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The adoption of sustainable practices in livestock production systems in tropical Andean Páramos

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The geographical areas of the Andean paramo are considered strategic and highly important ecosystems both for their ecosystem services and for being a great support for society based on what water resources imply. However, these ecosystems have been affected by livestock production, which is one of the main activities carried out in these areas. This study highlights the importance of approaching farmers who inhabit these areas from an approach of adopting sustainable technologies and practices in livestock farming so that they can contribute to the conservation of the environment. The study has two main objectives (1) to develop the concept of technology adoption in agriculture, starting from its main categories and approach variables until reaching its relationship with the adoption of sustainable and conservation practices in livestock farming, and (2) provide a conceptual basis that interrelates adoption, livestock and páramo areas as a geographic environment. Finally, this proposed framework can serve as a reference to carry out empirical analysis seeking to test various hypotheses.

KEYWORDS

geographic environment, perceptions, upland farmers, technological change, agriculture

1 Introduction

The paramo is a socio-ecological system that has been inhabited and shaped by human activity since approximately 10,000 years BC. High mountain ecosystems, located between the upper limit of the Andean Forest, and the lower limit of the glaciers or perpetual snow, are called paramos and are found in countries such as Colombia, Ecuador, Peru, Venezuela and Costa Rica (Avellaneda-Torres et al., 2018). This system is highly valued for the water-related ecosystem services it provides to millions of people because it forms the headwaters of the main rivers of the Andean Mountains and the Amazon region, including the Amazon River (Mosquera et al., 2023). Therefore, paramo areas in the Latin American Andean region constitute great sources of life, given the biodiversity they possess and the ecosystem services they contain. Furthermore, these areas are considered fragile ecosystems due to the large number of endemic species they have, as well as the important role in the production and storage of water sources and carbon capture (Sabogal, 2023).

This geographical environment is considered highly complex to approach, especially because of its characteristics that could be considered multidimensional, since it covers environmental, socio-cultural, as well as economic aspects, given that the population that inhabits these territories usually carries out various productive activities for their family

sustenance. This leads to interpreting the paramo as an environment inhabited by a social base that, although it has an influence on conservation and sustainable management, also incurs other uses of the soil and natural resources through activities such as intensive animal husbandry; large-scale agriculture, especially the production of potato varieties; and other economic exploitation activities. Therefore, from this perspective, the interrelation of how ecosystem services and water management can be affected by communities within páramo areas is important, which implies an interaction of what could be called an ecological dimension, but also socio-political that contributes to the understanding of the sustainable management of páramo water (Mosquera et al., 2022).

However, in this article we want to focus the analysis on agricultural activities, especially livestock, given the recognition that this type of productive activities have had in water management. Therefore, from the interrelation between an ecological and socio-political dimension, another important dimension also arises, such as the management of land use in paramo areas. This issue involves the issue of land ownership and the way it can influence the expansion of the agricultural frontier and the decision-making by its owners (López-Sandoval and Maldonado, 2019), but also the way in which that land tenure can be associated with the adoption of environmentally sustainable agricultural practices, given that in the land occupation model, the factors of size, geography and tenure can form a logic of the producer and inhabitant of these territories (Robineau et al., 2010).

In fact, the livestock-producing communities within the same Andean tropical paramo ecosystems are facing a set of complex challenges where they must associate their own production with the generation of family income, along with the sustainable conservation of the environment, and especially of the water resource. In any case, some studies have considered some of these variables mentioned as key within the adoption of sustainable practices, such as usefulness, ease of use and perceived confidence in a certain adoption technology (Adnan et al., 2017), as well as a set of variables related to the topic that can be grouped into categories such as behavioral factors, socio-demographic factors, structural factors at the farm level, and even institutional issues (Thompson et al., 2024).

