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The Knowledge-Behavior Gap in Soil Conservation: An Interventional Study with Small-Scale Farmers in Chile

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ABSTRACT

Scientific literature proposes that the central objective of soil science education, particularly within the context of soil management education, is to promote soil conservation. The purpose of the study was to analyze the impact of a soil management course, taught by soil professionals, on the farmers' soil science knowledge and their soil conservation behaviors. This research makes a novel contribution, as few existing investigations have examined potential behavioral changes resulting from an intervention with farmers. The research involved 33 small-scale farmers in the Arica and Parinacota Region, Chile. This study employed both qualitative and quantitative methods, with data collected through surveys (pre- and post- course, and a subsequent retention test) and interviews following the retention test. The training course significantly enhanced farmers' understanding of soil science, as demonstrated by their performance on the post-course survey and retention test. However, no statistically significant improvement was observed in farmers' soil conservation behavior. Interview results confirmed these quantitative findings, and provided insights into underlying mechanisms, which are consistent with the theories of the stage model of self-regulated behavioral change. Our study offers current evidence of the knowledge-behavior gap in agricultural decision-making. This study challenges the typical focus of agricultural extension activities on knowledge alone, highlighting how this approach overlooks potential behavioral changes resulting from the intervention. The format of our training program (traditional lectures and interactive discussions) is widely used in Chile. A future training course

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could focus on practical workshops and real-scale demonstrations of the recommended practices, as requested by participating farmers.

Keywords: Agricultural extension; Behavioral change; Land degradation; Pro-environmental behavior; Soil protection.

INTRODUCTION

Soil management practices are a critical component of human civilization's life support system (Liang *et al.*, 2024; Maruthi *et al.*, 2024). Indeed, improper soil management practices have been implicated in the collapse of several ancient societies (Hillel, 1992; Diamond, 2011). Taking this historical context into account, scholars emphasize the importance of soil conservation for advancing sustainable development (Koch *et al.*, 2013; Lal *et al.*, 2021).

Over the last decades, researchers have studied the factors that influence farmers' adoption of environmentally sustainable practices (reviews conducted by Baumgart-Getz *et al.*, 2012; Prokopy *et al.*, 2019; Ranjan *et al.*, 2019; Lu *et al.*, 2022). Research has shown that economic constraints and incentives are important drivers of farmers' decision-making (review by Bartkowski and Bartke, 2018). However, the review by Chouinard *et al.* (2008) revealed that many farmers are motivated by conservation goals, even if it means sacrificing immediate profits.

Currently, there is no single overarching theory that accounts for farmers' decision-making in relation to conservation practices (review by Dessart *et al.*, 2019). For instance, the review conducted by Winkler-Schor *et al.* (2024) identified 29 unique theories used in land management research.

A prominent theory explaining farmers' decision-making is based on a complex relationship between farmers' soil science knowledge, their attitudes toward soil conservation, and their actual soil conservation practices (Gholami and Papzan, 2021; Burnham *et al.*, 2023; Jalilian *et al.*, 2025; Neaman, 2025b; Piran *et al.*, 2025). Farmers' soil science knowledge refers to applied understanding of soil management techniques aimed at mitigating global soil degradation (Neaman *et al.*, 2024). In turn, "attitude" can be defined as a mental position with regard to a fact or state or a feeling or emotion toward a fact or state (Merriam-Webster Dictionary, 2025). The "knowledge-deficit theory" (Schultz, 2002) posits that a lack of environmental knowledge can hinder pro-environmental actions. Equally, it is well known that pro-environmental attitudes influence farmers' decisions to engage in conservation behaviors (Farani *et al.*, 2021). Therefore, a combination of improved attitudes toward soil and enhanced soil science knowledge among farmers will likely contribute to the adoption of more sustainable soil conservation practices (Jalilian *et al.*, 2025).

This study focuses on small-scale farmers in Chile. It focused primarily on soil science knowledge, attitudes toward soil conservation, and soil conservation behavior as previous studies (Burnham *et al.*, 2023; Neaman, 2024; Neaman *et al.*, 2024; Neaman *et al.*, 2025) have provided extensive evidence for the validity of scales to measure these constructs among Chilean farmers.

