinced of the technology and believed it has no benefits on potato cultivation at all.

> No, since I see that it has no benefit in growing potatoes, obviously I wouldn't improve my skills in using it.

The other half considered micro-irrigation difficult and exhausting to be implemented in potato cultivation.

Overall, it was found that "effort expectancy" plays a positive role in user's intention to use micro-irrigation technology.

4.2.1.3. Social influence

In the context of this construct, participants were asked to list people whose judgment is important to them and who would approve and disapprove their adoption of a micro-irrigation system. To this extent, 47% of the participants stated that they don't care about others' opinions, because each of them prefers to take his own decision concerning his work, and they know best what the soil requirements on their lands are; not every technique can be applied on all types of soil. For example, they said:

> I don't care about someone else's opinion. When I make my decision, I am convinced and sure that I will take advantage of it.
> Since I believe that each one has a different point of view, I have my own.

Moreover, 21% of the respondents considered the opinion of "other farmers" or "nearby farmers" important. They expressed their trust in each other's objective opinions about potato cultivation needs (irrigation, etc.) based on the soil type and the climate of the region.

> I only care about the opinion of the farmers, friends and relatives because I trust them and know they won't suggest anything but useful things to help me in agricultural issues.

> I am very interested in the opinion of my neighbouring farmers in the area, because they express their opinion relatively to our area; as each region is different from the other concerning the soil, water availability, air velocity, etc.
> The opinion of other farmers is very important to me because we are in the same sector, and we face the same risks and problems.

In addition, 20% of the farmers highlighted the importance of their family members' opinion such as fathers, sons and/or cousins. Two participants expressed this sentiment as

> My father's opinion is very important to me, because everything I have learned is from him as he has large experience in agriculture in general and especially in potato agriculture.

Furthermore, 12% of the farmers were interested in NGO's judgment and advice, as well as agricultural associations, organisations and engineers. According to those farmers, those organisations realise the significance of new agricultural practices and support the farmer in adopting these practices to develop his farm. They commented:

> I am also interested in the opinion of an agricultural organisation, because whenever it becomes clear that the farmer improves and adopts new technologies in his land, this agency supports and helps him by exporting cultivated yields.

Moreover, farmers responded to the question about the importance of collecting information from other farmers and observing what they think about their possible successes before adopting a new irrigation system. Nearly all participants, 94%, were very interested in having access to the experience and suggestions of other farmers. Inside this group, 50% voted for the collective benefit, and 44% were interested in continuous development and knowledge of existing and new agricultural practices. Two statements can represent the general feeling

> *Collecting information from other farmers is important in order to share experience and increase development. It helps us to discover all new agricultural techniques, to test them and find out if they are useful in the region or not; this is a common interest.*
> *For this reason, I created the syndicate of potato farmers to exchange our knowledge and experiences, to share with each other every new agricultural practice, as well as our successes and failures so that we can learn more.*

On the other hand, 6% of the participants were not interested in the exchange of experience, because they believed that each farmer has his own individual specific agricultural practices and requirements. For example,

> Each farmer has his own technologies and the specification of his land which differ from the other.
> Some farmers may give agricultural information that can't be adopted in the same way in my farm.

Obtaining a better understanding of the farmers' perspectives on climate change and water shortage was also connected to this construct. Participants were asked to define what these two terms meant for them. Firstly, half of the farmers believed that climate change and water scarcity lead to loss in yield, thus in profits. According to them, the scarcity of water resulting from climate change causes cultivated areas to be minimised, resulting in huge losses. They also stated that climate change and water scarcity have negative consequences on agriculture in terms of the quality of yields. Moreover, 16% argued that climate change and water scarcity affect potato farming in particular because potato crops are very sensitive to high temperatures and low precipitations. This group of farmers confirmed that climate change directly and negatively affects cultivation, especially potato crops, because it makes it vulnerable to climatic fluctuations. This fact may force them at some point to move from growing potatoes to rain-fed agriculture. Further, 16% of the participants claimed that climate change and water scarcity put agriculture continuity at risk, because they lead to disasters that negatively affect agriculture. Furthermore, 9% defined climate change as a fluctuation of precipitation and temperature during seasons. According to these farmers, climate change has led to changing temperatures during seasons, therefore to low precipitation rates, and consequently water scarcity. They also believed that climate change has caused the reduction of groundwater. Finally, 3% of the participants argued that climate change and/or water scarcity do not exist because they still find water in abundance.

In the same context of social influence, 91% of the respondents affirmed that a farmer should have moral norms and personal obligations as regards preserving water for the environment, future generations and for continuing appropriate agricultural practices.

They stated that

> It is compulsory to have ethical and personal values to be forced to save water in order to preserve nature, water wealth and to keep the water resource for our children as well as to ensure the natural and continuous development of agriculture.
> Personally, as I'm worried about climate change, if the government or a non-profit organisation will support us, I will adopt a micro-irrigation technique to conserve water

for the ecosystem's well-being and to maintain a normal life-sustaining environment.

Overall, it seemed that social influence does not influence the farmers' intention to use a micro-irrigation system.

4.2.1.4. Facilitating conditions

This construct is relevant to the question regarding the guidance role of the agricultural/irrigation extension services in the area. Seventy-nine percent claimed that there was no presence at all, neither of agricultural guidance and extension nor of training courses. They stated that the agricultural sector is marginalised and neglected; therefore, the farmers had to rely on their personal experiences or the experiences of other farmers in the surrounding areas. They added that the non-presence of extension services made them unaware of the existence of new agricultural practices. They stated that

> The agricultural sector is marginalised, there are no agricultural policies, not even agricultural extension, and we have become used to relying on ourselves, our individual information, and the information we take from each other. In Lebanon, we do not have agricultural policies, and farmers are not supervised by the Ministry of Agriculture, which does not provide any guidance. Every farmer in this area depends on himself and on his personal experience.

The other 21% of the participants stated that there was limited agricultural extension from some companies and institutions for the purpose of marketing. That is why they did not trust those types of companies and they relied on their personal experience. This common feeling can be summarised in the words of the participants:

> There is no appropriate agricultural extension role, there are some agricultural companies that deal with pesticides, they do some extension courses related only to the subject of insects so as to sell and market their products, but nothing more. So, I only rely on my personal information and experience.
> We have some agricultural guidance from some agricultural associations and institutions; they are doing all they can for agricultural extension. I take into account the information they provide, because agricultural guidance is necessary and sometimes it is a way to refresh my memory about things I know, but I do not remember.

In the same context of facilitating conditions, participants were asked about the barriers they thought might prevent them from implementing a micro-irrigation system. Participants had the possibility of multiple choices. Several barriers were mentioned by each participant and results are illustrated in Fig.4. All participants considered the most important barrier as the high initial expenses for installing the system: 53% stated they lacked the capital in order to cover the whole area; 53% believed they needed training to raise awareness about the benefits of the system; 44% said the sys-

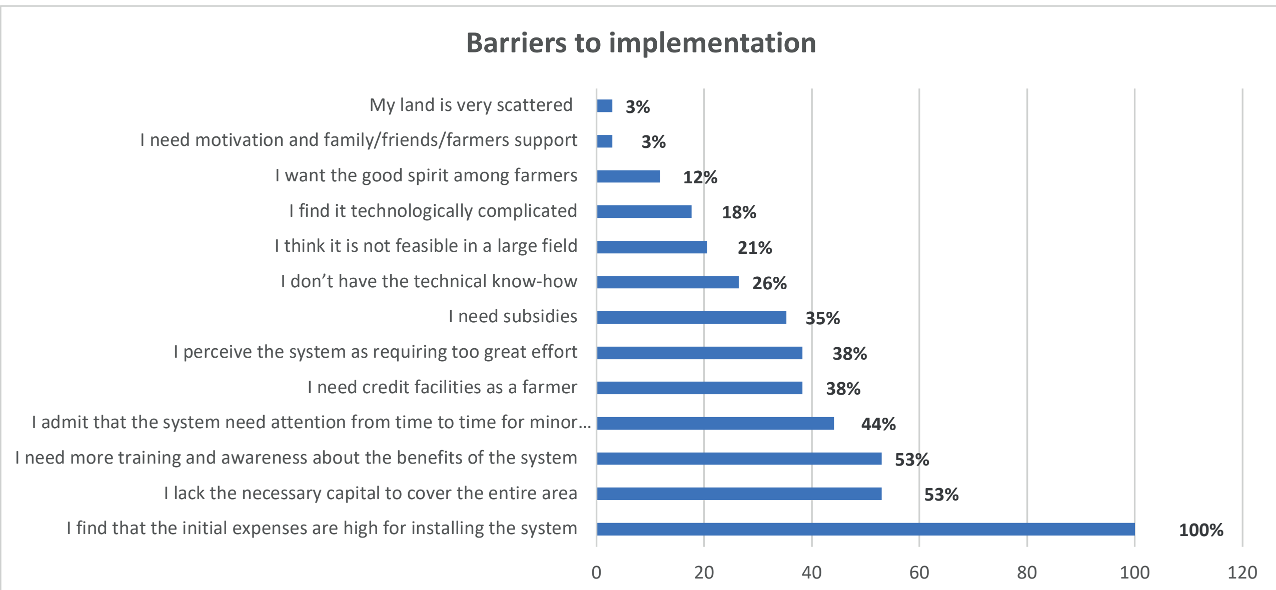

Figure 4. Barriers to implementation of a micro-irrigation system.

tem needed attention and time for minor repairs; 38% emphasised that micro-irrigation was effort consuming; 38% thought that they needed credit facilities as farmers; 35% believed that subsidies were necessary to implement this new technique with high costs; 26% said they did not have the required technical knowledge; 21% believed that micro-irrigation was not feasible on large fields; 18% found it technologically complicated; 12% stated that they wanted the good spirit among farmers because if famers cooperated they could support each other. However, only 3% needed motivation from family and friends in order to implement micro-irrigation, and another 3% believed that their land was very scattered, which impeded the installation of the system.

Overall, facilitating conditions could improve a farmer's use behavior of a micro-irrigation system.

4.2.2. Key moderators

In addition to the previously mentioned four main determinants, the UTAUT model included four main "moderating" factors: gender, age, experience, and voluntariness of use. Given that in this research all the farmers were of the same gender, the paper only included exploration of the possible effects of age, experience and voluntariness of use as moderating factors on the four main constructs.

4.2.2.1. Age

The question that was relevant to this factor was whether the participants believed that the age of the farmers affected their incentive to adopt new irrigation practices and in what way.

It emerged that 62% of the participants considered that age had no influence on the intention of use of a new agricultural technology. They stated that farmers adopted a new technology once convinced of the advantages of that technology. They asserted that, no matter his age, a farmer remains enthusiastic about adopting new technologies, thus developing himself and his land. According to them, if a farmer is convinced of the benefits of modern technology, he will adopt anything that is beneficial for his land. Some respondents commented that

> If it becomes clear to the farmer that the modern irrigation system will give him high profits, he will adopt it no matter what his age is.
> No, age does not decrease the incentive of adopting new agricultural technologies. A farmer who is convinced of the benefits of adopting new irrigation practices or other agricultural practices can only be hindered by financial capacity.
> No, there are young farmers who can't be convinced of changing and developing, whereas there are older farmers (70 years and over) who always are willing to to keep up with progresst.

However, 38% of the participants believed that age decreases a farmer's incentive to adopt new agricultural practices because the age lessens the farmers' enthusiasm. Age was an important moderator in the context of adopting a micro-irrigation system among potato farmers. The younger group affirmed that it would be more difficult to persuade the older generation who does not have initiative to try new technologies, contrary to what the elderly said. Moreover, in their opinion, elder farmers believe they have all the knowledge they need and that satisfies them. Thus, it would be very difficult for them to be convinced of adopting new practices. Those participants also added that, the older the farmer the more he rejects new technologies because he has no faith in them. In this case the usual comment was

> Yes, when a farmer gets older, adopting a new irrigation system on his land becomes a secondary matter for him. He no longer has the urge to learn agricultural practices.

