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Drivers of Adoption of Sustainable Prickly Pear (*Opuntia ficus-indica*) Innovations and Conservation Agriculture by Smallholder Farmers in Morocco

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Abstract: Climate change poses significant challenges for countries in Northern Africa such as Morocco. Smallholder farmers are especially vulnerable to climate change because they experience several challenges in the adoption of climate-resilient practices. The sustainable and well-managed cultivation of the cactus pear (*Opuntia ficus-indica*) could contribute to conservation agriculture (CA) in dry climates threatened by climate change. Due to its high-water-use efficiency and ability to withstand extremely dry conditions, the cactus pear is increasingly being recognised as a more sustainable alternative to traditional livestock foraging in dryland areas. Compared to many other common crops and fodder, the cactus pear is easy to establish, maintain, and has a wealth of uses. Two innovative cultivation techniques are being developed: (1) the use of mixed inoculum formulations containing AMF (Arbuscular Mycorrhizal Fungi) and PGPB (Plant Growth-Promoting Bacteria) in the soil; and (2) intercropping between perennial (cactus pear) and short-term species (field crops). We propose to identify factors that could facilitate farmers' innovation adoption. We conducted face-to-face interviews with 24 smallholder cactus pear farmers in Morocco. We concluded that farmers do not yet have a comprehensive understanding of the principles of the innovations. The main aim of farmers was to increase production and income. Farmers, in general, pay little attention to the environment. The recommendations that are given in relation to these issues are that training and social networks are essential in innovation transfer, adoption needs to be facilitated by providing resources, an innovation transfer needs to be adapted to the current and future needs of farmers, and we need patience so that farmers can slowly learn the innovations.

Keywords: climate change; climate-resilient practices; farmers' income; Mediterranean agriculture; drought resistance

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1. Introduction

Climate change poses significant challenges for 'developing' countries in Northern Africa such as Morocco because it causes high temperatures, droughts and soil degradation [1–3]. A statistically significant trend towards drier conditions has been detected in several Moroccan regions [4]. Currently, Morocco is trying to be a "model country" for green energy, even when it experiences challenges in reaching its sustainability goals, especially in rural regions where there is a high level of poverty [5,6]. This happens in a rural context of high poverty (14.4%) and vulnerability rates (23.6%) [7]. Smallholder farmers are especially vulnerable to climate change and because they live in marginal areas, they lack access to technical and financial support [8].

The cactus pear (*Opuntia ficus-indica*) is seen as a well-suited crop for harsh and arid areas, providing an interesting option for the farmers there [9]. Recent interest in the crop's multiple potential uses as a feed source and protection against soil erosion and water loss has opened up opportunities for export, job creation and income generation for smallholder farmers [9,10].

The cactus pear is often used as a fence around houses and small towns; fence plants are also used for fruit production and, in the dry season, as a source of forage. Fruits are harvested from unmanaged plantations and are used for home consumption or sold on local markets. The Opuntia cladodes are used as feed for small ruminants and camels. Nevertheless, the sustainable and well-managed cultivation of the cactus pear could contribute to conservation agriculture (CA) in dry areas threatened by climate change [11,12]. For some years cactus pear production has been increasing and the annual production in Morocco was reported to exceed 1.2 million tonnes from 150,000 hectares in 2011 [13]. At that time, the country started programmes to further expand the cultivation in arid regions (with UN support) [13].

As to make use of the potential beneficial effects of the cactus pear in the dry Moroccan climate, there is a need to focus on sustainable cultivation techniques [11]. CA innovations currently experience many challenges in their adoption like soil erosion and excessive pesticide and fuel use [14,15]. Sustainable practices that focus on soil cover and organic matter enhancement are displaying positive results for many farmers and could improve local resilience against climate change [16,17].

This paper is based on results of a research project that focuses on 'Promoting soil fertility, yield and income in Smallholder Agriculture of semiarid and arid Mediterranean regions by management of beneficial soil microbiota, conservation agriculture and intercropping'. This project looks at the potential adoption of a combination of several CA innovations by cactus pear farmers. This includes the use of mixed inocula containing AMF (Arbuscular Mycorrhizal Fungi) and PGPB (Plant Growth-Promoting Bacteria) in the soil and intercropping between perennial (cactus pear) and short-term species (field crops). The aim of developing these innovations is to reduce soil erosion and the use of chemical inputs, to increase crop productivity/quality and soil fertility and to stimulate smallholder associations and knowledge [18].