Scientific literature proposes that the central objective of soil science education, particularly within the context of formal soil management education, is to promote soil conservation (Muggler *et al.*, 2006). This objective of soil science education implies the need for longitudinal studies that investigate whether interventions are effective in promoting soil conservation actions among the participating farmers.

The review conducted by Floress *et al.* (2018) emphasizes the scarcity of interventional studies in soil conservation research. Likewise, the review conducted by Lobry de Bruyn *et al.* (2017) highlights the frequent reliance on simplistic metrics, such as attendance numbers and participant satisfaction, in agricultural extension activity reports. Despite the recognized importance of behavioral factors, few studies have employed longitudinal designs with validated, reliable scales to evaluate behavioral change among farmers (Neaman, 2025a). Many other studies primarily evaluate knowledge gains, overlooking potential behavioral changes (Rejesus *et al.*, 2012; Pan and Zhang, 2018). This limited scope undermines our understanding of the true impact of these interventions.

As previously mentioned, this study focuses on small-scale farmers in Chile. Previous research in the area (Burnham *et al.*, 2023; Neaman *et al.*, 2024) demonstrated that the farmers' possessed limited understanding of soil management principles, despite showing favorable attitudes toward soil conservation. Accordingly, our intervention specifically targets knowledge gaps in soil science rather than attitudinal aspects. We hypothesized that a soil management training course will improve farmers' knowledge, which, in turn, will lead to observable changes in soil conservation practices.

Some researchers posit that the evaluation of training programs should also analyze the impact on agricultural productivity and farm economic rentability (Kirkpatrick and Kirkpatrick, 2006). However, the study by Roesch-McNally *et al.* (2018) demonstrated that some farmers are able to overcome the issue of an apparent trade-off between short-term productivity goals and long-term conservation goals. For these reasons, we limited our analysis to farmers' knowledge and behavior, excluding long-term impacts on agricultural productivity and farm economic rentability.

While the chosen study area is particularly significant for Chile, it is important to recognize that soil degradation is a global issue (Editorial, 2004) undermining agricultural sustainability worldwide. This emphasizes the broader importance of our study, extending its implications beyond the local context.

It should be noted that this study was designed with a specific emphasis on scrutinizing the effects of a soil management course, administered by soil professionals, not only on enhancing farmers' soil science knowledge but also on influencing their soil conservation behaviors. Crucially, this dual focus on knowledge acquisition and behavioral adjustments distinguishes our study from others, offering a more comprehensive understanding of the impact of the course on farmers' practices and knowledge in the realm of soil conservation. This emphasizes the innovative nature of this study.

METHODS

Study area

The study area comprised the Arica and Parinacota Region, located in the northernmost part of Chile (Figure 1), known for the world's driest desert, the Atacama Desert (Figure 2A). However, in the Altiplano (a high Andean plain), there exists an interesting phenomenon, which brings heavy rain during the summer months. This phenomenon allows groundwater and rivers to replenish (Kikuchi and Ferré, 2017). This, in turn facilitates agricultural activities in the coastal areas of the region. Agricultural areas are located in the plain parts of river basins (Figure 2B). The region's favorable climate permits the year-round open-field cultivation of crops, including during the winter months. Aridisols and Entisols are the predominant soil types in the region (Casanova *et al.*, 2013).

One of the most pressing agricultural challenges in the region is the proliferation of plant diseases and pathogens (González Vallejos *et al.*, 2013; Mazuela Águila, 2013), which causes wide-spread use of synthetic pesticides. In general, farmers are uncertain of what to do with the agricultural production waste that is generated on their farm. In some cases, they dispose of it somewhere, e.g., along a road (Figure 3A). In other instances, farmers attempt to compost their agricultural production waste, but they approach it incorrectly. Instead of forming a pile, they place the waste in a box (Figure 3B), which prevents them from periodically turning the pile to ensure the required aeration. Only a small fraction of farmers conducts soil chemical analyses. This is particularly concerning given the widespread nutrient deficiencies observed in the region, as illustrated by a partially exfoliated citrus tree (Figure 3C) and tomato plants exhibiting clear symptoms of iron chlorosis (Figure 3D).