4.2.2.2. Experience

Experience was tested by the familiarity of the farmers with a micro-irrigation system either by their own trial on their crops or by observing others using it on potatoes or on other crops. Based on the analysis of the focus group discussion, some participants assumed that adopting micro-irrigation is not difficult for them as they witnessed its usage by other farmers on potato cultivation or on other crops. Therefore, they have the know-how which increases their incentive to implement it on potato cultivation if they have the capital for the investment. In the same context, a participant stated

> As a member of my family uses micro irrigation on watermelon, I have professional and technical knowledge of this subject, and therefore I will not find great difficulty in using it on potatoes.

Another added

> I am adopting micro-irrigation on a small part of my land in vegetable cultivation, so I have experience of how to install it in an efficient way.

4.2.2.3. Voluntariness of use

Moreover, "voluntariness of use" was measured by the tendency to adopt a micro-irrigation system in a situation where there is no external obligation to adopt the technology. External obligations can be defined for example as limited quantity of water usage imposed by the responsible authorities in the region. Almost half of the participants (53%) stated that they can adopt micro-irrigation without external obligations, in order to induce good results and to ensure the continuity of their land cultivation:

> Yes, I will move to a micro irrigation system in order to improve the quality of potatoes and produce more quantities, and the most important thing is to reduce water waste.

However, it is worth mentioning that only one participant asserted that he will gradually adopt micro-irrigation regardless of its high initial cost, because he believed that it will greatly improve the quality and quantity of his potato yield:

> Yes, I will move to the micro irrigation system, but in stages, due to the high cost.

On the other hand, the other half of the participants (47%) have no tendency to adopt micro-irrigation spontaneously without external obligations: half of them consider it an expensive technology and they do not have the financial resources. The other approximate half does not perceive any benefit from adopting it on potatoes, and only very few have abundance of water so they do not need -water-saving irrigation technology. Some comments were:

> No, because I am convinced that the sprinklers are better than the micro irrigation on potato crops, and I don't have the financial resources to try and attempt micro irrigation even on a small part of my land.
> No, because I have enough water and I pay careful attention to the amount of water that the plant needs (manual soil testing) so that I don't waste water and therefore micro irrigation won't help me.
> No, I am not convinced that micro irrigation would be better than sprinklers on my land, so I won't implement it.

Furthermore, participants were asked about the possibility of them adopting micro-irrigation if the government decided to subsidise the use of water-saving irrigation systems. Eighty-five percent of interviewees responded that they would prefer to use a micro-irrigation system if government incentives were available. According to them, subsidies would reduce the financial burden on them at the beginning of the investment, and encourage them to take the first step toward the total adoption of the micro-irrigation system:

> Yes, if the government provides subsidies, conducts training courses and supports us to export our production, of course I will adopt it.
> Yes, I agree, because the state and the government have an obligation to take care of the farmer, who is the core of the Lebanese economy. Hence, micro irrigation is essential and necessary in improving the quality of potatoes to become competitive with potatoes from other countries.

Nonetheless, 15% of the participants insisted on not moving to micro-irrigation system even if there is support, because they do not perceive any benefit from it:

> No, I don't agree… In the end, the productivity will be identical to that of the sprinklers.
> No, although this technique provides large quantities of crop production, it is not suitable for the large areas I cultivate, and thus the moth will surely appear resulting in high losses.

It is crucial to note in this part that individuals who initially tended to adopt micro-irrigation without external obligations are also likely to adopt it if subsidies are given since they reduce the financial burden. Further, participants who said they would not use micro-irrigation because of its expensive cost changed their mind when the interviewer mentioned the subsidies. The most notable change in intentions was that of the participants who had no tendency to adopt the system claiming that it has no benefits. However, 50% of them changed their answers when the question of subsidies was raised. They stated in this section that they would move to micro-irrigation gradually by applying it at first on a small part of the land to test its advantages. For example:

> Yes, it will be possible for me to start adopting it on only one hectare. If my results are positive and there are no diseases, then I will gradually adopt it year after year until I have thoroughly checked its benefits.

4.2.3. The direct determinant: the behavioural intention

The measurement of behavioural intention in this study included the intention and predicted use of a micro-irrigation system. The behavioural intention was measured by asking whether the participants had plans for the adoption of a micro-irrigation system in the following 12 to 24 months as well as the major concerns related to this system.

Fifty-nine percent of the participants said that they did not have any plan for the adoption of micro-irrigation in the next 12-24 months. This group of participants was divided into 3 groups according to the reason for not having a plan for adoption: a) the unstable economic conditions in Lebanon that do not encourage farmers to invest large amounts of capital (the majority); b) the lack of micro-irrigation usefulness in terms of profits and feasibility (a quarter of the respondents); c) lack of financial means (only 10%). The following quotes revealed the participants' views:

> No, because sprinkler irrigation is easier for the farmer and does not require much effort, and I am satisfied with the quality and productivity that I get.
> No, if the government does not support me, I will not adopt the micro-irrigation system.

Then again, 41% of the participants stated that a plan to adopt the micro-irrigation system was possible in the near future. This group was also divided into several groups in terms of implementation conditions: a) presence of subsidies by the government (approximately half); b) better economic situation in the country (one quarter); c) in case of water shortage (6%); d) no conditions at all (14%). The following quotes revealed the participants' views:

> In light of the current conditions in the country, I can adopt it in this period if there is protection for our products and if the State provides support.
> Yes, if the country's situation stabilises, I have the intention to adopt a micro-irrigation system soon;
> Yes, when necessary, and that means if the water runs out on my land, I will adopt a micro irrigation system."

Fig. 5 below shows the different answers obtained when investigating the concerns of the participants regarding micro-irrigation systems. Each participant had the possibility to mention multiple concerns. As is clear, the main concern was the high cost of initial equipment and the possibility of financial losses (47%). In addition, 15% confirmed that micro-irrigation is a labour intensive technique that requires a lot of effort, time and attention. Furthermore, 29% have no concerns at all. The remaining concerns differ in small percentages from the frequent maintenance to the emergence of diseases (fungal and moth), short lifespan, feasibility on large areas, no wind resistance.

Further, when asked about their willingness to adopt a new micro-irrigation system, 82% of the participants said yes and 18% said that they were not willing to.

In conclusion, in order to recapitulate the main results of each construct, Table 2 summarise the findings.

5. DISCUSSION

The purpose of this study was to obtain a deeper understanding of the influential determinants (socio-economic, psychological and behavioral factors) for

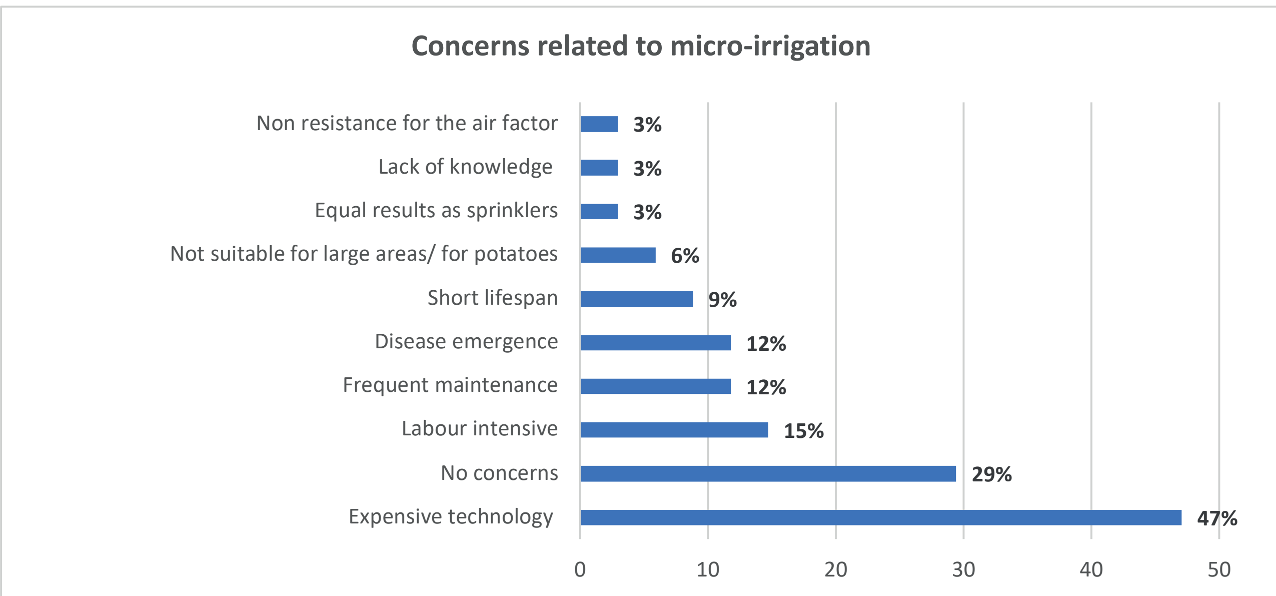

Figure 5. Concerns related to micro-irrigation systems.

Table 2. Main findings from the focus group discussions.

Construct or Moderator	Questions	Findings
Performance Expectancy	A. Knowledge of micro-irrigation systems.	Basic technological knowledge of micro-irrigation systems stating that it incorporates drip irrigation and mini-sprinklers irrigation.
	B. The reasons behind using ordinary sprinklers.	Sprinklers are less expensive.
	C. Possible advantages deriving from the adoption of micro irrigation systems.	Water saving, uniform distribution, yield increase, farm profits, energy cost reduction, reduction of pesticides and fertilizers.
Effort Expectancy	A. Perception of the easiness of use of a micro-irrigation system.	Easy extension over the field, labour and effort saving, time saving.
	B. Skillfulness in using micro-irrigation.	88% of farmers claimed that they would be skillful in using micro-irrigation.
Social Influence	A. List people whose judgment is important to farmers and who would approve or disapprove the adoption of a micro-irrigation system.	47% stated that they did not care about others' opinions. 21% considered the opinion of "other farmers" or "nearby farmers" important. 20% highlighted the importance of their family members' opinion such as fathers, sons and/or cousins. 12% of the farmers were interested in NGO's judgment and advice, as well as agricultural associations, organisations and engineers.
	B. The importance of collecting information from other farmers and observing their possible successes before adopting a new irrigation system.	94% of farmers were very interested in having access to the experiences and suggestions of other farmers.
Facilitating Conditions	A. The guidance role of the agricultural/irrigation extension services in the area.	79% claimed that there was no presence, neither of agricultural guidance and extension nor of training courses. They stated that the agricultural sector was marginalised and neglected; therefore, the farmers had to rely on their personal experience or the experience of other farmers in the surrounding areas.
	B. Barriers that farmers thought might prevent them from implementing a micro-irrigation system.	The most important barrier was the high initial expense of installing the system.
Age	A. The age of the farmers affects their incentive to adopt new irrigation practices.	62% of the participants considered that age had no influence on the intention of use of a new agricultural technology because no matter his age, a farmer remains enthusiastic about adopting new technologies, thus developing himself and his land.
Experience	A. The familiarity of the farmers with micro-irrigation systems either through their own trial on their crops or by observing others using it on potatoes or on other crops.	Participants assumed that adopting micro-irrigation is not difficult for them as they witnessed its usage by other farmers on potato cultivation or on other crops. Therefore, they have the know-how which increases their incentive to implement it on potato cultivation if they have the capital for the investment.
Voluntariness of use	A. The tendency to adopt a micro-irrigation system in a situation where there is no external obligation to adopt the technology.	Half of the participants (53%) stated that they can adopt micro-irrigation without external obligations, in order to induce good results and to ensure the continuity of their land cultivation.
	B. The possibility of adopting micro-irrigation if the government decides to subsidise the use of water-saving irrigation systems.	85% of the participants stated that they would adopt a micro-irrigation system if there were subsidies from the government. According to them, subsidies would reduce the financial burden on them at the beginning of the investment and encourage them to take the first step toward the total adoption of a micro-irrigation system.