The development of CA innovations could be made part of a viable strategy to contribute to the food security of smallholder farmers, but they currently experience many challenges in their adoption and diffusion [19]. Many of the commonly used options in response to climate change are resource-intensive and beyond the reach of resource-poor smallholder farmers. Ecosystem-based practices, like intercropping, may be more accessible to smallholder farmers as they are based on the management of existing resources. This provides the opportunity for farmers to adapt according to their contexts, needs and experiences and to combine multiple practices that provide long-term resilience [8].

Based on a farmer-centred innovation adoption perspective, we propose in this paper to identify the main drivers and barriers to the adoption of technological innovations by smallholder farmers.

The Literature on Farmer's Innovation Adoption

There is a substantial body of the literature on the adoption of innovations by (smallholder) farmers. Several authors have talked about the need to look at the economic, social, technical and ecological viability of a specific innovation [20,21]. It is important to build partnerships with farmers in the value chain to enhance innovation, as these partnerships can integrate profitability, societal needs and environmental sustainability [22].

Until now, studies have looked at the extrinsic factors impacting adoption rather than at how farmers perceive the benefits and challenges of innovations. Even if researchers observe advantages of an innovation, farmers do not necessarily perceive this in the same way [23]. There is a gap between the development of sustainable practices and the implementation of these practices, which is thought to reflect the low adaptive capacity of smallholder farmers because of constraints in their ability to invest in resilient practices [8]. More in-depth research is needed into how smallholder farmer's decision making varies across different farming practices and socioeconomic conditions.

A farmer-centred approach can be used to engage smallholder farmers in the development of context-specific innovations [24]. A good understanding of the local context and the farmer response can provide information about pitfalls and opportunities [15,25]. The adoption of innovations by (smallholder) farmers is determined by many factors: the availability of technology and infrastructure, human resources, knowledge transfer, access to (public) extension services, financial resources, market access, risk perception, land/property rights, social interaction, gender, food security, agriculture dependency, agro-ecological conditions and attitudes towards the environment [9,25–30]. Research is needed to gain a better understanding of these determinants [31,32].

There is a need to study innovations that are accessible for smallholder farmers and fit their agro-ecological and socioeconomic contexts [8]. To define the relevant adoption factors, interviews with Moroccan smallholder cactus pear farmers were conducted and analysed about farm and farmer characteristics, costs and benefits, as well as preferences, experiences and attitudes in innovation adoption. This paper begins with an introduction to the study area. It then examines the methodology. The results are then presented in several sections. Finally, the discussion, conclusions and recommendations are presented.

2. Materials and Methods

2.1. Study Area

This study took place in Morocco. The economic growth of North African countries depends on the sustainable use of water resources due to the (semi)arid climate. This is why they need crops that can adapt and grow in these areas [33]. Morocco is already on the arid side of the climate class spectrum, with six interviewed farmers living in an arid climate, fifteen farmers living in a semi-arid climate and three farmers living in a dry sub-humid climate (Appendix A).

The average annual rainfall does not exceed 412 mm in all of the Moroccan regions. It was observed that more dry periods are taking place in several regions of Morocco compared to the past, which challenges several agricultural practices.

In this case, it becomes clear that the cactus pear is suitable in terms of climate and a rather important plant species for smallholder farmers in Morocco [34]. The cactus pear is often planted for fencing off an agricultural area [12]. The cactus pear is a suitable crop for personal consumption and care, animal feed and commercial purposes [35]. Moroccans also eat the fruits, providing them with a source of fibre, vitamin C, antioxidants and laxative properties [35]. Traditionally, a small amount of the fruit production (10%) is used locally and a large part (80%) is sold fresh on the national market [36].

2.2. Farmer's Questionnaire

The farmer-centred approach was used to define the variables that can affect the adoption of innovations by smallholder farmers. Different variables were used to make a questionnaire including: (i) environmental regional data; (ii) identification; (iii) housing; (iv) farm; (v) cactus plantation; (vi) technical knowledge; (vii) agricultural practices; (viii) production system; (ix) product processing; (x) marketing; (xi) benefits, constraints and support needs; (xii) income and expenses; (xiii) farmer behaviour towards innovation; (xiv) knowledge and practices about soil fertility; and (xv) willingness to adopt innovations.

The questionnaire was used in structured face-to-face interviews, which were carried out in May and June 2023 with smallholder farmers who were cultivating the cactus pear in seven regions of Morocco.

2.3. Sampling

A sample of farmers was found by using snowball sampling. This method consists of asking each interviewee to identify another person to contact for an interview. Snowball sampling can be a useful way to conduct research about farmers who have experience with cactus pear cultivation. Through this process, a sample size of 24 Moroccan farmers was gained in different regions of Morocco (sample list in Appendix A). This research is qualitative, so it does not seek to be representative of the whole population of Moroccan farmers. Instead, this research discovers the factors and mechanisms that influence agricultural innovation adoption in different climatic conditions (Appendix A).