Study population

The total population of the Arica and Parinacota Region is ~226,000 people, concentrated predominantly in the city of Arica, contrastingly the rural population is only ~4,500 people (ODEPA, 2020). Given the extensive area of the region (16,873 km^2) and the difficult accessibility to the Altiplano areas (located at an elevation of more than 3000 m above sea level), it was essential that we focused our research on the coastal area of the region, around the city of Arica.

The population of interest for this study were small-scale farmers because, as mentioned above, they possess a poor understanding of soil management principles and there is a need to enhance their soil conservation actions (Burnham *et al.*, 2023; Neaman *et al.*, 2024). Around the city of Arica, such small-scale farmers are located in the Concordia and Lluta river basins (Figure 1). Accordingly, we approached the following two agricultural communities located in these river basins:

1) a group of 80 farmers, located in the Concordia River basin,

2) a group of 50 farmers, situated in the Lluta river basin.

We announced a free-of-charge training course on soil management, delivered by soil science experts. Similar training courses for farmers were held in Chile on other topics, such as biodiversity conservation (Márquez-García *et al.*, 2018).

In response, 33 small-scale farmers enrolled in the course, i.e., the response rate was 25%. This approach corresponded to convenience sampling (also known as opportunity sampling), a common approach in research. However, it is important to note that findings derived from convenience samples are not generalizable to the broader population (APA, 2018).

Furthermore, it is important to acknowledge that this study is somewhat limited given the relatively small sample size. With 33 participants, we were able to detect large effects (Faul *et al.*, 2007). Nonetheless, rural studies notably use both qualitative and quantitative research methods

(Strijker *et al.*, 2020). Therefore, we decided to mitigate the limitation of small sample size by including qualitative analysis (see "Qualitative method" below). As discussed below, the qualitative analysis effectively confirmed the results of the quantitative analysis.

Socio-demographic characteristics of the participants were as follows: age of 52 ± 15 (range of 25–77) years old; 48% females, 67% self-identifying as Aymara (an indigenous ethnicity of northern Chile) and 33% as not belonging to any indigenous ethnicity; 58% without any professional degree and 42% possessing a professional degree, 85% declared not having any previous training in soil management and 15% had such previous training. Importantly, none of the participating farmers had a professional degree related to agriculture. All participating farmers possessed relatively small land parcels (smaller than four hectares), which were used for both annual crops (e.g., tomato, Figure 3D) or fruit trees (e.g., citrus, Figure 3C).

All participants received comprehensive information regarding the study's objectives, methodology, and potential implications. The informed consent procedure highlighted the voluntary participation principle, guaranteeing farmers complete autonomy to withdraw from the survey at any stage without consequence. Data collection procedures were designed to minimize participant burden while strictly maintaining confidentiality, in full compliance with established research ethics protocols.

Training description

The training program combined traditional lectures with interactive discussions among participating farmers. This is a typical format used in Chile for farmers' training programs (Márquez-García *et al.*, 2018). The interactive discussions focused on: 1) farmers' evaluations of their current soil management practices, 2) the applicability of knowledge gained from the training, and 3) challenges in adopting new practices based on their learning.

It is important to mention that the income of small-scale farmers in Chile tend to be unstable (Castillo *et al.*, 2022). Furthermore, economic constraints are the most important factors on farmers' decision-making worldwide (review by Bartkowski and Bartke, 2018). For this reason, we decided to focus our training on soil conservation practices that require minimal (if any) economic investment. Specifically, six sessions were delivered over a six-month period, covering the following topics:

1) Importance of soil as a resource in agriculture,

2) Management of saline and calcareous soils,

3) Compost, fermented organic fertilizers, *Rhizobium* bacteria and other beneficial bacteria, symbiotic fungi (mycorrhiza).

4) Soil disinfection by solarization, fallow use, stubble burning alternatives, alternative pesticides (biopesticides).

5) Soil structure, soil erosion, use of mulch and cover crops.

6) Importance of the chemical analysis of the soil, irrigation water, and organic matter to be applied to the soil. Estimation of the dose of fertilizers to be applied based on the results of the analyses.