Construct or Moderator	Questions	Findings
Behavioural Intention	A. A plan for the adoption of a micro-irrigation system in the following 12 to 24 months as well as the major concerns related to this system.	59% of the participants said that they do not have any plan for the adoption of micro-irrigation in the next 12-24 months due to the unstable economic conditions in Lebanon which do not encourage farmers to invest a large amount of capital; the lack of micro-irrigation usefulness in terms of profits and feasibility and the lack of financial means. 41% of the participants stated that a plan to adopt the micro-irrigation system is possible in the near future if there is the presence of subsidies by the government.
	B. Concerns regarding micro-irrigation systems.	The main concern was the high cost of initial equipment and the possibility of financial losses (47%). 15% confirmed that micro-irrigation is a labour intensive technique that requires a lot of effort, time and attention. 29% have no concerns at all. The remaining concerns differ in small percentages from frequent maintenance to the emergence of diseases (fungal and moth), short lifespan, feasibility on large areas, no wind resistance.

potato farmers' adoption of micro-irrigation technology on their lands in the Bekaa region in Lebanon. This research further examined which factors seem to influence the farmers and their willingness to use a micro-irrigation system.

Based on the focus group analyses performed, performance expectancy, effort expectancy and facilitating conditions could have a significant effect on the acceptance of micro-irrigation technology while social influence does not.

The effect of performance expectancy on behavioural intention was found to be relevant for many participants, which reflects the perceived benefits obtained using micro-irrigation systems. The benefits were identified as saving water, reducing labour effort and time, saving energy, increasing yield, improving crop quality and improving agricultural operations. Farmers' performance expectancy might increase by emphasizing the usefulness of micro-irrigation systems. That means if the advantages of micro-irrigation systems were presented in meetings conducted by specialists, this probably would increase the acceptance and adoption by people who were against this method, and who preferred ordinary sprinklers. Almost all the participants declared that generation of good results and water saving were the main advantages of micro-irrigation systems. However, they were very anxious about losing financial investments if they could not apply this method without professional guidance. This asserts the idea of the essentiality of establishing agricultural guidance, in order to promote the advantages of micro-irrigation systems and its usage. This result was found to be consistent with previous research findings (Louho et al., 2006; Bahramzadeh & Shokati Mogharab, 2010; Im et al., 2011; Yu, 2012; Nejadrezaei et al., 2015; Sa'ari et al., 2017; Ronaghi & Forouharfar, 2020) that have found a positive relationship between performance expectancy and behavioural intention to use technology.

Effort expectancy was measured by the perception of ease of learning and using the system, as well as how much effort should be spent on using the micro-irrigation system on potatoes. From the focus group analysis, it seemed that farmers preferred to adopt an easy way to use systems which required less effort and time than ordinary sprinklers on potato crops. Furthermore, almost all participants, including a part of those who showed a high effort and attention concerns in extending the micro-irrigation system on their potato lands, demonstrated their willingness to learn about the micro-irrigation functions. For that, organising training and pilot studies could be a way for farmers to decrease their level of doubt. During on-field training courses, farmers discover how micro-irrigation functions, and the right way to install it in potato fields. Similar with other research (Venkatesh et al., 2003; Louho et al., 2006; Birch & Irvine, 2009; Im et al., 2011; Nkandu & Phiri, 2022), effort expectancy could have an effect on behavioural intention.

The third determinant, social influence, seemed to have an insignificant impact on behavioural intention to use micro-irrigation. This result was consistent with Venkatesh et al.(2003), Rosen(2005) and Yang et al.(2020). In his research, Venkatesh et al. (2003) had found that the adoption of a new system depends on the user's beliefs and not others' opinions. Social influence was not found to affect potato farmers' willingness to adopt a micro-irrigation system since the vast majority does not care about the opinion of nearby farmers, family members, NGOs, engineers, agricultural associations or organisations. This is why promoting the importance of agricultural associations and farmers' gatherings, would revitalise the spirit of collaboration among farmers and the cooperation between them which enhances the spread of innovations as highlighted by Nkegbe & Shankar (2014) and Lopolito et al. (2022).

Lastly, the facilitating conditions determinant was measured by evaluating the available resources and support to use micro-irrigation systems. The study results clearly depicted the direct effect of facilitating conditions on use behaviour of using micro-irrigation systems consistently with Venkatesh et al. (2003), Hung et al. (2006) Wang & Shih (2009) and Im et al. (2011). Guidance departments at the Ministry of Agriculture, non-governmental organizations (NGOs) working in agricultural extension, particularly on the subject of climate change, social media advertising raising awareness of new ways of saving water, and any other available services to assist individuals in adopting and using micro-irrigation systems could be an important way to increase the adoption of a micro-irrigation system. Nevertheless, all farmers confirmed that these conditions were unavailable in Lebanon, and there was no guidance regarding agricultural practices in the country, which meant that they could not know about the benefits of micro-irrigation, or its right usage.

With respect to the moderating effect of age, it was found that it was an important moderator in the context of adopting a micro-irrigation system among potato farmers. The younger group affirmed that it would be more difficult to persuade the older generation who did not have the initiative to try new technologies, contrary to what the elderly said. In fact, moderation by age impact was reported in several studies (Venkatesh & Morris, 2000; Venkatesh et al., 2003; Morris et al., 2005).

Experience was considered by Venkatesh et al. (2003) as one of the important factors that affect behaviour intention. In this study, it was shown that the effect of effort expectancy on behaviour intention was in fact moderated by experience. The findings of this study revealed that, in terms of micro-irrigation usage, experienced farmers were more likely to accept and use micro-irrigation than inexperienced farmers.

However, it appeared that experience was not a moderator of the effect of the facilitating conditions construct on use behaviour because farmers with different levels of experience have almost the same perceptions towards the resources supporting the use of micro-irrigation. This result is not consistent with the study of Alshehri et al. (2013) who claimed that experience moderates the effect of facilitating conditions on use behaviour.

Voluntariness of use had moderated the effect of social influence on behaviour intention. It was measured on the basis of not using external obligations or incentives in order to implement the new irrigation system. The results confirmed that in the case of subsidies, the level of adoption would increase, and farmers would definitively implement the system. That is, if the micro-irrigation system was financially subsidised, almost all farmers in Lebanon would adopt it. Furthermore, the study findings showed that almost half of the participants did not have the tendency to adopt a micro-irrigation if there was no external obligation which is consistent with what Venkatesh et al.(2003) had reported. In this case, if the government granted subsidies to support the implementation of a micro-irrigation system, the vast majority would adopt it gradually or immediately. This is compatible with what Nkegbe & Shankar (2014) found, that providing facilities to farmers, such as accessing credits in their case, could promote and intensify the adoption of agricultural technology.

6. CONCLUSIONS

The aim of this study was to investigate the potato farmers' behaviour in adopting a micro-irrigation system. To achieve this objective, we adapted the unified theory of acceptance and use of technology (UTAUT) model.

The outcomes offer visions for policymakers to encourage potato farmer to adopt a new micro-irrigation system. Firstly, farmers are willing to accept micro-irrigation technology when they can make gains and reduce task uncertainty on their farming activities. Secondly, they are keen to adopt a micro-irrigation system if they find that it reduces effort and time spent on their farming activities. Finally, it is relevant to encourage farmers to adopt it through financial aids or subsidies which provide opportunities for farmers to decrease the financial burdens on them. Furthermore, agricultural extensions, field training and pilot area studies are also important in increasing the farmers' intention to adopt a micro-irrigation system.

However, the study suffers from some limitations. Legal restrictions and safety measures linked to the COVID19 pandemic were a reason for the limited sample size. Also, the sample used lacked gender differentiation since no females operated farms in the study area. Thus, it would be useful to repeat the analysis with a larger sample for focus group discussions incorporating female participation and extending the study to other countries.

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Reducing food-related economic loss to improve food security and cattle trade in the Sahel: the case of agropastoral systems in Senegal

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Abstract. Food loss is a critical issue in Africa, but investigation has mainly been limited to quantity loss. Economic losses are likely to be more significant but are widely ignored. Regarding ruminant-related losses, it remains challenging to identify the optimal harvest point. Focusing on Sahelian agropastoral systems, where stakeholders operate in a shock-prone environment, our paper explains how critical actor behaviour is, and it addresses economic losses on live-animal transactions while integrating market behaviours into the analysis. Loss elimination being illusory in such a context, our findings pioneer a loss reduction approach that is supported by an appropriate optimisation programme tested on primary data collected from 202 agropastoral households in Senegal.

Keywords: behaviours, economic loss, optimal loss, pastoralism, Sahel.
JEL codes: C61, D13, Q12, Q13, R20.

HIGHLIGHTS

- Post-harvest losses in African livestock and pastoral systems are narrowly limited to loss of physical quantity of product while loss of economic value is largely ignored.
- Livestock multifunctionality and behaviours of individual actors in increasing uncertainty led Sahelian pastoralists to behave with a bounded rationality.
- An optimization model subject to pastoral constraints allows for the determination of the optimum number of animal species that must be sold to cover household expenditures and animal loss.
- Simulation of ad hoc loss reduction scenarios reconciles food security and competitiveness of livestock economics in the Sahel.

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1. INTRODUCTION

A growing local and regional demand for meat and milk has provided opportunities for pastoral producers in the Sahel. However, several factors make it difficult for Sahelian producers and other actors in the livestock value chain to take full advantage of this positive trend. Ickowicz et al. (2012), Hollinger and Staaz (2015), and Diawara et al. (2017) all highlight low herd productivity as a critical constraint. Together with structural constraints relating to logistics, infrastructure, public policy and enabling environment, low productivity contributes to sub-optimal performance in the livestock sector. The Sahelian livestock sector is vulnerable to multifaceted shocks, mainly relating to climate, disease, natural disasters and market fluctuations. Some of these shocks are severe, leading to quantitative, qualitative and economic loss (IFAD 2016).

There is ongoing interest in this issue, even though there is scarcity of information and the evidence on the extent of the losses is mixed with estimates ranging from 2% up to 27% (FAO, 2011; Blanchard et al., 2016).

A quantitative evaluation of the different types of loss remains challenging for several reasons. While productivity gaps have been documented, food loss in the livestock sector has received far less attention. Comprehensive modelling methods are needed to clarify spatial and temporal fluctuations in loss rates and to make credible estimates of the quantitative, qualitative and economic losses. Further complicating the situation in the Sahel is the perceived dualism between commercial and communal livestock keepers and between modern and traditional systems (Lyet et al., 2010). The structure of the livestock value chain is extremely nuanced. There are considerable differences in the levels of market integration, motivation and vulnerability among value chain actors, and this influences the nature and perceptions of loss. Furthermore, small-scale producers have a 'producer–consumer model,' as articulated by Chayanov (1926, 1990). The goal of pastoralists in a changing environment, such as the Sahel, is to balance short-term consumption needs with long-term herd-building strategies to meet future consumption demands (Fadiga, 2013). Consequently, an understanding of the motivation to increase sales is key to understanding decision-making strategies. Moreover, the parameters of the livestock market remain relatively rigid, with a low supply of animals and high price levels.

Food loss has adverse effects on food safety and security, particularly for poor and vulnerable people (Sheahan and Barrett, 2016), on the livestock market (Wane and Mballo, 2016) and on sustainable development (Gustavsson, 2011).

Concerns about food loss frequently give rise to quantitative and qualitative estimates, which tend to be followed by remediation (in a 'zero loss' approach). However, when considered from a different economic perspective, not all loss is undesirable. This opens the opportunity to explore an exciting loss assessment method in which mitigation is the goal (an 'optimal loss' approach). The optimal loss approach is based on two key assumptions. First, the cost of total elimination of loss is prohibitive, regardless of the availability of technology and institutional arrangements. Second, a certain level of loss is inevitable and not necessarily undesirable, particularly in the agricultural sector.