The interviews with these respondents each took about 1–1.5 h per person (including, e.g., eating, drinking, phone calls and smoking). The respondents could speak the language in which they were most comfortable. This meant that all of the interviews were conducted in the Moroccan dialect. The answers were written down next to the questions, after which each form was signed by the participant to acknowledge their consent. Adding to that, some observational notes were made.

2.4. Data Analysis

After executing the interviews, the answers were translated into English and the data were implemented and categorised in Microsoft Excel. Suitable methods and procedures were used to analyse the innovation adoption factors. The environmental factors were combined, so that the environmental context of each region was defined.

Then, the answers to the open questions of the interviews were given different codes using Excel and they were divided into code groups/themes. This can be completed in either an inductive or deductive fashion or using elements of both [37]. This research used both inductive and deductive elements. The concepts which were derived from the literature were implemented into the coding, but the data had influence on the codes which were applied in the end.

All the information about the farm and the farmer as well as their environment was combined to develop a farmer typology [29].

3. Main Results

We present the results of this research in three separate sections. In Section 3.1, the traditional production process followed by the cactus pear farmers interviewed is explained. Section 3.2 discusses the potential adoption of innovations by these farmers. Finally, the factors that may be associated with the adoption of innovations are presented (Section 3.3).

3.1. Farm Characteristics and Production Resources

All of the interviewed farmers were men. All of these farmers were married, except the youngest interviewed farmer. Women play a role in the cooperative, processing and selling part, but the wives of these farmers are in the background of the farmer's home. The age of the farmers was mainly between 40 and 59; only six farmers were younger than 40 and three were older than 60. A total of 11 out of 24 farmers had a formal education level up to primary education, which means that they had education until the age of 12. Four of the farmers did not have any formal education. Four farmers had reached a secondary education level, and three farmers reached a tertiary (professional school/university) level of education.

Many of the interviewed farmers own minimally managed cactus fields without adopting a lot of new techniques or equipment and none of the farmers use electricity. According to almost all of the farmers (23), they use a traditional production system in their farming. Only one farmer said that he uses a semi-intensive production system instead. Another farmer uses both systems, meaning that he made a semi-intensive system in two plots while the other plots remained traditional.

The household size determines the amount of human resources that are available on the farm. Most farmer households consist of household sizes that extend outside of the nuclear family, with more than two adults per household (20 households). These adults provide the workforce for the households which mostly exceed four members (23 households).

A five-hectare area was used as a threshold for smallholder farmers. Medium-sized farms are 5–15 hectares and large farms are +15 hectares [38]. According to these criteria, 16 of the interviewed farmers are smallholders, five own medium-sized farms and three own large farms. All of the interviewed farmers live in a self-owned house and own land; there are only a few farmers who make use of rented (four farmers) or collective (one farmer) land. Most of their cultivated land is rain fed and only two farmers own a small amount of irrigated area.

From Table 1 it becomes clear that knowledge transfer through social interaction plays an important role in the knowledge acquisition of the interviewed farmers. The two farmers with no level of and beginner-level education both only rely on daily practice for their knowledge acquisition. Farmers who say that they have an intermediate and experienced level of knowledge rely more on social interaction, meaning heritage (17 farmers) and trainings (2 farmers). As a knowledge channel, most farmers (16) use direct contact, but some farmers (10) also use the Internet to connect with others.

Table 1. Source, channel and level of knowledge of interviewed cactus pear farmers about cactus pear cultivation.

Source and Channel of Knowledge	Level of Knowledge About Cactus Pear Cultivation			
	No Level	Beginner	Intermediate	Experienced
Heritage	0	0	10	7
Daily practice	1	1	2	3
Training	0	0	2	0
Direct contact	1	1	7	6
Internet	0	1	5	4

In terms of access to transportation infrastructure, almost half of the interviewed farmers (10) do not own a means of transport. In addition, none of the interviewed farmers own heavier means of transport like a pick-up truck and instead, cars, motorcycles, bicycles and animal-drawn carts are more common. Additionally, some farmers live a few kilometres away from a paved road, which makes it hard to travel.

Some interviewed farmers have fewer resources than others; this is shown through the asset index (domestic assets, transport, livestock and farming equipment).