Research approaches

This research employed both quantitative and qualitative approaches. Data was collected through surveys and interviews, as described in detail below.

Enrolled farmers were initially screened with the question: "Do you make decisions related to soil management on your farm?" Among 33 participating farmers, 21 had made independent decisions regarding soil management on their farms. An additional 12 farmers had relied on decisions made by external soil management experts who provided professional consulting services to them.

Based on this initial screening, we decided to consider the responses from all the participating farmers (n = 33) on soil science knowledge and attitudes toward soil. However, in the analysis of the soil conservation behavior results, we only considered farmers who made independent decisions regarding soil management on their farms (n = 21). Similarly, only farmers who made independent decisions regarding soil management on their farms were involved in the interviews.

Quantitative method

The quantitative approach involved a self-administered pen-to-paper survey, which incorporated three key scales: (1) soil science knowledge, (2) attitudes toward soil, and (3) soil conservation behavior.

1) The scale of soil science knowledge (Supplementary Table 1) utilized true/false questions to assess farmers' objective understanding of soil management practices related to preventing various

types of global soil degradation (Editorial, 2004). Validity criteria for this scale are presented in our previous Chilean research (Neaman, 2024; Neaman *et al.*, 2024).

2) We used a 5-point Likert scale to measure farmers' attitudes toward soil (Supplementary Table 2). This scale included the following five options: (1) strongly disagree; (2) disagree; (3) neither agree nor disagree; (4) agree; (5) strongly agree, allowing for nuanced responses. Validity criteria for this scale are presented in our previous Chilean research (Neaman, 2024; Neaman *et al.*, 2024).

3) The scale of soil conservation behavior (Supplementary Table 3) evaluated actions related to various areas of soil management. Soil conservation behavior was assessed using a 5-point Likert scale with options ranging from "never" to "always". It is worth noting that the soil conservation behavior scale utilized in the present study included a "not applicable" option. This allowed farmers to skip a question if it did not apply to their specific farming situation. Validity criteria for this scale are presented in our previous Chilean research (Burnham *et al.*, 2023; Neaman *et al.*, 2025).

Reliability is a key concept in psychometrics, referring to the trustworthiness or consistency of a measure (APA, 2018). One common method for assessing reliability is Cronbach's alpha (Cronbach, 1951). The scales of soil conservation behavior and soil science knowledge used in this study demonstrated acceptable reliability (Cronbach's alpha values of 0.74 and 0.72, respectively), whereas the scale of attitudes toward soil demonstrated an excellent Cronbach's alpha value of 0.95. The reliability of the scales measuring soil science knowledge and attitudes toward soil was assessed using pre-test responses from all participating farmers ($n = 33$). However, the reliability of the scale measuring soil conservation behavior was determined based on the pre-test responses of farmers actively making decisions about soil management on their property ($n = 21$).

With respect to the statistical analysis of the quantitative survey, paired analysis of variance (ANOVA), also known as repeated measures ANOVA, was used to examine the effect of the training course on farmers' soil science knowledge, attitudes toward soil, and their soil conservation behavior. A confidential code was used to match pre-, post-, and retention test scores for each farmer. A Tukey test was used for multiple comparisons.

Qualitative method

The qualitative approach consisted of interviews. Each farmer was visited by the research team on their farm. Based on the recommendations of Berroeta *et al.* (2024), we introduced the interview as follows: "Let us go for a walk on your farm; please show us your farm". This approach allows participants to feel more relaxed during the interview (Berroeta *et al.*, 2024). It also allowed the interviewers to observe and validate the adoption, or lack thereof, of diverse soil management practices, such as:

Use of cover crops and/or mulch,
Composting of vegetal materials or, opposingly, piling plant debris as waste,
Production of fermented organic liquid fertilizers,
The use of fallow land,
Soil disinfection by solarization,
Use of conventional synthetic agrochemicals (pesticides, herbicides, fungicides, nematicides),
Burning of stubble and/or pruning residues and/or leaves.