Regarding this issue, it can be stated that the discussion has focused on three key axes. The first is that human presence in paramo areas should not be essentially stimulated by livestock activities as the main source of income; therefore, a possible transition, at least towards more sustainable production, may be promoted by the role of social interactions as a process of construction of technological practices and the creation of new realities in a socio-technical space (Molina Benavides et al., 2019; Torres et al., 2023). Secondly, in relation to what is involved in the aspects that facilitate the decision-making of livestock producers in paramo ecosystems towards the preservation of the hydrological resource, but also of the flora and fauna, there is a need to harmonize livelihoods at a small scale in the páramo with sustainability (Rey-Romero et al., 2022). Thirdly, and finally, because the influence of broad socioeconomic factors, psychological factors, and producers' perceptions on the adoption of sustainable agricultural and conservation practices has been demonstrated, they can help understand key entry points for making decisions (Foguesatto et al., 2020). Therefore, after describing what the notion of adoption of technology and practices implies, as well as its approach to sustainability in agriculture, this article seeks to expand the discussion.

However, in the discussion of this problem, we still find a knowledge gap around the relationship between the producer, the adoption of sustainable livestock practices, and the theoretical paramo ecosystem that relates the adoption with the environment and the livestock, finally contributing with an analysis framework that allows interrelating categories and adoption variables.

2 Research method

This article followed a two-step research design: first, a systematic literature review with qualitative content analysis was conducted to explore the understanding of the agricultural technology adoption, their dimensions and agricultural sustainable practices discourse. Content analysis was selected as the research technique for the objective, that seeks to quantify content in terms of some key categories, furthermore seeks analyze context when sorting text into groups of related categories to identify similarities and differences, patterns, and associations (Kleinheksel et al., 2020). Therefore, this literature review aimed to illustrate the state of research and scientific discourse within our field of analysis. This helped to identify recurring phenomena, common understandings and research gaps and thus ultimately contributes to conceptual analysis framework development (Tranfield et al., 2003).

Second, we are based on an abduction research approach, which refers to a creative inferential process aimed at producing new hypotheses and theoretical frameworks based on research evidence (Timmermans and Tavory, 2012). Although it has to be clarified that abductive reasoning is similar to deductive and inductive approaches in so far as it is applied to make logical inferences and construct theories, the researcher then seeks to choose some answers from among many alternatives in order to explain a particular fact or phenomenon associated to research interest (Mitchell and Education, 2018).

3 The adoption of technology and practices in agriculture and bridges to sustainability

3.1 Main axes in the agricultural adoption process

The adoption of technologies in agriculture has been a topic of the broadest relevance in scientific literature. In fact, new approaches and analyses constantly emerge that seek to improve the understanding of the influence of aspects and variables in this process, in which the involvement of multiple fields of knowledge has been demonstrated. Agricultural technology adoption theory is a multidisciplinary field that combines elements of decision theory and innovation diffusion theory in an attempt to explain why some farmers adopt new technologies and others do not (Ruzzante et al., 2021). In fact, a set of economic, social and environmental aspects have been identified that can be interrelated and influence agricultural producers differently (Pannell et al., 2006). However, the decision process to adopt a practice or technology by agricultural producers can also be divided between two specific environments: the internal one, that is, where certain characteristics of the producer and his productive farm intervene; and

the external, where a meso level is involved that has to do with the entities of the territory, their particularities, the networks of relationships and the provision of rural extension services and advice to the producer, and government support entities.

From the internal environment, the existence of variables that have a broad influence on the adoption of technologies and practices of the producer has been discussed, such as age, level of education, gender, and even the characteristics of the farm itself where the producer may perceive the advantages and disadvantages of implementing a certain practice, and where behavioral beliefs and psychological factors may intervene (Martínez-garcía et al., 2016). This specific behavioral perspective also puts trust in context as one of the most influential aspects in the decision to adopt by the agricultural producer (Ramírez-Gómez et al., 2020). For this aspect, there are studies that show that trust is an internal perception that could seek to be strengthened through education and rural extension programs, managing to improve producer interactions (Joffre et al., 2019). Furthermore, one of the issues that are considered most important in farmer adoption continues to be a matter of perceived risk (Giampietri et al., 2020). This aspect is key given that there may be a distinction between risk attitude and risk perception, which allows a differentiation to be made between farmers who are willing to take risks and who are more inclined to apply risk management strategies before adopting a policy. Technology or practice, compared to risk-averse farmers, who are generally more willing to face the consequences of their adoption decisions (van Winsen et al., 2016).