Using the asset-based approach of Morris et al. [39], the wealth of the farmer respondents was categorised so that different wealth levels were distinguished. This is an approach that aggregates assets into an index using weights for each asset equal to the proportion of households who do not own this asset. The assumption is made that only the few wealthiest households would be likely to own an asset with a high monetary value [40]. Following [39], the asset score was derived by assigning to each asset (g) a weight equal to the reciprocal of the proportion of the study households who owns one or multiple units of that asset (w_g), then multiplying that weight by the number of units of assets owned by the household (f_g) and summing the product over all assets. Thus, for each household (j), the following equation was used:

$$\sum_{g=1}^{G} f_{gj} \times w_g$$

Then, the asset scores for all farmers were divided into quartiles and they were categorised into different socioeconomic positions according to their score so that they could be compared with each other [39] (Figure 1).

The Asset Index distribution among the farmers (Table 2 and Figure 1) presents a great diversity of farmer's wealth, with a minimum that is lower than 10 and a maximum that is higher than 90. If we look to the observed distribution of wealth (Table 2), we can see that the different farmers are equally divided between the different categories. This means that there is no over-representation of one wealth category.

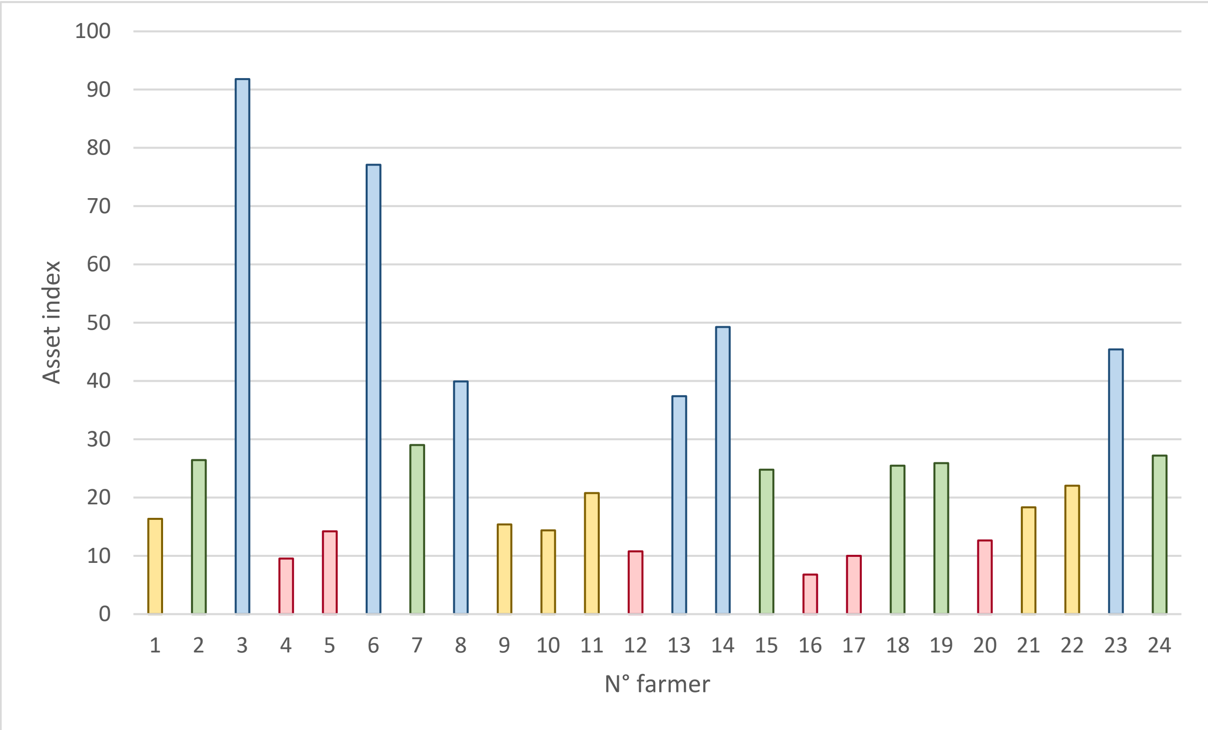

Figure 1. Asset indices of farmers, with 1st quartile (red), 2nd quartile (yellow), 3rd quartile (green), 4th quartile (blue).

Table 2. Distribution of asset index.

Category	Range	Number of Farmers
1st quartile (red)	6.78–14.33	6
2nd quartile (yellow)	14.33–23.41	6
3rd quartile (green)	23.41–31.12	6
4th quartile (blue)	31.12–91.82	6

The housing quality of most Moroccan farmers is good; only one farmer seems to live in a poor housing condition. Several cactus pear farmers own multiple livestock species (e.g., quails, chickens and bees), which are seen as both an asset and a source of income as they can provide products like eggs, honey, milk and meat.