During the farm visit, we asked each farmer the following questions:

– How do you perceive the impact of the course on your knowledge of soil management practices?
– What do you think about the current soil management practices on your farm?
– Are you interested in implementing some of the soil management practices that were discussed during the course?
– What practices have you been able to implement during the three-month period since the last session of the course?
– What challenges are associated with implementing this/these practice(s)?
– Based on the information you gained during the training sessions, what additional information do you need in order to implement soil management practices?

Through these interviews, the research team gained a nuanced understanding of each farmers' situation, as well as a deeper insight into the factors influencing the adoption of soil conservation behaviors among the participating farmers. To guarantee the validity of the qualitative analysis, members of the research team conducted an independent analysis of the interviews, and then discussed the results, reaching a consensus.

Process

A pre-test was administered at the beginning of the first class, a post-test was administered at the end of the sixth class (6 months after the beginning of the course), and a retention test was administered at the follow-up class (4 months after the post-test). As previously mentioned, a confidential code was used to match the two tests completed by each respondent.

In Supplementary Tables 1-3, specific items of the scales under study are ranked based on the mean score obtained from all the participating farmers' pre-test responses. This form of presenting the results allowed us to identify items with the lowest scores, which were appropriately addressed during our intervention.

After the completion of the sixth session, there was a four-month break. Farmers were requested to implement soil management practices, according to the knowledge obtained during the training. Four months later a follow up session was held in which participating farmers were given a retention test and had their questions answered. In parallel, an interview was conducted with each of the participating farmers who were making independent decisions regarding soil management on their farms.

RESULTS AND DISCUSSION

The training course resulted in a statistically significant improvement in farmers' soil science knowledge (Figure 4A). This knowledge level was sustained, as reflected by the results of the retention test. Specific p values for multiple comparisons (Tukey test) were as follows: pre-test versus post-test: $p < 0.0001$; pre-test versus retention test: $p = 0.003$; post-test versus retention test: $p > 0.05$. The Cohen's (1988) *d* values were 1.8 and 1.2 for the comparisons of pre-test versus post-test and pre-test versus retention test, respectively. These effects are large according to the Cohen's (1988) classification. However, there was no statistically significant improvement in farmers' attitudes toward soil (Figure 4B, $p > 0.05$) nor in their soil conservation actions (Figure 4B, $p > 0.05$).

Based on the qualitative analysis, farmers' opinions during interviews can be summarized as follows:

– The delivered course greatly improved farmers' knowledge about soil management practices,

– Farmers recognized that current soil management practices on their farms could be improved,

– Farmers were interested in implementing soil management practices that were discussed during the training course, such as the use of compost, solarization, fermented organic fertilizers, as well as performing soil chemical analysis,

– Despite the aforementioned interest, farmers were unable to implement any new practices during the three-month period since the last training session,

– The primary barrier to implementing such practices was uncertainty about how to effectively put them into action, rather than economical constraints or other limitations,

– Farmers requested additional practical workshops and real-scale demonstrations of the recommended practices, to better equip them to implement these actions on their farms.

In other words, the training course only resulted in a significant improvement in farmers' knowledge, while their soil conservation practices remained unaffected. These results partially confirm our original hypothesis which stated that training course improve farmers' knowledge, which, in turn, will lead to observable changes in soil conservation practices.

As mentioned above, the format of our training program (traditional lectures and interactive discussions) is quite typical in Chile (Márquez-García *et al.*, 2018). This emphasizes the importance of having a platform to publish the results of studies that did not work out. Negative results are important and should be a vital part of the scientific community's body of knowledge. Below, we discuss in detail the implications of the results of the study.

Implications of study results

The opinion that increased environmental knowledge leads to pro-environmental behavior is disputed. For example, in their seminal paper in the field of environmental education, Hungerford and Volk (1990) demonstrated that knowledge does not automatically lead to behavior change in the environmental dimension. Furthermore, the review conducted by Kollmuss and Agyeman (2002) notably highlights the well-documented gap between possessing environmental knowledge and actually implementing pro-environmental behaviors. In the literature, this phenomenon is known as "knowledge-action gap" (Colombo *et al.*, 2023).