This paper contributes to a long-standing debate on risk in the agricultural sector (Wane and Mballo, 2016; Chavas et al., 2021) and decision-making related to risk perception (Wane et al., 2020).

To address the complex issue of loss in the Sahelian pastoral areas, we used a sequential approach by which qualitative data was collected from approximately 15 people in each of the three targeted sites, and these results guided the subsequent collection of quantitative data from 202 households.

This paper pioneers the idea that it is possible to improve food security in the Sahelian region by minimizing losses in the production stage of the live animal value chain. The paper contributes by developing an optimisation model that determines the optimum numbers of different animal species to be sold to counteract losses while also being subject to the farmers' constraints. Our methodology is pragmatic in that the recommended optimisation approach aims for loss reduction rather than illusory loss eradication. In addition, unlike measures of loss in the crop sector, which focus entirely on post-harvest losses, in our analysis of loss in the livestock sector, we consider both pre-market and market losses to be equally significant. Second, our model shows the ideal sales volume, age at sale and price at sale that will allow the livestock farmer to generate sufficient income to cover his expenditure. Third, we simulate loss reduction scenarios, with their effects on volume and market price parameters, and we show how these scenarios can result in a decline in average market prices, with the result that buyers can access more affordable live animals. Overall, our paper demonstrates that addressing economic losses offers a more impactful perspective than focusing solely on the more commonly emphasized physical losses.

This paper is organized as follows. Section 2 reviews the literature discussing the issues and challenges faced by people living shock-prone dryland areas. It analyses the relevance of the optimal loss approach by emphasising the effect of multifaceted exogenous shocks on producer market behaviours. Section 3 describes the economic loss model to the Senegalese Sahelian agropastoral production system. Section 4 describes the study area and data used in our analysis. Section 5 presents the main results of the optimization, identifying optimal quantity and price in different loss reduction scenarios. Section 6 discusses the main results and concludes.

2. LITERATURE REVIEW

There are many definitions of food loss, from the more operational (Bourne, 1977; Parfitt et al., 2010; Hodges et al., 2011; FAO, 2011, 2013; Aramyan and van Gogh, 2014; de Gorter, 2014) to the more comprehensive (Papargyropoulou et al., 2014). Food loss occurs at the production, pre-harvest, harvest and post-harvest stages (Parfitt et al., 2010). Food waste refers to the unconsumed portion that is discarded as waste at any point in the food chain (Hodges et al., 2011).

Although food loss and waste, especially the location and type of loss, have been discussed, loss has received relatively little attention due to the difficulties of measurement. Several attempts have been made to estimate loss, particularly in the grain and crop sectors. Early estimates, which used mass flow models, set loss and waste at one-third of the physical mass of all foodstuffs worldwide (FAO, 2013; Lipinski et al., 2013). The World Bank (2011) reported the yearly grain loss in sub-Saharan Africa as approximately US$4 billion. Highlighting these issues is helpful for donors and funding agencies. However, these global estimates have increasingly been challenged, especially in Sub-Saharan Africa, where recent scientific studies have found the magnitude of the loss to be overestimated. More recent estimates have ranged from 4% in the presence of prevention mechanisms to 20% in their absence (Affognon et al., 2015; Rosegrant et al., 2015).

In 2012, the FAO estimated milk loss in the sub-Saharan African dairy sector at 27%; this was found to occur mainly in the early or middle parts of the food chain. However, extensive fieldwork conducted by a CIRAD–Pastoralisme et zones sèches (Pastoralism and dry lands; PPZS) team in 2016 to evaluate loss in the Senegal and Burkina Faso dairy supply chain, valued total milk loss at 4% to 14%, which was very different from the FAO estimate. The potential for recycling and reusing food that is diverted from human consumption to animal consumption has led to the adoption of a more inclusive definition of food loss and waste, which considers both humans and animals in its calculations (Mokkar, 2017).

A key challenge is that the methodological approaches, which were designed and initially applied in developing countries, have relied on the experiences of those countries (Sheahan and Barrett, 2016). In 2009, the European Union tried to support Sub-Saharan African countries by implementing the African Postharvest Losses Information System (APHLIS). This involved a network of local experts and facilitated the collection and sharing of cereal grain weight loss data by country and province (Hodges et al., 2010; Rembold et al., 2011). However, this attempt took place in an oversimplified post-harvest loss environment and there were challenges with data quality (Affognon et al., 2015).

At the micro level, cross-country surveys of farmers in relation to post-harvest loss in Sub-Saharan Africa have revealed interesting findings, with relatively low loss indicators, ranging from 1.4% to 6.9% of total production (Kaminski and Christiaensen, 2014; Abdoulaye et al., 2015). Although designed for large samples, these surveys cannot be readily generalized to the national level because this was not built into their design.

From a value chain perspective, and regardless of variations in magnitude, grain and cereal loss seems to occur more frequently during handling and storage in the on-farm phase. In contrast, fresh product loss is reported to occur more often in the processing and distribution phases. From a technical perspective, this consensus on loss distribution from farm to fork can be explained by the fact that most surveys have addressed on-farm storage loss (Affognon et al., 2015). Current trends and projections for food value chains challenge traditional methodological approaches to integrate chain modifications arising from urbanization and other modern drivers. However, these approaches do provide powerful analytical tools for describing complex interactions between physical and social systems and for enhancing well-being through the reduction of loss in the primary sector. New insights into food loss and waste estimates, particularly in the livestock sector, could contribute to a converging research agenda on the challenges presented by the stress of global, social and environmental change.

Optimising the management of scarce resources, possibly through the minimization of constraints, is a critical theme in economics. Optimisation relies on economic rationality, a fundamental economic principle that guides the decision-making of actors. However, the inclusion of uncertainty leads to the choice of a specific analytical structure that cannot be appropriately represented by the usual constrained optimisation model (Arrow, 1971; Machina, 1987; Kreps, 1988; Dixit, 1990). Moreover, it is well established that behavioural choice may be more fundamental than the rational pursuit of self-interested goals (Bossert and Suzumura, 2012). A flexible approach to rationality-based optimisation facilitates a paradigm shift to a form of bounded rationality (with limited information, cognition and decision-making time), as articulated in Herbert Simon's (1955) seminal work. This also relaxes the constraint that links optimisation to instrumental rationality (Mongin, 2000). In this study, both approaches were considered to reconcile the Sahelian pastoralists' bounded rationality, context-driven behaviours and optimisation processes under conditions of uncertainty.

Risks are a central part of life for most households, especially those in low-income countries (Banerjee and Duflo, 2011). An increased understanding of the risks and the associated coping strategies is key for policymakers. The main challenge in risk analysis is that the presence or perception of risk can significantly affect the intertemporal behaviours of households in their allocation of resources. This applies not only to poor households but also to non-poor households that have a higher probability of becoming poor in a less safe environment. In developing countries, hazards are ubiquitous in the lives of most farmers, who must secure their livelihoods and minimize their loss. Those with weak assets are usually pushed to engage in low-return and sometimes risky non-farming activities (Barrett et al., 2001), while those who have better financial support, or who are living in regions with favourable alternatives, tend to focus on revenue growth and wealth accumulation (Loison, 2016).

Pastoralists live and operate in shock-prone environments (Wane et al., 2010) in which climate variability plays a central role. This has a direct impact on natural resource dynamics, as herders must deal with spatiotemporal variations. Climate change has exacerbated economic, social, cultural and political unease (e.g., national and international food and feed price volatility, disease, political instability and social transformation). Pastoralists also face market uncertainty and a lack of infrastructure, both of which severely affect their livelihoods. They adapt to these conditions by using mobility and diversification strategies to enhance production and secure their livelihoods (Alary et al., 2015). Their choices are limited by complex relationships and by the multifunctionality of their livestock assets. Some pastoralists breed livestock species with short life cycles to make quick gains and to escape poverty (Alary et al., 2015). Others prefer large ruminants that represent long-term capital investments (Wane et al., 2020).

It should be noted that in a risky environment, holding animals beyond an optimal market period corresponds to a form of contingency rationality. Imperfect and incomplete market information encourages pastoralists to adopt a prudent position that is based on their circumstances and is therefore contingent on the socioeconomic environment (Wane et al., 2009). This explains their opposition to regular animal 'destocking,' even when it is encouraged by national technical support services. Far from being indifferent to market prices (Kerven, 1992), livestock farmers make trade-offs between short-term consumption needs and long-term herd-building strategies to meet future needs (Fadiga, 2013).

With varying levels of success, pastoral and agropastoral households have developed adaptation and coping strategies that reflect a range of responses to stress. This illustrates the close relationship between social and biophysical factors. Extensive pastoral and agropastoral systems cannot be measured purely in terms of assets because they continually evolve and adapt to accommodate their increasingly uncertain biophysical environment and monetized world (Chambers, 1989; Van Dijk, 1997; Bovin, 2000; Ancey et al., 2009).

Over time, smallholders in the Sahelian livestock system have tried to secure production and their livelihoods by considering the uncertainties and disequilibrium of their environment (Benkhe and Scoones, 1983; Wane et al., 2010). Studies on inequality (Sen, 1982; Sutter, 1987; Wane et al., 2009; Mulder et al., 2010) and on the vulnerability of pastoral populations (Swift, 1989; Ancey et al., 2009) have discussed the complexity of the farmers' securitization. The importance of the social and biophysical factors embedded in extensive African crop–livestock systems must be considered. Given these uncertainties, Sahelian farmers are opportunistic in their approach to the markets for goods and services. Market fundamentals are not the primary drivers; rather, cultural, social and non-commercial factors often play a more significant role in producers' selling decisions. These behaviours are so deeply rooted in market practices that two key concepts are critical in any discussion of the issues affecting post-production loss in Sahel ruminant farming.

A key question that needs to be examined is whether complete loss eradication along the agricultural value chain is a feasible option or is loss reduction through optimisation more realistic? Regardless of the level of adoption of technologies, innovations and institutional arrangements, it is reasonable to assume that the cost of eliminating all loss in agricultural value chains would be prohibitive. Accepting that a certain level of failure and loss will inevitably arise in a risky environment is economically rational, because some contamination or spoilage is inevitable (de Gorter 2014). Assuming that a certain amount of loss in agricultural value chains is necessary and even economically rational, the focus should be on improving the microeconomic behaviours underpinning the potential sources of loss before developing strategies to mitigate the effects of individual decisions (Waterfield and Zilberman, 2012; Horton and Hoddinott, 2014; de Gorter, 2014; Goldsmith et al., 2015; Sheahan and Barrett, 2016). Losses may also arise from the voluntary and intentional decisions of economic actors, particularly those focused on profit rather than production maximization. Brazilian soybean farmers exemplify this situation (Goldsmith et al., 2015). In terms of food safety, it is also possible that loss may be desirable when unsafe food is removed from the system to avoid human or animal contamination (Magoha et al., 2014). In a dynamic analysis, the management of farm loss could yield mixed results. For example, by expecting losses due to a lack of storage facilities, farmers could be forced to sell products at lower price. In this case, quantitative loss could be low, while value-related loss would be very high, as was the case for maize farmers in Benin (Kodjo et al., 2015). Because zero loss is likely to be an unattainable ideal, especially for Sub-Saharan livestock farming, an optimal loss approach would be more appropriate.

Identifying the main loss sources and estimating the amount of loss is only a starting point of the analysis. In fact, a major difficulty is the choice of counterfactuals against which the loss is to be measured. Naturally, these counterfactuals are related to the production system. Producers hold the females and sell the steers in an extensive production system. The useful life of a Zebu cow is 4.5 to 8.5 years, during which time parturition, including abortion, occurs approximately five times (Mukassa-Mugerwa, 1989). Following production, live animals are moved along the value chain to downstream markets for final use, and loss occurs at each stage. For livestock systems, especially those in Sub-Saharan Africa, this is the central theme of a debate that does not occur in crop systems.