The fresh cactus pear fruit is the main product from the cactus pear crop that these Moroccan farmers are manually harvesting. The farmer uses some kind of grass or foam, which he rubs on the skin of the fruit to remove the spines. After that, he can either eat or sell the fruit, without hurting himself. Eight farmers harvest the cladodes and six of these farmers sell these cladodes to the market. One farmer made it a habit to sell also the cactus pear flowers. The cactus pear seed oil is the main marketed product when the fresh fruit is not available (observations). Farmers do not process the fruits into cactus pear oil themselves; organisations, specifically cooperatives, perform the oil pressing and sell it as a beauty product. However, due to a cochineal pest infestation (*Dactylopius opuntiae*), many cooperatives that were involved in cactus pear processing have been closed down and many farmers have stopped any processing activities that they did before (observations). None of the farmers process and/or sell processed cactus pear products for the market. The farmers usually produce for the local fresh market and just five farmers produce for a larger market. None of the farmers produce for export.

According to farmers, the greatest benefit of cactus pear farming is the drought resistance of the crop as it helps them to use fewer resources. The farmers are also happy about the medicinal virtues, economic profitability, crop production in summer, fodder production and a favourable climate and soil (Table 3). Yet, this is threatened by cochineal pest infestations. The farmers also mention constraints in cactus pear valorisation, the physical difficulties of farming, transport, marketing, water scarcity and technical constraints.

Table 3. Main benefits of cactus pear cultivation.

Benefits of Cactus Pear Farm According to Farmers					
Answers	**1st Answer**	**2nd Answer**	**3rd Answer**	**4th Answer**	**Total Answers**
Drought resistance	12	6	1	0	19
Use as fodder	1	3	5	0	9
Economic profitability/Income	4	2	2	0	8
Medicinal virtues of the fruit	1	4	2	0	7
Favourable climate and soil	2	1	2	0	5
Limited need of inputs	0	3	1	1	5
Summer product	1	1	1	0	3
Total mentioned benefits	21	20	14	1	56

3.2. Potential Innovation Adoption

According to the first technological innovation based on intercropping, a few of the farmers sometimes use intercropping with annual or other perennial species, so these farmers do not need to change much regarding this part of the innovations. Nevertheless, most farmers do not grow cactus pears in rows with rows of intercrops in between, but use mixed cropping with random patches of cactus pear and some other crops. For the second innovation about the use of bacteria and mycorrhiza fungi, none of the farmers display knowledge about beneficial soil bacteria and mycorrhizal fungi, microbial fertilisers, biostimulants or biochar. Additionally, less than half of the farmers (10) use a type of fertiliser. Eight farmers let part of their land lay fallow so that it can recharge for the next crop. About half of the interviewed farmers (11) give importance to soil fertility, but the other farmers (13) say that soil fertility is not important. They do not give importance to the soil fertility, even though that most of the farmers mention that many of their farming plots have poor soil fertility (32 plots) (Figure 2).

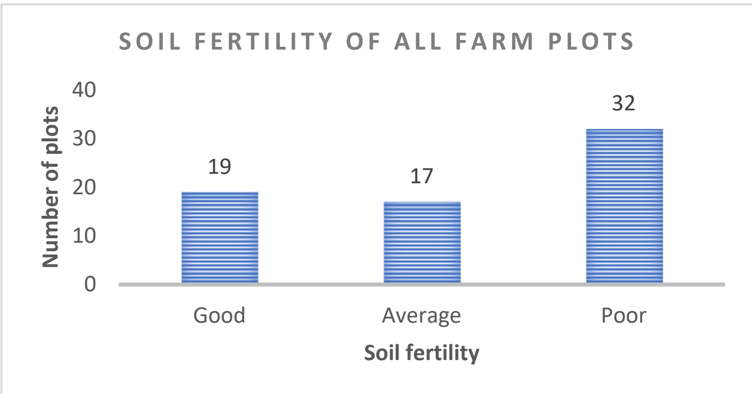

Figure 2. Soil fertility of farm plots on the land according to farmers.

However, farmers have some knowledge about and use practices that reinforce the soil fertility (Table 4).

Table 4. The soil fertility practices that farmers know and use.