In light of previous research, it is not surprising to observe this knowledge-behavior gap in the present study. The findings of this study challenge the typical focus of agricultural extension activities on knowledge alone, pointing out how this neglects potential behavioral changes resulting from the intervention (Rejesus *et al.*, 2012; Pan and Zhang, 2018). Our findings reflect the results of the interventional study of Márquez-García *et al.* (2018), which involved training Chilean winegrowers on the topic of biodiversity conservation on their farms. The latter study showed that farmers' knowledge about the importance of biodiversity was considerably improved as a result of the training. However, the biodiversity conservation behavior of participating farmers remained unchanged in the study of Márquez-García *et al.* (2018).

It is well established that behavior change is a gradual process (Prochaska and Velicer, 1997). The stage model of self-regulated behavioral change (SSBC) offers a framework for understanding this process, outlining four distinct stages that individuals progress through (Bamberg, 2013):

1) Pre-decision: at this initial stage, individuals may lack awareness of the problem or its consequences.

2) Pre-action stage: individuals recognize the need for change but are yet to form a concrete plan of action.

3) Action: individuals actively implement new behavior(s).

4) Post-action: focus shifts to maintaining the adopted behavior(s) and preventing relapse.

Informed by the SSBC model, at the beginning of the training course, farmers participating in the present study were at the pre-decision stage. Based on the aforementioned interview results and the quantitative results (Figure 1A), the intervention successfully raised awareness of the issues of soil conservation, and helped foster a sense of personal responsibility among the farmers. Furthermore, the training course provided farmers with valuable information on alternative behaviors, including their pros and cons. As a result, farmers developed a willingness to achieve a soil conservation goal, although they lacked a specific plan for how to accomplish it. Consequently, as a result of the training, farmers progressed from the pre-decision stage to the pre-action stage, based on the SSBC model classification (Bamberg and Schulte, 2019).

A future interventional study is necessary to support farmers at the action and post-action stages, as outlined by the SSBC model. Specifically, a new training course could focus on practical workshops and real-scale demonstrations of recommended practices, as requested by participating farmers. During this proposed future training, farmers may require support in developing detailed implementation plans to translate intentions into actions, and maintain the changed behavior (Gollwitzer, 1999). Specifically, agricultural extension agents could help farmers to form a behavioral intention (a concrete plan to perform a specific soil conservation action), and subsequently an implementation intention (a detailed strategy for "how, when, and where" to achieve the intended soil conservation goal) (Gallo and Gollwitzer, 2007).

CONCLUSION

Our study provides timely and pertinent evidence of the knowledge-behavior gap in agricultural decision-making. The findings of this study challenge the common focus of agricultural extension activities on knowledge, overlooking any potential behavioral changes due to the intervention.

In our opinion, there is an urgent need to address a widespread reliance on knowledge as an expected predictor of farmers' conservation behavior. There is also a need for future longitudinal studies to enhance our understanding of the mechanisms underlying the knowledge-behavior gap, in the context of farmers' conservation practices. The scales used in the present study will be useful in these future studies on diverse farmer populations.

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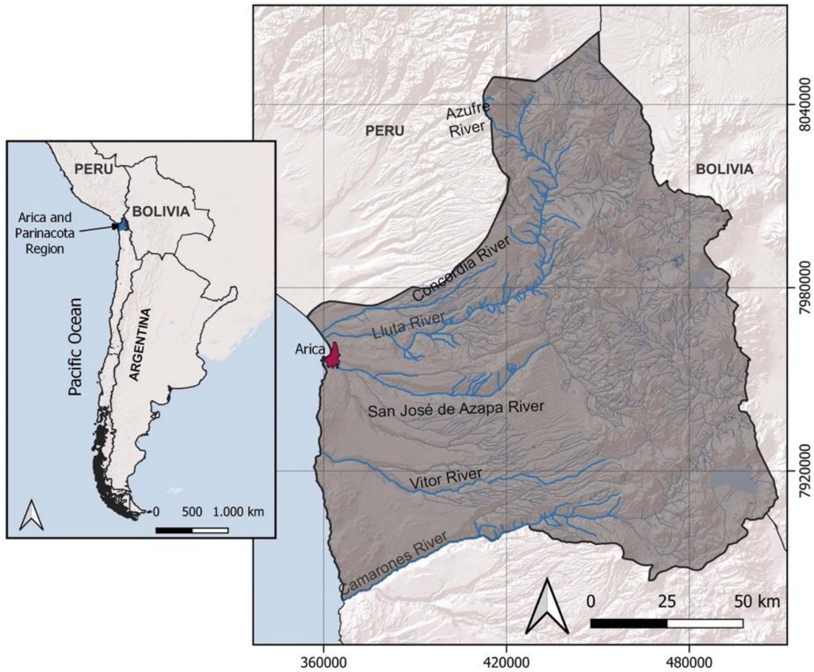