'Postproduction loss' and 'postharvest loss' have been used interchangeably to reflect specific problems in the agricultural sector. These concepts, which refer to the temporal dimension, are equally relevant to studies on the livestock sector or to specific products, which may be perishable (e.g., meat, milk) or non-perishable (e.g. cereals). Bourne (1977) made an operational distinction based on three periods during which food loss occurs: 'pre-harvest,' 'harvest,' and 'post-harvest'. This classification allows for harvest and post-harvest losses to be combined into a single category: post-production loss. Thus, combining pre-market and market losses to focus on post-production loss would appear more relevant. Recent definitions of food loss integrate the whole process, including food grown to maturity but not harvested and left in the field for any reason (Minor et al., 2020).

3. MODELLING ECONOMIC LOSS IN SAHELIAN ANIMAL PRODUCTION SYSTEMS

Two distinct phases of economic loss in live-animal rearing should be considered. The first is the pre-market phase, in which animal mortality, theft and disappearance occur. This type of loss is related mainly to the costs of managing animals prior to their theft or death. In other words, the farmer loses the entire investment made in such animals. The second is the market phase, which starts with the decision to sell the animal and ends with the actual sale. Two types of loss can occur at this stage: (i) death or disappearance at the mark-to-market stage or (ii) loss of profits or opportunity costs at sale. This second stage could be summarized as follows: what would have been earned if the farmer had sold the animal at the ideal age vs. what would have been earned if the animal had been sold earlier (for animals above the ideal age). Optimisation would involve the sale of animals that are close to the ideal age at a good price while maintaining the herd structure. In other words, it involves the minimization of economic loss in the production of live animals. Finally, there are various stages at which loss is calculated in both the pre-market and market phases. This leads to a global loss function as follows:

$$f(x_i^{as}, P_i^{as}) = \sum_{as \in AS} \Big[\big(P_{M_1}^{as} - \bar{C}^{as} * A_{M_1}^{as}\big) * M_{PM}^{as} + \big(P_{V_1}^{as} - \bar{C}^{as} * A_{V_1}^{as}\big) * V_{PM}^{as} + \big(P_{\Delta_1}^{as} - \bar{C}^{as} * A_{\Delta_1}^{as}\big) * \Delta_{PM}^{as} + \big(P_{M_2}^{as} - \bar{C}^{as} * A_{M_2}^{as}\big) * M_{MP}^{as} + \big(P_{V_2}^{as} - \bar{C}^{as} * A_{V_2}^{as}\big) * V_{MP}^{as} + \big(P_{\Delta_2}^{as} - \bar{C}^{as} * A_{\Delta_2}^{as}\big) * \Delta_{MP}^{as} + \big[\sum_{i<\bar{A}^{as}} (\bar{P}^{as} - P_i^{as}) x_i^{as} - \bar{C}^{as} x_i^{as} (\bar{A}^{as} - i)) + \sum_{i=\bar{A}^{as}}^{A^{as}} (\bar{P}^{as} - P_i^{as}) x_i^{as} + \bar{C}^{as} x_i^{as} (i - \bar{A}^{as}))\big]\Big] \quad (1)$$

where x_i^{as} = number of animals sold at age i by species, P_i^{as} = sale price of animals at age i by species, A^{as} = ideal age for sale according to livestock keepers, $P_{M_1}^{as}$ = cost of dead animals during the pre-market phase, $P_{V_1}^{as}$ = cost of stolen animals during the pre-market phase, $A_{M_1}^{as}$ = age of dead animals during the pre-market phase, $A_{V_1}^{as}$ = age of stolen animals during the pre-market phase, $P_{M_2}^{as}$ = cost of dead animals during the market phase, $P_{V_2}^{as}$ = cost of stolen animals during the market phase, $A_{M_2}^{as}$ = age of dead animals during the market phase, $A_{V_2}^{as}$ = age of stolen animals during the market phase, $\bar{P}^{as}$ = average price of animals at ideal age at sale, C^{as} = average cost of managing an animal by species, M_{PM}^{as} = number of animal deaths during the pre-market phase, V_{PM}^{as} = number of animals stolen during the pre-market phase, Δ^{as}_{PM} = other animals lost during the pre-market phase, M^{as}_{MP} = number of animal deaths during the market phase, V^{as}_{MP} = number of animals stolen during the market phase, Δ^{as}_{MP} = other animals lost during the market phase.

Optimisation process and numerical resolution

For the numerical resolution of the loss function, two strong assumptions were made:

- *Assumption 1*: Stolen, lost or dead animals in the pre-market phase would have reached the ideal age at sale.
- *Assumption 2*: Most stolen, lost or dead animals in the market phase would have reached the ideal age at sale.

Thus, equation (1) can be rewritten as follows:

$$f(x_i^{as}, P_i^{as}) = \sum_{as \in AS} \Big[(\bar{P}^{as} - \bar{C}^{as} * \bar{A}^{as}) * \ [(M^{as}_{PM} + M^{as}_{MP}) + (V^{as}_{PM} + V^{as}_{MP}) + (\Delta^{as}_{PM} + \Delta^{as}_{MP})] + \big[\sum_{i<\bar{A}^{as}} \big(\bar{P}^{as} - P_i^{as}) x_i^{as} - \bar{C}^{as} x_i^{as} (\bar{A}^{as} - i) \big) + \sum_{i=\bar{A}^{as}}^{A^{as}} (\bar{P}^{as} - P_i^{as}) x_i^{as} + \bar{C}^{as} x_i^{as} (i - \bar{A}^{as})) \big] \Big]$$

where x_i^{as} = number of animals sold at age i by species, P_i^{as} = sale price of animals at age i by species, $\bar{A}^{as}$ = ideal age for sale according to livestock keepers, P^{as} = average price of animals at ideal age at sale, $\bar{C}^{as}$ = average cost of managing animals by species, M^{as}_{PM} = number of animal deaths during the pre-market phase, V^{as}_{PM} = number of animals stolen during the pre-market phase, Δ^{as}_{PM} = other animals lost during the pre-market phase, M^{as}_{MP} = number of animal deaths during the market phase, V^{as}_{MP} = number of animals stolen during the market phase, Δ^{as}_{MP} = other animals lost during the market phase.

The optimal loss approach is meant to minimize the loss function subject to constraints by considering $P=(P_i^{as}) =(P_j)_{1\leq j\leq n}$ and $X=(x_i^{as})=(X_j)_{1\leq j\leq n}$ vectors corresponding to the unit price and the number sold, respectively, by species, season and age; with $n=\sum_{as\in AS} A^{as}$; where A^{as} is the maximum age reached by animal species on a family farm.

Definition of constraints in the optimisation programme

The minimization of the post-production loss function was performed on variables P_i^{as} and x_i^{as}. Because of the nature of these variables, P_i^{as} and x_i^{as} were positive $\forall i \in \{1,\dots,A\}$ and $\forall as \in AS$. This paper distinguishes between the main and complementary constraints to facilitate the resolution of the optimisation problem.

The main constraint is based on the overall income constraint: the sum of the farmer's annual sales is sufficient to cover all the total consumer expenditures (food and non-food) made by the farmer, leaving a profit margin that is at most equal to a share a of total expenditures.

$$\textit{Total expenditures } D \leq \sum_{as\in AS} \sum_{i=1}^{A^{as}} P_i^{as}(s) x_i^{as}(s) \ \leq a^{*} \textit{total expenditures}$$

This constraint can be written as follows: $D \leq \sum_{j=1}^{n} P_j X_j \leq a^{*} D$

Additional constraints are defined on critical parameters, such as the loss function, prices and number of animals.

Constraint on the loss function

The mathematical function for defining the loss function can be negative for some parameters. Therefore, it is important to constrain it to a positive value. The constraint is defined as follows: $f(x_i^{as}, P_i^{as}) \geq 0$.

Constraints on prices

Several constraints on prices were considered to avoid price outliers.

- *Constraint 1*: The vector P^0 is a system data point obtained from the database. Without harming generality, vector P^0 is equal to the vector of the ideal selling prices, which are informed by each farmer for a species at the favourable age at sale. This constraint is defined as follows:
  $P=(P_1,P_2,\dots,P_n) \leq P^0=(P_1^0, P_2^0,\dots,P_n^0)$
- *Constraint 2*: This stipulates that the sale price of a species at age i must be greater than the cost of the animal incurred from birth (the average age at which the animal entered the farm) to the age at which it is sold. This translates into the following:
  $P \geq CU \Leftrightarrow P_j \geq CU_j, \forall j \in \{1, \dots, n\}$
  $\Leftrightarrow P_i^{as} \ \geq CU_i^{as}, \forall i \in \ \{1, \dots, A\} \ et \ \forall as \in AS$
  with $CU = \left(CU_j\right)_{1\leq j\leq n} = (CU_i^{as})$ with $CU_i^{as} = \bar{C}^{as} * i$
- *Constraint 3*: The selling price curves for each species are concave functions of age. Thus, prices increase with age until they reach their maximum at the ideal age, then they decrease. This can be expressed as follows: $P_1^{as} \leq \cdots \leq P_{\bar{A}^{as}}^{as} \geq P_{\bar{A}^{as}+1}^{as} \geq \cdots \geq P_{A^{as}}^{as}$.

Constraints 2 and 3 will cause some prices to be higher than they would have been before the ideal age (see all) because the producer would have spent more on an older animal than on a younger one. This result is unlikely in the case of female cattle because they are more expensive when younger (up to a certain age) due to their milk production capacity. Therefore, for female cattle, the fact that the price of cattle older than 10 years is lower than the price of those three years old is added to the previous constraint. For female cattle, the constraint is presented as follows:

$P_1^{as} \leq P_2^{as} \leq P_{\bar{A}^{as}}^{as} \leq \cdots \leq P_{\bar{A}^{as}+1}^{as} \leq P_3^{as} \leq \cdots \leq P_{\bar{A}^{as}}^{as}.$

Constraints on the number of animal species sold

- *Constraint 4*: This is based on the animal off-take rate. A previously explained, farmers in pastoral and agropastoral systems will sell a limited number of animals just to meet their needs. The herd off-take rate is relatively constant. This constraint stipulates that the total number of animals (of any species at any age) sold is, at the most, equal to the herd off-take rate. It is defined as follows:

$$\sum_{as\in AS}\sum_{i=1}^{A} x_i^{as} = \sum_{j=1}^{n} X_j \leq \textit{off-take rate*herd size}$$

- *Constraint 5*: There is a hierarchy in the pastoral and agropastoral species that are sold. Small ruminants are more likely to be sold than cattle, which are the main assets of livestock producers. The constraint therefore stipulates that the total number of cattle sold is lower than the total number of small ruminants sold.

For the remainder of the paper, the following group of constraints is considered: $Ens_{cont}1$={(X,P) that meet constraints 1,2,3,4 and 5}.

Formulation of the optimisation problem

Without any intervention, the number of dead, stolen or lost animals is given for the farmer who is unable to minimize this loss. Quantity loss (by theft, death and disappearance) during the premarket and market phases should be considered as a constant in the minimization problem. Therefore, the following is posed:

$$G = \sum_{as\in AS} (\bar{P}^{as} - \bar{C}^{as} * \bar{A}^{as}) * [(M_{PM}^{as} + M_{MP}^{as}) + (V_{PM}^{as} + V_{MP}^{as}) + (\Delta_{PM}^{as} + \Delta_{MP}^{as})]$$

subject to:

$$(\mathrm{P}) : \begin{cases} min\, f(X,P) \\ sc \\ D \leq \sum_{i=1}^{n} P_i X_i \leq a * D \\ f(X,P) \geq 0 \\ (X,P) \in Ens\_cont1 \\ X_i \geq 0, \forall i \\ P_i \geq 0, \forall i \end{cases}$$

with $f(X,P)=Losses_{Value}(X^{as},P^{as})+G$.

Solution for the optimisation model: convexity or concavity of the loss function

The nature of the loss function can be analysed in its matrix form.