Soil Fertility Practices Which Farmers Know Versus Use				
	Know (Number)	**Know (%)**	**Use (Number)**	**Use (%)**
Farmyard manure	24	100	11	46
Mineral fertilisers	24	100	3	13
Crop rotation	10	42	9	38
Mixed cropping	10	42	2	8
Mulch	8	33	4	17
Compost	7	29	0	0
Reduced tillage	5	21	3	13
Green manure	4	17	1	4
AMF and PGPB	0	0	0	0
Microbial fertilisers	0	0	0	0
Biostimulants	0	0	0	0
Biochar	0	0	0	0

Farmers use these practices for different reasons: crop rotation is used for yield improvement and because it is part of heritage and usual practices, mixed cropping is used because it is part of the usual practices, mulching is used for water conservation and fertilisation and farmyard manure and mineral fertilisers are used for fertilisation and yield improvement.

The other farmers do not plough the soil for cactus pear production. For intercropping and the use of beneficial microorganisms, a no/minimal tillage system is the most suitable system.

All of the farmers are interested in learning more about beneficial soil bacteria and mycorrhiza for income improvement, knowledge development, quality improvement, yield improvement, curiosity or organic production (Table 5).

Table 5. Main reasons for learning more about the innovation.

Why Are Farmers Interested in Learning More About Beneficial Soil Bacteria and Mycorrhiza?		
Reasons	**Number of Farmers**	**% of Farmers**
Income improvement	12	50
Knowledge development	4	17
Quality improvement	3	13
Yield improvement	2	8
Curiosity	1	4
Organic production	1	4

However, they do not know how to answer the question about what they expect from the innovations. Ten farmers say that there are multiple differences between the innovations and their current practices, but they do not know what the differences are. Many farmers (18) think that the innovations fit their cultural traditions, as they can improve yields, modernise current practices, improve income and make work easier. Six farmers indicate that the innovations might not fit with their traditions and current practices, but they can again not tell the reasons (Table 6).

Table 6. Farmers' opinions about proposed innovations.

How Do Innovations Fit in Traditions of Farmers?		
Reasons	**Number**	**% of Farmers**
Improves yields of current crops	6	25
Does not fit/no benefit	6	25
Fits, but no reason	5	21
Improves income	4	17
Modernises current practices	2	8
Makes work easier	1	4

Only five farmers are willing to adopt the innovations. According to them, the factors that might accelerate their decision making towards adopting the innovations are financial aid, training, profitability, availability of equipment and technological advantages (Table 7).

Table 7. Facilitators of innovation adoption.

What Do Farmers Need to Adopt Innovations?		
Needs	**Number**	**% of Farmers**
Financial aid	6	25
Training	4	17
Profitability of innovations	3	13
Equipment	1	4
Technological advantages	1	4

This is in line with what the farmers say they need for their farm in general. Receiving training is one of the most important needs as only two farmers have followed a training until now. Many farmers also say that they are in need of financial support, an increase in the availability of pesticides and technical equipment and fertilisers.

Farmers will need to make different investments to be able to use intercropping and the inoculum of beneficial microorganisms in their farm. They need to buy and apply the inoculum, which is not yet sold commercially (it is produced in-lab by the project partners). The farmers also need to measure their soil fertility to know how much inoculum to use, so they will need to pay for an analysis of their soil. They will also need to plant an intercrop for which there are costs for the seeds and planting in rows. Training sessions to learn the techniques will be organised, which will take time and money (e.g., for transport) from farmers to be able to join.

The innovations will provide several expected benefits. For example, AMF inoculation could enhance the relative water content (RWC) in inoculated cladodes (in progress). Secondly, soil fertility could be increased (in progress). Thirdly, AMF inoculation has a positive effect on the number of new cladodes and their size.

3.3. Factors That Are Potentially Related to Innovation Adoption

Cactus pear production provides some income for the interviewed farmers, but the amount is relatively low. This means that the income that comes from the cactus pear does not cover the living costs of an average Moroccan household (21% of the living cost per year). Even the farmer who earns the highest return from cactus pear production does not surpass 43% of the living cost and the farmer with the lowest return covers only 4% of the living cost.

One farmer explained about the risks involved in relying solely on the income of cactus pear farming. That is why he diversified his income by working on other businesses, e.g., quail farming. Some farmers diversify their income outside of agriculture, either as their main activity or as secondary activity. Three farmers have agriculture as their secondary activity and have a main job as a security guard, gas station manager or construction worker.

4. Discussion

The discussion first covers the attitude towards the innovation and sustainability of farmers. The second matter that is discussed comprises the main barriers to adoption. Third, recommendations to contribute to the transfer/adoption of innovation are made. Then, the overall conclusions are made. Finally, the limitations of the study and future research are considered.