Figure 1. Geographical location of the study area.

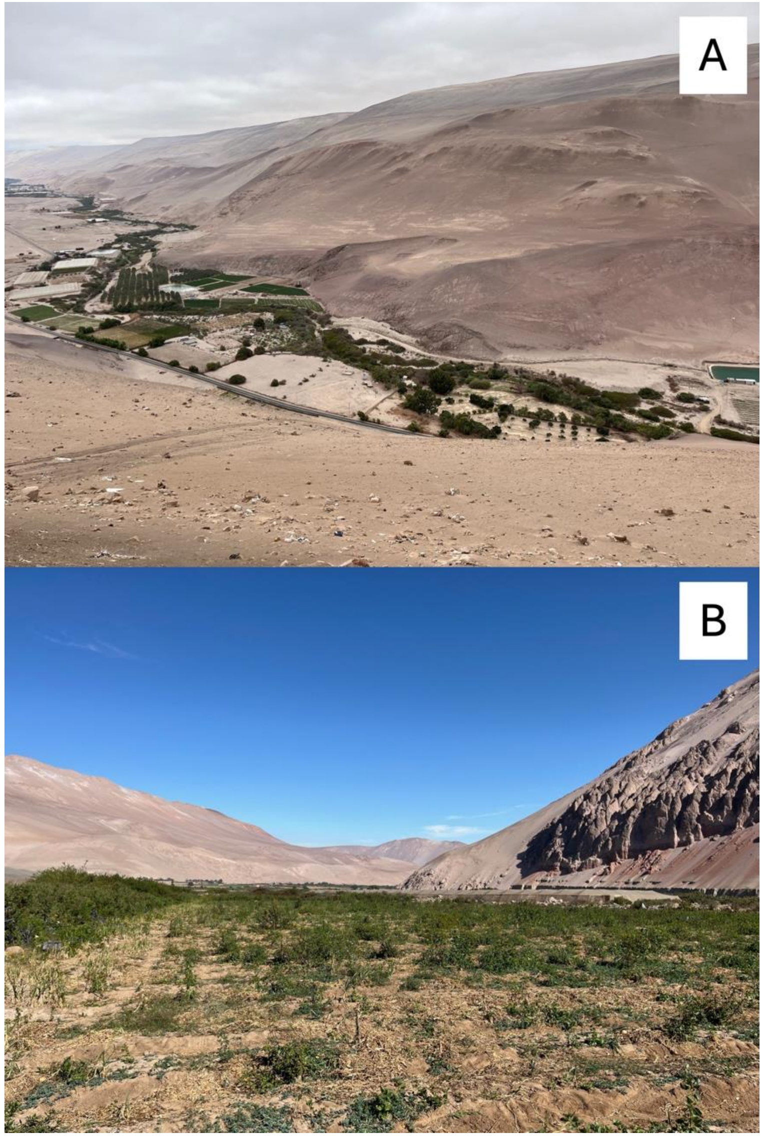

Figure 2. Typical view of the coastal area of the Arica and Parinacota Region (northern Chile), illustrating extreme aridity of the Atacama Desert (A). Agricultural areas are located in the plains of the rivers basins (B).

Figure 3. Examples of typical agricultural management issues in the area under study: (A) agricultural production wastes disposed of along a road, (B) an attempt to compost agricultural production wastes by placing them in a box, instead of creating a pile, (C) a partially exfoliated citrus tree, and (D) a tomato plant with visible symptoms of iron chlorosis.