Of course, within the framework of the internal environment of aspects that influence the adoption of sustainable practices in agriculture, there is also an interrelation between characteristics and perceptions of the farmer together with his environment. In fact, the influence of incentives on the motivations to adopt sustainable practices has been demonstrated (Greiner et al., 2009). This is how this motivation can also be mediated by the form of land ownership, if it is taken into account that this aspect can generate certain resistance to the adoption of sustainable and conservation practices, and restriction of access to sources of information, knowledge, and government programs (Varble et al., 2016). Given that the literature refers to the fact that the process of technological adoption and practices by the farmer also constitutes a social and interactive process both with his own peers and with other actors, new categories of analysis have been generated such as participation in rural extension and training programs. Therefore, in this relationship between the farmer and the external environment, it has been shown that the adoption process is partially influenced by the farmer's learning environment, and the way in which he assimilates knowledge and information from various local and external sources to the territory, incorporating their learning capacity (Gómez et al., 2023; Ramírez-Gómez and Cuevas Reyes, 2023).

Furthermore, it has been shown that the participation of farmers in both producer organizations and agricultural extension programs positively influences the adoption of agricultural technologies (Wossen et al., 2017), and especially through the formation of information exchange networks and resources that facilitate sustainable practices (Wossen et al., 2013). Finally, we cannot lose sight of the fact that the adoption process in agriculture in rural areas involves a sociological, ecological, but also geographical dimension, given that the specificities of the place constitute influential aspects, such as the forms of relationships, the historical roots of practices,

beliefs, and in general of a culture that must seek to be understood on a larger scale (Audouin et al., 2018).

3.2 Key considerations in the process of adopting sustainable and conservation practices

The consideration of sustainable practices in agricultural production activities has been widely recognized in the literature. In fact, there are many approaches that can differentiate between factors that constitute barriers or incentives for the process of technological adoption and environmental and sustainable practices in agricultural production systems (Rizzo et al., 2024). However, in this section we intend to place greater conceptual emphasis on the involvement of what are called sustainable practices in agriculture and some of the most prominent variables, in order to build a narrative around what it means to use, manage, and conserve natural resources from the notion of adoption.

For example, one of the key axes within the transition towards sustainable agriculture has to do with soil conservation practices, based on the existence of few universal variables that can properly explain the process of adoption or non-adoption of this type of practices by farmers. However, there are at least certain categories that can group a set of variables, and that in various parts of the world have been seen as important to understand what technologies and practices imply for soil resources: characteristics of the farmer; biophysical characteristics of the farm; property administration; and exogenous factors, within which government policies have a lot of influence, such as subsidy structures and payments for environmental services (Knowler and Bradshaw, 2007). Therefore, based on a possible interrelation between internal and external factors, it can be mentioned that the adoption of sustainable practices in soil management in many cases is influenced by aspects such as the farmer's perceptions of the impact and productive performance, beliefs regarding land use improvement, and even government payments for impacts against the carbon market (Ogieriakhi and Woodward, 2022).

For its part, sustainable practices for the management of water resources in agriculture have been a topic of broad interest, even due to the variables that determine the possibilities of adoption by farmers. In fact, water management is a key issue due to its high requirement in agricultural production, but also due to the impact on human consumption, especially in paramo areas as an environment of natural water production. Given that livestock farming is probably the main agricultural activity in moorland and highland areas, it is important to be able to classify some considerations regarding the adoption of sustainable water management practices. Faced with this, we can propose that there is a lot of agreement between various authors regarding a set of variables that affect the adoption of the water resource. Therefore, sociodemographic aspects such as education, the number of economically active family members, and contact with extension actors are prominent issues (Wordofa et al., 2020). Furthermore, it is important to note that although soil and water practices are usually linked in an integrated manner, the impact of various variables on water conservation practices in agriculture can also be sought to be evaluated. Some of these practices have been specified as the management of canals, adequate efficient irrigation

systems, or structures for water conservation; they may be influenced by issues such as access to credit and incentives versus a greater tendency to adopt (Jara-Rojas et al., 2012).