4.1. Attitude Towards Innovation and Sustainability of Farmers

As mentioned before, the climate in Morocco keeps becoming drier and soil fertility is low. To address these matters, the project innovations are relevant as the innovations contribute to a lower level of soil evaporation and improved soil fertility. The attitudes of farmers towards the environment and innovation affect the decision making of them towards sustainable innovations. The interviewed farmers are producing in a traditional and non-intensive way without much pesticide, fertiliser and water use. Yet, they want to use these resources so that they can increase their yields. It seems like the farmers are not using this non-intensive system of production by choice; instead, restricted access to resources has caused them to use this system. Some farmers give importance to soil fertility and know several soil-fertility-improving practices, but just a few of them in fact use these practices. They would be willing to intensify their production without looking at the impact on the environment if they had the resources. Farmers are rather aiming for yield and income improvement than for CA.

It can be said that cactus pear farming in Morocco is mainly dominated by men. Community norms define how traditional roles in gender can affect whether a technique or crop is considered socially or culturally appropriate [27,39]. However, as we only talked to male farmers, we cannot know about the role of women in cactus pear farming. This means that the focus is on men for the decision making in cactus pear farming because traditional gender roles are indeed affecting the decision-making process. Nevertheless, as women are a part of the farmer's household (almost all of the farmers are married) and are observed to be part of the processing and selling part of the cactus pear, they have an influence on the income that can be generated from cactus pear production. Their role should not be neglected, as they might contribute to making the final adoption decision.

The farmers do provide some input, but they find it difficult to think about foreseeable advantages and drawbacks as they have not yet adopted the innovations. Farmers do not (yet) display an understanding of what the innovations can mean for them (benefits and risks). At least they like to discuss and ask questions about these issues, but it does not seem as an equal exchange of information as the presenters provide all the information, so this is not really a participatory approach and there might be hierarchical interactions coming into play. Some people might have more to say than others and decide about what the benefits and limitations of the innovations are. Researchers can define benefits for the farmers, but they first need to experience it for themselves by making trials with the innovations and/or observing and interacting with trials at other farms. This is necessary because, even if researchers observe advantages of an innovation, farmers do not necessarily perceive this in the same way [23]. In the heterogeneous agricultural sector, this means that farmers in other regions might have differing opinions on the innovations, which also need to be taken into account.

4.2. Main Barriers of Adoption

The adoption of innovations is said to be hindered by inequalities in the household socioeconomic status [27]. However, in this case, there is no correlation or pattern observed in the wealth distribution between the farmers. Additionally, land rights are causing no limitations for any of the farmers, which is in contrast to the statement that [15,41] made that smallholders have less motivation to make investments because of unclear land rights. Next to that, farmers are thought to be more likely to adopt the innovations when they had received formal education [41]. In this case, it does not seem that important as none of the farmers gained knowledge about beneficial soil microorganisms, regardless of their education level. The non-availability of family labour can be another limiting factor in innovation adoption [15]. Most of the farmer households consist of household sizes that extend outside of the nuclear family, which means that a lack of labour is not an issue for them.

This study instead defined other issues that influence how farmers behave towards innovation adoption. As a cactus was considered as a weed in some countries, and in order to control these plants biologically, the false carmine cochineal scale was introduced in infested areas. The *Dactylopius opuntiae* cochineal species became a pest with a devastating impact on the cactus pear production in the Mediterranean area. Climate change plays a role in changing the development and survival of all insect species and rising temperatures increase the risk of infestations. This means that climate change is not only making the area hotter and drier, but also increases the risk of pest occurrence [42].

Thus, developing conservation agriculture in the area should include dealing with risks of pests next to dealing with desertification. It is important to look at the most important risks in each context and in Morocco, the cochineal pest forms the most important risk for cactus pear cultivation at the moment. However, farmers do not have sufficient access to resources to fight this pest [43]. In agreement with the literature, the lack of resources seem to be the main problem for farmers in changing their practices. Many farmers want to follow training, but a lot of them did not participate in any training because they felt restrained.

The knowledge transfer between researchers and farmers is quite difficult as cactus pear farmers do not live close to the university that works on the innovations, they mainly use direct contact to communicate and many of them do not own a mode of transport and live in mountainous areas. This means that these services do not contribute to making farmers part of a social network. Alternatively, farmers might experience support from institutions, but are afraid to mention it in the interview, as there are some issues of trust between the farmers and researchers. In addition, many women are working as researchers while all farmers whom we met were male, which means that viewpoints might be different due to gender differences.

Access to adequate information through social interaction plays a critical role in shaping the decisions which farm households make about the adoption of new innovations [28,31,41]. This study's results also show that a knowledge transfer is taking place mostly through social interaction and is family-oriented because they mostly learn through heritage. Nevertheless, the farmers who already adopted new technologies say that they use these technologies based on 'self-knowledge' and they do not transfer them to others. At the same time, they say that they will base their innovation adoption decision on others and some farmers use the same technologies in the same region. Thus, there must be some type of technology transfer taking place, but farmers do not recognise the process.