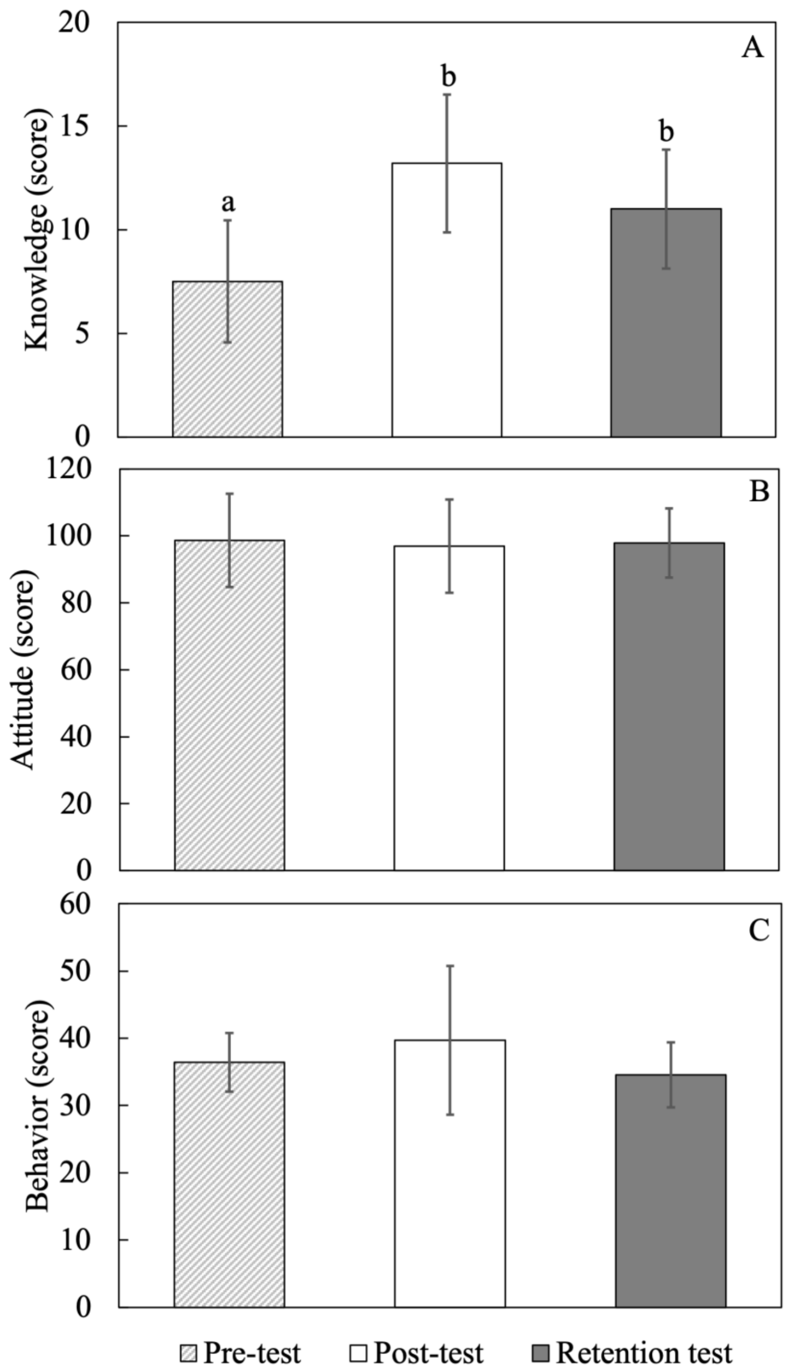

Figure 4. Quantification of the impact of farmers' training on (A) soil science knowledge, (B) attitude(s) toward soil, and (C) soil conservation behavior. The mean scores for each scale are shown; error bars show standard deviation. In the case of soil science knowledge, different letters represent statistically significant differences between the tests (ANOVA, Tukey test for multiple comparisons). Pre-test versus post-test: $p < 0.0001$; pre-test versus retention test: $p = 0.003$; post-test versus retention test: $p > 0.05$.