To make a transition towards sustainable agricultural production systems, it is important to thoroughly consider the conservation decisions of farmers so that it is possible to face the challenges in aspects such as the conservation of water resources, soil, as well as the biodiversity that surrounds the area and rural landscape. Even in the face of obvious threats such as climate change and accelerating natural resource loss, it remains difficult to explain why farmers adopt despite extensive research on the topic. Precisely for this reason, since the adoption of conservation practices by farmers, analytical frameworks have emerged that suggest addressing the role of environmental programs, delving into the perceptions and social norms of the farmer where possible social pressures and local conflicts can be understood, as well as the interpretation of the geographical context, placing the farmer within the framework of a human-natural system (Yoder et al., 2019).

3.3 An approach to the dynamics of sustainable livestock practices adoption in geographical areas of highlands and paramos: a matter of perceptions?

One of the topics that we seek to highlight in this section in order to delimit a conceptual approach is that the influence of geographical patterns is also an important topic in the process of adoption of technology and sustainable practices by farmers. In fact, the importance of different environments and geographical contexts with the implementation of environmentally friendly practices has been considered, so that even the analysis of dynamics and phenomena can be specialized in specific areas (Mozzato et al., 2018). Especially the development of agricultural productive activities tends to take place in an environment of great tension in highlands given the complexity of generating a harmonious relationship between productivity and landscape management, where the use and management of natural resources is an issue that causes the problem, if it is taken into account that high geographical areas are usually oriented from an institutional and regulatory environment that could be rigorous, as well as a set of public policies that seek to intervene and regulate productive activities in these areas of influence.

Given that the tension generated by livestock production in high geographical areas due to the aforementioned relationship is evident, some analytical trends seek to propose the narrative according to which the transition towards better practices in high geographical areas needs to take into account that farmers can be involved in a dilemma related to the exploration of their values, and their own assessment of their lifestyles and social structures in terms of the relationships in which they operate in a local environment (McCarthy et al., 2023). Thus, it is evident that even in livestock production, farmers can involve different socio-relational and socio-functional aspects, and where perceptions are more associated with the identity of the farmer himself, in regards to a transition towards sustainable practices (Saleh and Ehlers, 2023).

Therefore, we consider that technological acceptance models that seek to understand the adoption of sustainable practices, based on the analysis of perceptions of usefulness and ease of technological use

by the farmer, are insufficient (Schaak and Mußhoff, 2018), precisely because the geographical environment involves a set of elements that make the analysis more complex and profound. Therefore, we want to propose some conceptual elements that contribute to understanding how adoption by farmers located in these high geographical areas can be addressed and better understood and how their production and business model can be better understood. In this way we raise the idea that the adoption process in highlands and paramos is an issue that should seek to be understood differently for some reasons. First, because livestock activity is perhaps the main form of production in highlands, and is in fact one of the activities that has most sought to involve in transition processes towards productive, economic, environmental and social sustainability (Ogawa et al., 2023).

However, there are very few studies that address the issue of sustainable adoption in livestock farming and especially in the Andean paramo area from a perspective of seeking the conservation of natural resources in this environment, and even in the highlands themselves. One of the most notable works on highland agriculture reveals six basic reasons for the non-adoption of sustainable practices in these areas, generally characterized by resource-poor farmers living on soils with high possibilities of degradation or even in the process of it leading to lose soil and further technical problems (Fujisaka, 1994); however, knowledge gaps still persist that may constitute future lines of research. Therefore, we consider that it is also important to delve into new forms of perception of farmers who inhabit strategic paramo ecosystems, in accordance with studies that demonstrate that the perception of water scarcity in a context of climate change is a determining factor of farmer behavior, especially collective adaptation (Leroy, 2019), and even the need to take into account local perceptions when assessing which ecosystem services farmers value, in order to inform policy decisions with concrete data (Leroy and Barrasa Garcia, 2021).