$f(X,P) = G + \sum_{as\in AS}\big[\sum_{i<\bar{A}^{as}}\big(\bar{P}^{as} - P_i^{as}\big)x_i^{as} - \bar{C}^{as}x_i^{as}(\bar{A}^{as} - i)\big) + \sum_{i=\bar{A}^{as}}^{A^{as}}(\bar{P}^{as} - P_i^{as})x_i^{as} + \bar{C}^{as}x_i^{as}(i - \bar{A}^{as}))\big]$

thus, $f(X,P) = \sum_{as\in AS}\sum_{i=1}^{A^{as}}(\bar{P}^{as} - \bar{C}^{as}|\bar{A}^{as} - i|)x_i^{as}(s) - \sum_{as\in AS}\sum_{i=1}^{A^{as}} P_i^{as}(s)x_i^{as}(s) + G$

by posing $B_i^{as}\bar{P}^{as} - \bar{C}^{as}|\bar{A}^{as} - i|$; therefore:

$$f(X,P) = \sum_{j=1}^{n} B_j X_j - \sum_{j=1}^{n} P_j X_j + G$$

where $B = (B_i^{as}) = (B_j)_{1\leq j\leq n}$ $P = (P_i^{as}) = (P_j)_{1\leq j\leq n}$, $X =$, $(x_i^{as}) = (X_j)_{1\leq j\leq n}$.

With the same calculations at the constraint level, the problem (P) becomes:

$$(P1) : \begin{cases} min\, f(X,P) = (B-P)'.X + G \\ sc \\ D \leq P'.X \leq a * D \\ f(X,P) \geq 0 \\ (X,P) \in Ens\_cont1 \\ X_j \geq 0, \forall j \\ P_j \geq 0, \forall j \end{cases}$$

Starting with the minimization problem ($P1$), the unknowns in this minimization system are the vectors P and X.

$$f(X,P)=(B-P)'.X+G=\sum_{i=1}^{n} B_i X_i - \sum_{i=1}^{n} P_i X_i + G$$

The Hessian matrix of the function $f(X,P)$ is given by:

$$H(X,P)=\begin{pmatrix}\frac{\partial f(X,P)}{\partial x_1\partial x_1} & \cdots & \frac{\partial f(X,P)}{\partial p_n\partial x_1}\\ \vdots & \ddots & \vdots\\ \frac{\partial f(X,P)}{\partial x_1\partial p_n} & \cdots & \frac{\partial f(X,P)}{\partial p_n\partial p_n}\end{pmatrix}$$

Thus,

$$H(x^{as},P^{as})=-\begin{pmatrix}0 & \ldots & 0 & 1 & 0 & 0\\ \vdots & \ddots & \vdots & 0 & \ddots & 0\\ 0 & \ldots & 0 & \vdots & 0 & 1\\ 1 & 0 & \vdots & \ddots & \ldots & 0\\ 0 & \ddots & 0 & \vdots & \ddots & \vdots\\ \vdots & 0 & 1 & 0 & \ldots & 0\end{pmatrix}$$

with $\frac{\partial f(x,y)}{\partial x_i\partial p_i}=\frac{\partial f(x,y)}{\partial p_i\partial x_i}=-1$.

The following is considered:

$$M=\begin{pmatrix}0 & \ldots & 0 & 1 & 0 & 0\\ \vdots & \ddots & \vdots & 0 & \ddots & 0\\ 0 & \ldots & 0 & \vdots & 0 & 1\\ 1 & 0 & \vdots & \ddots & \ldots & 0\\ 0 & \ddots & 0 & \vdots & \ddots & \vdots\\ \vdots & 0 & 1 & 0 & \ldots & 0\end{pmatrix}=-H$$

However, $det(M)=1>0$ means that M is positive, and H is negative; thus, the loss function $f(X,P)$ is concave. The concavity of the function $f(X,P)0$ makes conventional methods inadequate for achieving the loss minimization objective. Therefore, a non-linear programming approach, the method of moving asymptotes (MMA), was used. This numerical resolution method, which belongs to the family of convex approximation methods, is suitable for structural optimisation problems. The MMA provides the best results for concave minimization problems.

4. DATA

A mixed approach to data collection was used to answer the research questions about economic loss. Qualitative and quantitative data were sequentially collected in northern Senegal pastoral and agropastoral areas (Ferlo region).

The area of Ferlo is 67,610 km², nearly one-third of the country. The climate is characterized by rainfall concentrated over two to three months. The annual average is less than 200 mm in the extreme north and more than 550 mm in the south.

In the vast area of Ferlo, the selection of sites for the study was based on a previous study by Wane et al. (2007, 2009, 2010) who had distinguished one agropastoral area (Thiel) and two pastoral sites (Tatki and Rewane) on a North-South gradient for their representativeness of the ecological, geographical, pastoral and biological diversity of the extensive production system of Senegal (see, their socioecological characteristics in Appendix 1). The data collection tools, administered in July and August 2016, addressed the 2015 rainy season[1] through until early 2016 rainy season.

The study focused on a sample of 202 encampments out of 389 potential encampments, for which complete data on the pastoral households was obtained. There was an error margin of 4.79%, with a confidence interval of 95%, thus keeping within standard statistical norms.

Focus groups were conducted at each of these three locations in November 2015. The composition of the focus groups was as follows: 14 participants (14 men) in Tatki; 14 participants (13 men and 1 woman, who did not participate in the discussion) in Rewane; and 14 participants (13 men, including the sub-county chief and 1 woman) in Thiel. The main information collected from these group discussions related to household income-generating activities and animal species traded in the production area, livestock loss in the production area and seasonal loss.

Additional primary data[2] were gathered from responses given by 202 livestock farmers raising small ruminants and/or cattle – 40% from Thiel, 31% from Tatki and 29% from Rewane – to a detailed questionnaire.

[1] Two distinct seasons characterize Senegal's climate: a dry season from roughly October to May and a rainy season from June to September. While the arid zones receive a total rainfall of under 300 millimetres per year, the forested south receives an average of 1200 mm/year. Rainfall is highly variable, both on the interannual and inter-decadal timescales. The average annual temperature for Senegal was 27.8°C for the period 1960–1990, with monthly averages in the hottest seasons of up to 35°C. (https://climateknowledgeportal.worldbank.org/country/senegal/climate-data-historical)

[2] The following data were collected from household investigations: pastoral encampment location, household socio-demographics, herd species composition, ideal average age and selling prices by species and sex, sales decision-making, number of pastoral sub-seasons, average sales volume and prices by species and sub-season, sales motivations, sub-season sales locations, mortality-related quantitative loss, theft and loss, risk hierarchy by species, average animal weight loss during transport to market, herd maintenance and transportation expenses, and the hierarchy of strategies dealing with shocks. The questionnaire ended with a question on the worst rainy season in the previous decade. Pastoral encampments are identifiable socioeconomic settlement units that reveal an aggregate income. They can involve one or more households, which are defined as nuclear or relational units of married couples or blood relatives.

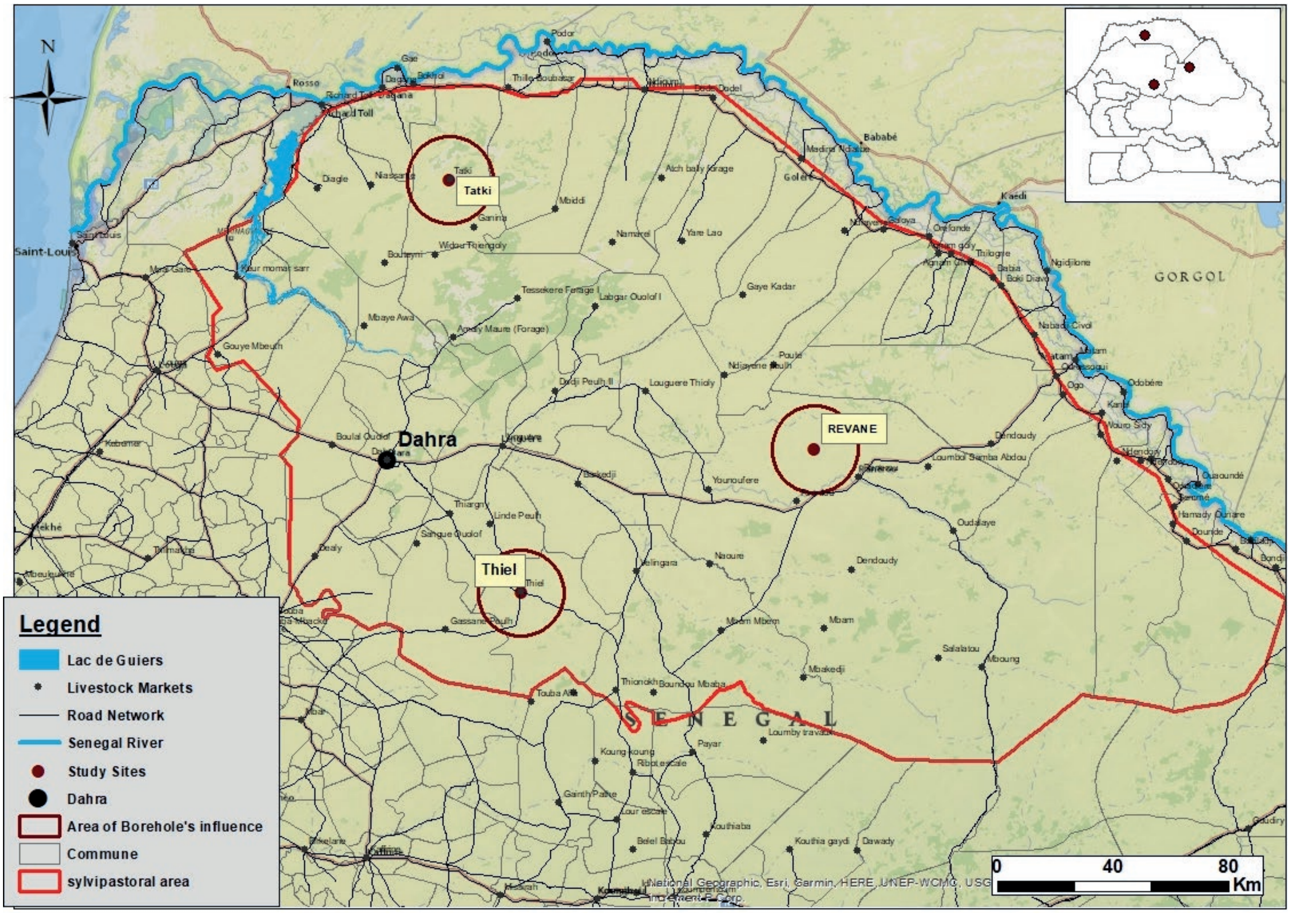

Figure 1. Map of the study location.

5. RESULTS

The results of the optimisation model, which was applied to 202 agropastoral encampments, focussed on a combination of sales volume and selling price by age and species. These data should make it possible for average livestock farmers to minimize their economic loss by generating income to cover their expenditures.

Sales volume

To minimize their economic loss, the average farmer would have to sell 4% male cattle, 26% female cattle, 22% male sheep, 13% female sheep, 17% male goats and 16% female goats from their herd annually (Table 1). The same trends have been observed in other pastoral and agropastoral production systems. Because of the multiple non-commercial roles of cattle in the lives of pastoral producers, cows are not primarily for sale. In uncertain environments, pastoralists always try to maximize the non-monetary benefits from their cattle, despite the long-term costs of raising the animals. Therefore, loss minimization would require the increased application of these strategies to the more effective marketing of cows.

Ideal age at sale

The distribution of optimal sales by species and area shows that the 4% male cattle sales should consist of 58% bulls at an average age of 5 to 6 years (Figure 2). Spatial differences are related to differences in the production systems. Loss optimisation follows the climatic gradient because the bulls sold must be approximately 5 to 6 years old. The data showed that 77% of male cattle are sold in Tatki, the driest zone; 54% in Rewane, the intermediate zone; and 41% in Thiel, the wetter zone.