Farmers do not perform any processing activities and do not export. This means that there is an opportunity here for the farmers to enhance marketing. The cactus pear is not profitable enough on its own to fill in for the living expenses of a household, so farmers respond by investing in other types of income outside of cactus pear production. Most farmers use more area for other crops compared to cactus pear and the income gained by the cactus pear is relatively low compared to the amount of land that the crop occupies.

4.3. Recommendations to Contribute to Innovation Transfer/Adoption

There is a gap between the development of sustainable practices and the implementation of these practices, which is thought to reflect the low adaptive capacity of smallholder farmers [8]. There might be some difficulties in adopting beneficial microorganisms, as testing bacteria and fungi in the lab is not in the same circumstances as on the farm. Many of the farmers do not even use the common types of fertilisers, so it will be difficult to adopt a new type. Farmers would like to use fertilisers, but prices might be too high for the farmers to make the investment in either beneficial soil microorganisms or other fertilisers. For intercropping, some farmers already use mixed cropping and have different crops growing among the cactus pear crop. Even though the farmers often do not plant in rows, mixed cropping can be easily transformed into intercropping. The farmers already use a no/superficial tilling system, which makes the soil suitable for the innovations. Thus, intercropping does not require a lot of new inputs, and the microorganisms could be sold like a fertiliser with a long-term effect on the soil. If the innovations form an affordable alternative with increased yields and income besides improving CA, this might lead to farmers preferring the innovations over commonly used resources for yield improvement and intensification.

The community knowledge and technology exchange that is already present can be enhanced by making farmers more aware of the knowledge transfer process and their understanding of the innovations. This means that more and continued training as well as discussions and interactions with researchers are needed to see what works best for each individual. A way to bridge the gap between farmer and researcher might be to use cooperatives, (farmer) associations and/or community networks to provide a platform for trainings as well as to provide financial support. These services and networks are critical in improving credit access, lowering the investment risk and averting a lack of technical know-how, information asymmetry and input constraint [28]. Many of the interviewed farmers are already connected through one of these mediums and it will be easier for them to be brought together. As multiple farmers are connected to the internet, this medium might provide another opportunity for communication. Yet, access to telephone services and the Internet is still often lacking in smallholder communities [15]. Nonetheless, even though many of the farmers do not use the Internet, this might change in the future as the role of ICT continues to grow in rural areas [44].

After learning about the great threats of the cactus pear pest in the Mediterranean region, the research in the beneficial effects of beneficial soil microorganisms, conservation agriculture and intercropping should be extended towards improving pest management. For example, beneficial soil microorganisms can contribute to fighting the cochineal pest through improving integrated pest management. Additionally, the results of El Aalaoui and Sbaghi [45] indicated that one of the isolates (EL01SB) of the *Pseudomonas* spp. bacteria species could be included in integrated pest management against the cochineal pest [45].

Adding to that, resistant varieties are being developed by several research institutions with regards to the cochineal pest through in vitro propagation. This option is rather investment-intensive and the quality of the yield is lower for resistant varieties. The project innovations should be adapted to the most significant current risks and threats, so that we, as researchers, can respond to what farmers currently need. Other parts of the cactus pear production, like marketing, can only be improved if the farmers can obtain a sufficient yield. Not enough research has been completed yet to find the best cultivation methods which take into consideration the current risks and threats to mitigate the cochineal pest in an effective and affordable way.

5. Conclusions

To conclude, cactus pear farmers do not (yet) seem to have a comprehensive understanding of the principles of the project innovations, especially of beneficial soil microorganisms. If the innovations will not contribute to reducing risks, it is highly unlikely that farmers will adopt these innovations. However, if integrated pest management is developed to fight the cochineal pest, farmers will have more space to utilise innovation, diversification and marketing opportunities.

The main aim of farmers is to increase production and income while the main aim of the researchers is to improve the soil fertility (and consequently increase production and income). Even though some farmers care about the soil fertility, they, in general, have a poor attitude towards the environment and have little knowledge about their knowledge transfer process. In addition, farmers have limited access to the work of the researchers as well as other resources. These limiting factors make the communication between farmers and researchers and, consequently, innovation adoption rather difficult. For example, internet communication, training, the linkage of the research with cooperatives and associations, financial support and/or farm trials of the innovations can contribute to bridging this gap between farmer and researcher.

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Appendix A. Distribution of the Cactus Pear Farmers Included in the Sample, Across Morocco

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