Secondly, we propose here that despite the existence of extensive experiences on sustainable management of natural resources in highlands, there are still poorly understood aspects that can influence farmer behavior, such as institutional failures, and market and access policies with few incentives for the decisions implemented by farmers (Shiferaw et al., 2009). Especially from an institutional political perspective, it is worth highlighting key aspects in the construction of a conceptual framework regarding the adoption of sustainable livestock farming, because these páramo areas can be governed by regulatory frameworks that could either encourage or, on the contrary, restrict the implementation of practices that are more sustainable for livestock production. Regarding this issue, the set of perceptions that the farmer has about the regulatory environment can also play an important role, which has been explained as one of the disregarded and little considered aspects in the process of adoption of sustainable practices by farmers, generating even a large knowledge gap (Guo et al., 2022).

4 Towards the integration of a conceptual framework on adoption, livestock, and paramo areas

Sustainability in livestock production in high geographical areas and paramos is usually a framework with few approaches, specifically

from the adoption and what the role of the farmer in the productive activity and its tendency to technological change implies. However, in order to reduce the impacts on nature of human activities, different practices and behaviors have been proposed that promote sustainability, based on a search for balance between society, nature, and resources for future generations, with a fundamental emphasis on what is known as landscape sustainability (Wu, 2013). It is in this sense that livestock production activity in paramo areas must seek to maintain active the capacity of the landscape, its basic structure, and ecosystem services.

In the Andean paramo areas, two types of livestock production systems can generally be found, such as intensive and extensive grazing, which are framed in a broad technological spectrum, productivity, profitability, and environmental impact (Holmann et al., 2002). However, we are not interested in differentiating production systems, but rather we seek to contribute with a conceptual approach that interrelates variables and concepts associated with the objective of this study, where we propose an analysis of the adoption of practices and technologies for sustainable livestock farming in Andean paramo areas (see Table 1), in accordance with the approaches that point out the interrelation of three categories adapted for sustainable livestock farming in this geographical environment (Botía et al., 2018).

Furthermore, our proposed analysis framework also has some similarities and adaptations of the approaches of Dessart et al. (2019), who point out that the adoption of sustainable practices is influenced by cognitive factors that bring together a set of perceptions about risks, control, and costs; social factors that involve interactions,

various norms and forms of social approval; as well as the so-called dispositional factors, which refer to farm objectives and even personality aspects. For this theoretical and conceptual approach, we propose the interrelation of three key categories that can direct livestock farming towards sustainable production based on the recognition that grassland management has on production from a multidimensional vision, both for food production and for land rehabilitation, environmental management, in addition to its ecosystem functionality in the face of the water cycle and soil conservation, and the search for a harmonious relationship with the adequate management of animal production (Kemp and Michalk, 2007).

Furthermore, given that livestock production is one of the main global sources of greenhouse gas emissions, it has been suggested that high livestock density in certain areas can also create local environmental problems (Leinonen, 2019), which is why Density is one of the key variables in the management of animal production, as well as other types of livestock practices that clearly – from the vision and management approach – can be associated with the reduction of environmental impacts, especially in fragile ecosystems (Kleppel, 2020). In this sense, we consider that livestock production in the Andean paramo as a strategic ecosystem also represents a challenge for farmers based on the implementation of a wide set of practices such as the rotation of pastures, diversification of species of forages, the establishment of food banks, organic fertilization and soil improvement with microorganisms and other minerals (Durana et al., 2023).

TABLE 1 The adoption of sustainable livestock practices in the Andean paramo area.

Category	Description	Adoption key variables	Key authors
Grassland management	This category covers thematic issues such as the management of grasslands and paddocks, the consideration of topography for soil resource management, and the alternative management of pasture health problems.	Usefulness and importance of technology	Martínez-García et al. (2013)
		Producer attitude and social pressure	
		Subjective norms (influence of neighbors, family, local workers)	Borges et al. (2014)
		Farmer's innovation capacity	Hyland et al. (2018)
		Land ownership	Elahi et al. (2021)
		Socio-economic features	
Environmental and water resource management	Sustainable practices that integrate livestock, forestry, water management, adequate waste management and landscape management are addressed based on the adequate management of the areas of influence.	Cultural aspects and beliefs	Gil et al. (2015)
		Aprovisionamiento del crédito	
		Involvement of government stakeholders	Mekuriaw et al. (2018) and Belachew et al. (2020)
		Technical support	
		Perception of the environmental problem	Sileshi et al. (2019)
		Educational level of the head of the family	
		Participation in development projects	Jara-Rojas et al. (2020)
		Presence of water sources	
Management of animal production	It is related to the implementation of good production practices, which even includes formal process certification processes.	Technology cost perception	Bechini et al. (2020)
		Livestock density	
		Complexity and advantages of practices	Campbell and King (2022)
		Land tenure	
		Access to qualified workforce	
		Financial incentives	Tapasco et al. (2019)
		Productive planning vision	