The situation is slightly different for female cattle. In the study area as a whole, the optimal combination of 92% of sales should comprise cows at an average age of three to five years. The optimal sales volume of cows

Table 1. Approximate distribution of retained animals and optimum number for sale by species and area.

		Rewane (%)		Tatki (%)		Thiel (%)		Survey area (%)	
		Retained	Sold	Retained	Sold	Retained	Sold	Retained	Sold
Cattle	Male	7	8	4	4	2	3	4	4
	Female	18	25	21	27	15	27	18	26
Sheep	Male	14	25	13	22	7	21	11	22
	Female	41	10	47	13	54	16	49	13
Goat	Male	2	19	3	18	3	14	3	17
	Female	18	12	12	17	18	18	16	16

of three to five years old decreases from the wettest area around Thiel (92%) to the intermediate area around Rewane (91%) to the dry area around Tatki (90%).

Regarding small ruminants, a very large number of male sheep are sold during the Tabaski festival. Tabaski, or Eid ul Adha [the Feast of Sacrifice], is a religious festival and the most important feast in the Muslim calendar, requiring the sacrifice of rams. This suggests that optimal sales (49% of the herd) would be rams at the average age of two, three or even four years.

Female sheep and male and female goats play a role in short-term cash flow. The optimal sales are almost equally distributed across all ages, beginning with the first year, which is devoted to animal fattening. The animals sold are mainly male sheep (36% of herd) and female sheep (32%) aged two to three years. For goats, the target composition is males aged two to four years (48% of herd) and females aged five to six years (29%).

Ideal price at sale

The unit price of an animal is a concave function of its age. The optimal model would be for the farmer to sell male cattle at seven years of age at an average price of 271,000 XOF (Figure 3). Before this ideal age,

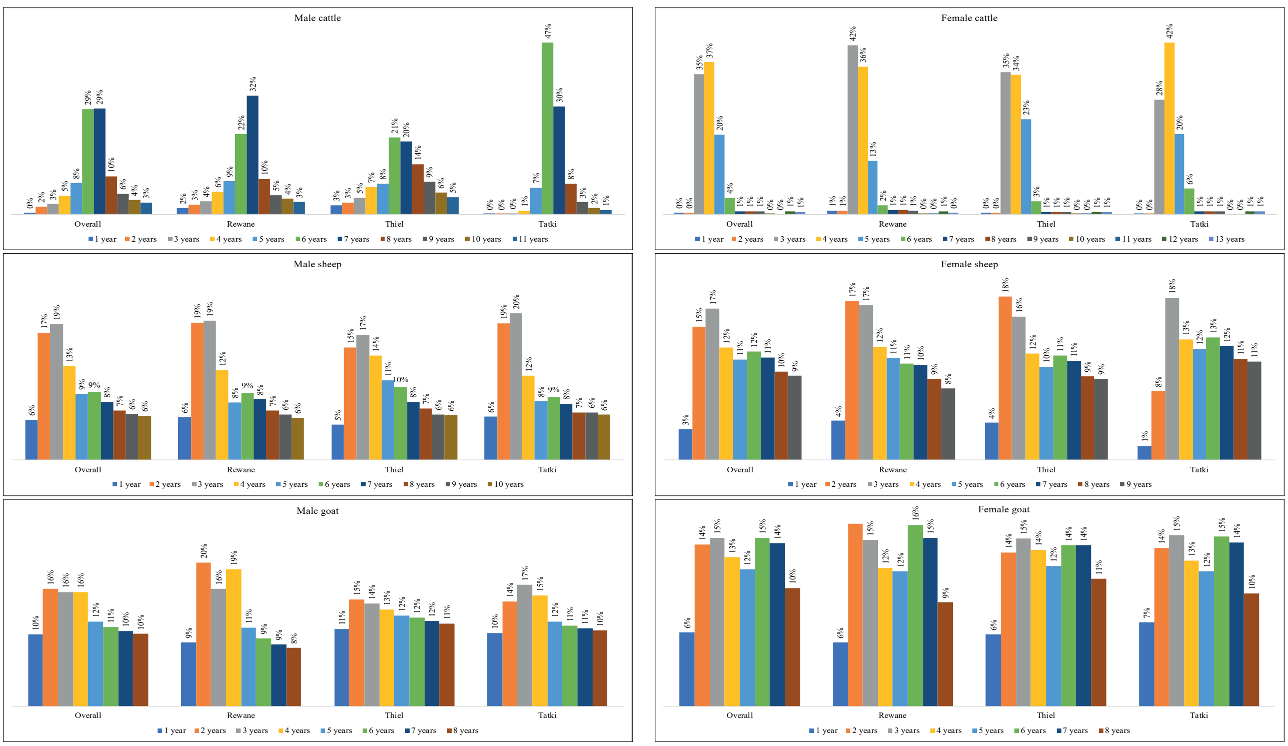

Figure 2. Optimal number of animals for sale by age, species and area.

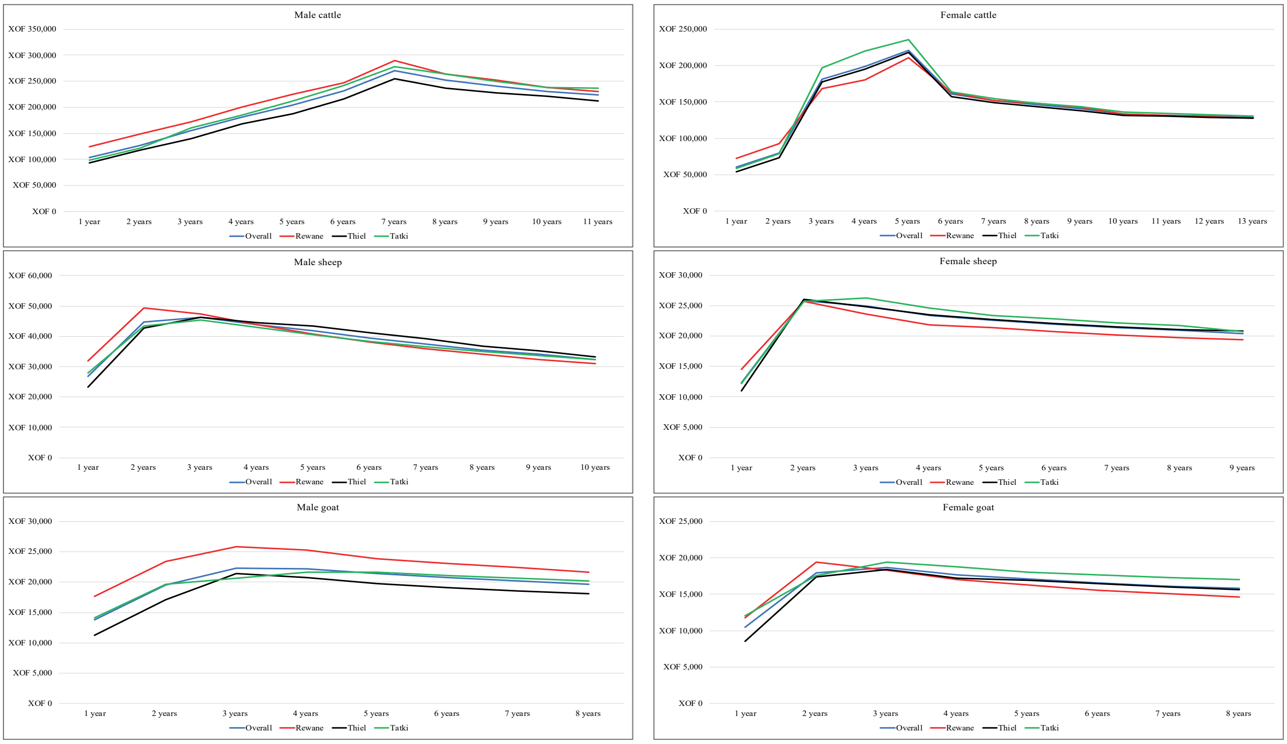

Figure 3. Optimal selling price of animals by species and area.

the average price rises and then falls, while remaining close to the price level for the five- to seven-year-old cattle. For female cattle, the model shows that the ideal age at sale would be reduced to five years (the farmers had initially indicated eight years) for a maximum unit gain at the optimum price of 221,000 XOF. The trajectories of the price curves were similar to those observed for the male cattle. The prices for male cattle tended to be higher in Rewane and Tatki, which are the more isolated areas in the more arid northern region.

For sheep, the ideal age at sale is approximately two years for both males and females. The difference lies in the optimum price, which would be 49,000 XOF for males and roughly half, at 26,000 XOF, for females. The average annual prices for male sheep are relatively high, particularly during Eid ul Adha, which is celebrated by the dominant community (nearly 94% of the population) in Senegal. As with cattle, male sheep have a higher value in Rewane.

For goats, the average ideal age at sale is zone-dependent. In Rewane and Thiel, breeders must sell their male goats at approximately three years of age for an average of 21,000–26,000 XOF. In Tatki, breeders must wait five years to realise an average of 22,000 XOF. For females, there is less variation by area. If the Rewane and Thiel breeders can sell their two-year-old female goats for an average of 17,000–19,000 XOF, the Tatki breeders will realise 19,000 XOF for three-year-old animals.

The optimisation model describes a situation in which the average farmer can minimize physical loss through animal theft and death. This is considered a reference point, or 'business as usual'. Consequently, the study arbitrarily chose three loss reduction scenarios: with a 25%, 50% and 75% reduction in average loss. The effects of these scenarios on the market parameters were then simulated.

Simulation of ad hoc *loss reduction scenarios*

Two radically contrasting periods experienced in Sahelian pastoral areas (including Northern Senegal) were compared: 2014–2015 (period 1), which was characterized by very scarce rainfall in several areas, and 2015–2016 (period 2), characterized by plentiful and evenly distributed rainfall. The comparison showed that losses involving the total herd population on transhumance were 23% in period 1 and 9% in period 2 for cattle; 26% in period 1 and 8% in period 2 for sheep and 43% in period 1 and 11% in period 2 for goats. These figures are far from the 40% to 70% loss rates observed during the droughts of the 1970s and 1980s (Thebaud, 2017). Based

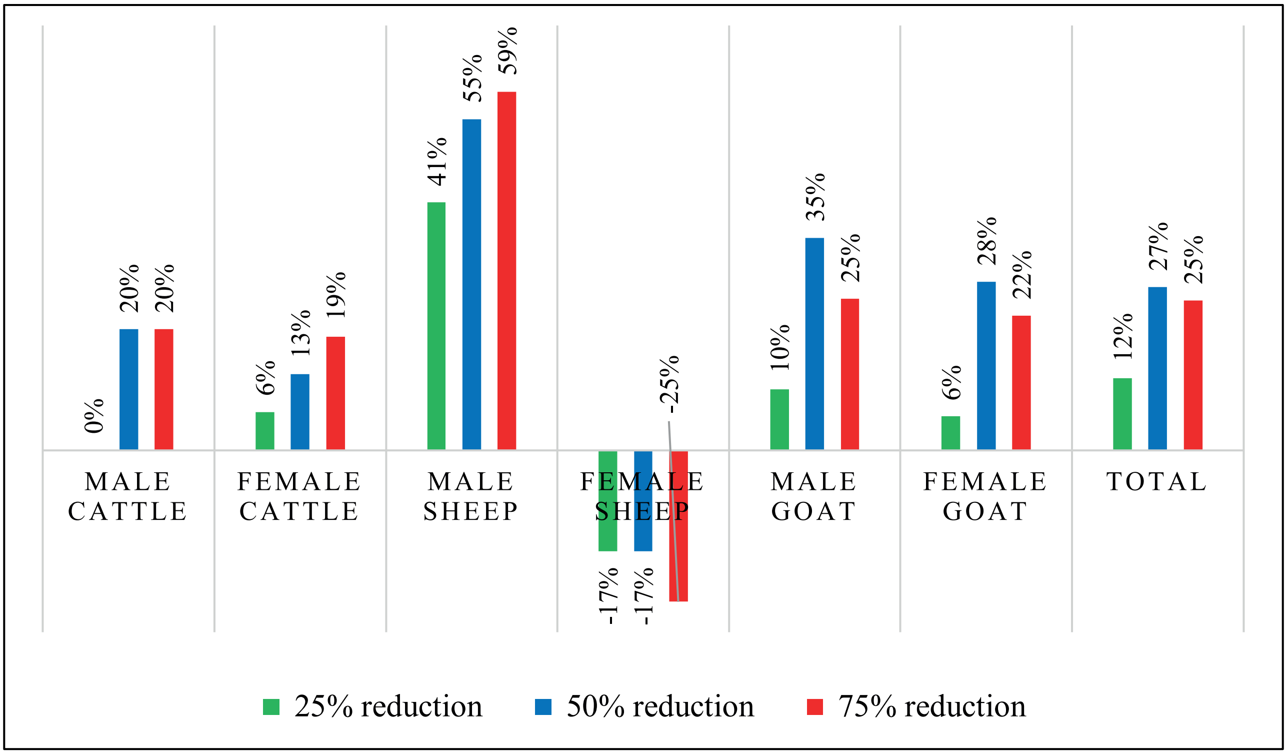

Figure 4. Changes in numbers available for sale with varying loss reduction scenarios.

on this analysis, we developed three ad hoc loss reduction scenarios – 25%, 50%, and 75% – to determine their effects on volume and market price parameters.

Decreases of 25%, 50% and 75% in losses from theft and death would result in increases of 12%, 27% and 25% in the number of cattle, sheep and goats, respectively, available for sale (Figure 4). The exception would be female sheep, for which there would be a 17% to 25% decrease in the number available for sale. The species most sensitive to loss reduction would be male sheep, which, given their market value, particularly during Eid El Adha, are prime targets for theft. Small ruminants are easier to steal and conceal.

The reduction in the loss of female sheep would lead to a decrease in their available number and in the selling price. The relative stability in the number of male cattle available for sale is indicative of the market relationship with this main element of the pastoralist's heritage. First, only 20% would be available for sale following a 50% reduction in loss. For female cattle, the greater the loss reduction, the greater the number available for sale.

All loss reduction scenarios resulted in average market prices generally declining (Figure 5). In the 25% reduction scenario, the smallest negative price change was observed for female cattle, and the largest negative price change was observed for male goats. The 50% reduction scenario allowed for a minimum negative price change of 3% for male cattle and a maximum of 15% for male sheep and female goats. The 75% reduction scenario resulted in a minimum negative price change of 5% for male cattle and a maximum negative price change of 18% for male sheep.

6. CONCLUSION

Given the complexity of loss issues in the ruminant sector, this study identifies several dilemmas presented by the existing analyses of the post-production loss of livestock. These include the zero loss vs. optimal loss approaches. Other issues include the starting point for analysis: pre-market vs. market vs. post-market; enterprise vs. pastoral household model for production systems; intensive vs. semi-intensive vs. extensive; quantitative loss vs. qualitative loss vs. economic value loss; and constraint management vs. risk management.

This study adopted a framework previously tested in the Senegalese livestock production system. It applied a risk approach to analyse the quantitative and economic value of pre-market and market loss in the extensive pro-

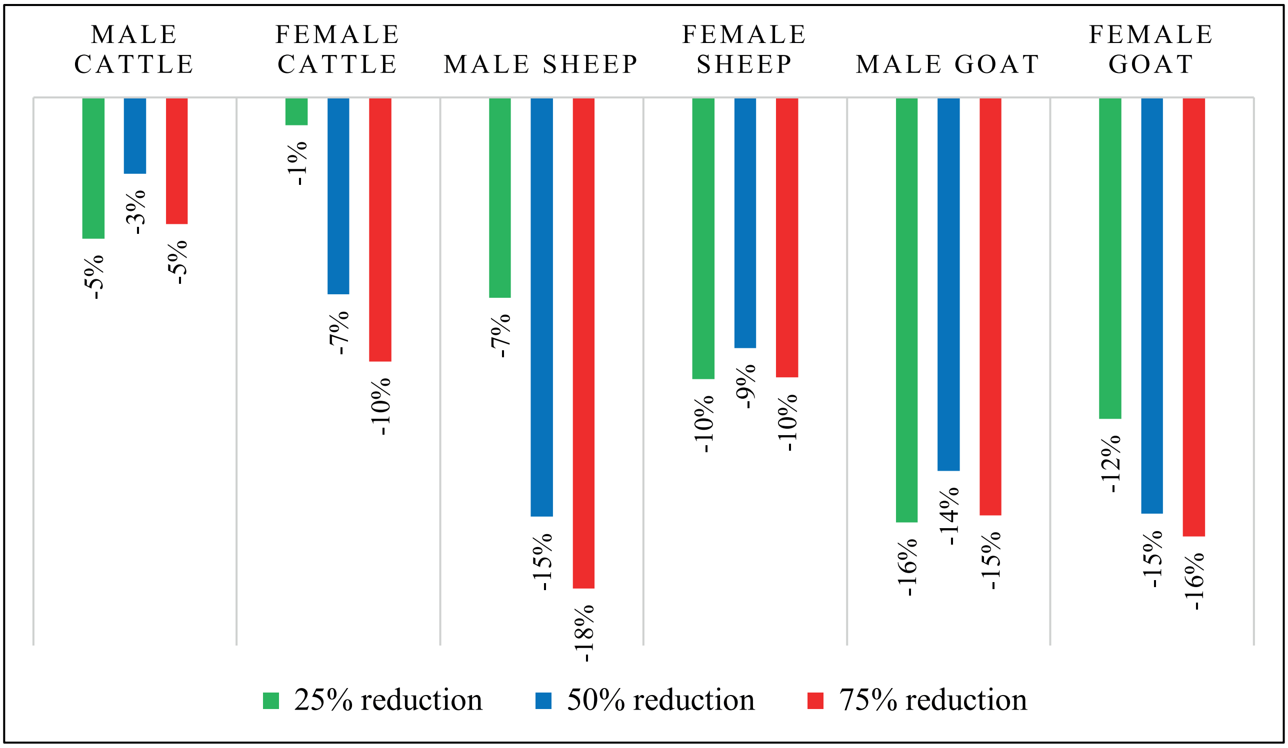

Figure 5. Selling price changes in loss reduction scenarios.

duction systems in Senegal. It elaborated a loss function by summarizing the global monetary loss for big and small ruminants based on the producers' perspectives of the number and prices of animals sold at different ages and sub-seasons. Overall, the study supports the idea of an optimal loss, beyond which further loss reduction is not feasible due to the costs of mitigation. Finally, based on the field data, an empirical exercise was performed to minimize the losses related to animal mortality and theft, subject to the constraints intrinsic to the Sahelian pastoralist. Thus, the effects of the three loss reduction scenarios on market parameters were modelled.

Although intuitive, a new perspective on the value of loss reduction emerged from this study: addressing economic loss is essential. It must be noted that quantitative loss is not necessarily detrimental in the context of general or partial equilibrium because a decrease in food availability can lead to an increase in prices and, thus, in pastoralists' revenues. Therefore, an identification of market fragility and reasoning in terms of opportunity costs or gains allows for a more comprehensive understanding of the economics of pastoralism. However, the simultaneous challenges of food security and improved market parameters (quantities and prices) remain.

The optimisation model also shows that loss reduction can have beneficial effects in relation to the number of animals (except female sheep) available for sale, precipitating a downward trend in market prices. Male sheep were the species most sensitive to loss reduction. All the ad hoc loss reduction scenarios resulted in lowered market prices. Showing the flow of the economy through a social accounting matrix would provide a comprehensive and economy-wide database of the transactions between economic agents during a specific period. In addition, it would be useful for highlighting the importance of loss reduction.

These insights indicate the relevance of loss-reduction policies and actions for addressing food security and competitiveness in the live ruminant sector. Due to the growing complexity and uncertainty in this sector, policies and actions should contribute to the reduction of risk and uncertainty and the prevention of potential conflicts while contributing to growth and resilience. A priority should be the development of a genuine risk culture by providing information on the main risk factors and their occurrence; analysing their economic, social and environmental impact; identifying and evaluating existing risk management tools; and providing guidance on risk prioritisation and management.

In recent years, policies have been developed to create an enabling environment in Senegal. In addition, emerging initiatives address various degrees of severity. However, innovative financial instruments (livestock insurance and credit) and effective information systems could complement the standard approaches to combating disease, animal theft and productivity, as well as the rehabilitation and development of the market infrastructure. As a risk-transfer instrument, the development of livestock insurance could contribute to the reduction of vulnerability by providing compensation against economic loss. Thus, smallholders could avoid using suboptimal coping strategies that further weaken their precarious food and nutritional status or prevent them from using the limited basic infrastructure (e.g., schools, health centres and markets). In addition, productivity could be improved through revitalized investments.

This paper breaks new ground on economic loss in livestock production systems in the Sahel. Given the multifunctionality of livestock and the objective effects of increasing uncertainty, Sahelian pastoralists have mostly used bounded rationality. Thus, integrating their motivations to sell was key. Therefore, an optimisation model subject to pastoral constraints enables the determination of the optimum number of animal species that must be sold to cover expenditure and animal losses.

DATA AVAILABILITY STATEMENT

The datasets, programmes, a full list of data sources, and information on empirical analysis, experiments and simulations generated for this study are available on request from the corresponding author.

ETHICS STATEMENT

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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APPENDIX 1 – SOCIOECOLOGICAL CHARACTERISTICS OF THE TARGET SITES

Tatki, a sandy area in the northern frontier of Ferlo, is exclusively pastoral. Its proximity to national roads and the Senegal River Valley (40 km away) facilitates trade and social links between farming populations. The communities are scattered around a pastoral borehole built in 1953. There is a basic infrastructure that does not function very well. Health services are provided through the intermittent presence of a health officer. A primary school is located close to the borehole, and there is a weekly livestock market mainly for small ruminants, which are prevalent in the herds. Comprising 60% of the Tatki herds, sheep are the dominant species. Cattle account for 25% and goats for 15% of the herds.

Rewane, in east central Ferlo, is an extensive livestock production area. The infrastructure here is mostly non-functional. There is a health office, a school with only two teachers, and a non-resident extension agent who makes occasional visits from Dahra, which is 82 km away. Almost all residents are animal producers. There is one trader and one transporter. The Rewane herds have the lowest proportion of sheep: 55% sheep (41% female and 14% male), 25% cattle and 20% goats.

Thiel, which is further south in Ferlo's agropastoral area, is inhabited by Fulani livestock keepers and farmers of other ethnic groups. Thiel is an important hosting area for transhumance. The basic infrastructure here functions better than those identified in Tatki and Rewane. Two boreholes were built before 1993. The presence of sedentary family farmers explains the school's relatively good functioning. Thiel's bi-weekly market might result from its proximity to Dahra (40 km away), the country's biggest cattle market.

Following Wane et al.'s (2009) study, different settlement units were targeted. These were first stratified by locality, which indicated the pastoral households' place of physical presence and economic activities. This locality then made it possible to identify both the encampments, concessions and households. The encampments are large units of residence, and because they are directly identifiable settlement units, they revealed the level of market income aggregation that we chose to assess in this study. In addition, there are concessions, socio-economic units in which individuals (possibly blood-related) pool their resources for the common good. Finally, there are households of atomic relational units comprising blood-related or married individuals. The sample was structured according to the density of the geo-referenced encampments. The definitions for the weightings of the encampment categories ('very big,' 'big,' 'middle,' and 'small') were validated by the livestock producers and allowed for weighting according to initial densities. As we obtained various perceptions of these categories, we built ours around the average thresholds.

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