For its part, the transition towards comprehensive water management, waste management and natural resources constitutes a key category with regard to sustainable livestock production in paramo areas. In this perspective, it has been proposed that in the highlands of páramo an extension of grasslands, livestock management and a certain density of trees can converge, especially in certain hillside areas, generating acceptable ecological conditions from a more sustainable vision (Molinillo and Monasterio, 1997). However, beyond establishing and sustaining the existence of a set of sustainable practices in livestock production, the interest in building an analytical approach has more to do with the grouping of categories and a set of variables that influence the adoption of technology either to favor or restrict this process by the farmer. This framework integrates not only the geographical perspective and its characteristics, but also various perceptions, aspects of the farm, socio-demographics and social issue. In this sense, it is expected that this framework can be used in empirical evaluations both in this paramo environment and in other agroecosystems, either using this approach or generating an adaptation of it.

This previously proposed integrated framework of analysis has broad implications for public policy at the international level. First, because many countries, and specifically in Latin America, must seek to promote agricultural productivity, without losing sight of the effects on sustainability, placing special emphasis on what corresponds to land ownership (Adesida et al., 2021). Second, because the páramo areas, due to their conditions of vulnerability, imply that public policy incorporates better mechanisms for monitoring the potential use of the ecosystem's soil for protection and water production, so that not only can there be punitive interventions, but also better mechanisms for incentives and education (Thompson et al., 2021).

Finally, the conceptual analysis of the literature carried out in this research shows that the approaches to the adoption of sustainable practices in agriculture and their adaptation to livestock production systems are viewed with a broad spectrum of approach, which is important because it provides diverse analysis perspectives. However, it is evident that empirical approaches around the process of adoption of sustainable technology and practices in livestock systems in páramo areas, still lack empirical approaches that allow not only to contrast new hypotheses, but also to generate information that is more useful for decision makers in the design and implementation of public policies.

5 Conclusion

This research developed a conceptual analysis examining the notion of adoption of technology and practices in agriculture, its most determining key factors, in addition to its relationship with conservation and sustainability in agriculture and livestock activity. Although the theoretical approach to the adoption of technology in agriculture and livestock is perhaps one of the broadest in the literature, here we develop the idea according to which the environment and geographical context constitute a key piece of the approach. Specifically, we propose that geographical patterns have an impact on the adoption process by farmers, either due to an institutional and regulatory environment, as well as a set of perceptions

of the farmer within their own geographical environment and their socio-relational perspective, based on their identity and interrelation of values with the environment; as well as from a socio-functional vision that allows dimensioning what the farmer conceives of certain sustainable practices and their relationship with the natural resources of the environment.

More specifically, we refer to the geographical context of paramo areas as a strategic and highly fragile ecosystem, which is affected by mainly livestock activity, on which farmers have developed their livelihoods and subsistence. Although technological adoption is mediated by a wide set of categories and variables, some of which we were able to develop in the text, in this study we propose an approach to the integration of the adoption of technologies and sustainable livestock farming practices in paramo Andean areas. Therefore, for the purpose of expanding the conceptual discussion on the topic, our study shows, based on the literature, that there is a set of key variables of the adoption of sustainable technologies and practices that can be adapted for a greater understanding of technological change in livestock farming towards sustainability in paramo areas.

Author contributions

CR-G: Conceptualization, Formal analysis, Investigation, Methodology, Writing – original draft. AG-C: Conceptualization, Formal Analysis, Investigation, Methodology, Writing – original draft. HR-E: Funding acquisition, Resources, Writing – review & editing.

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Conflict of interest

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