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Enhancing farmers' soil conservation behavior: Beyond soil science knowledge

Elliot Burnham [a], Sarah Zabel [b], Claudia Navarro-Villarroel [c], Dmitry S. Ermakov [d], Mónica Castro [a], Alexander Neaman [e,*], Siegmar Otto [b]

[a] Escuela de Agronomía, Pontificia Universidad Católica de Valparaíso, Quillota, Chile
[b] Institute of Education, Work and Society, University of Hohenheim, Stuttgart, Germany
[c] Área de Educación, Instituto de Estadística, Universidad de Valparaíso, Valparaíso, Chile
[d] Department of Psychology and Pedagogy, Peoples' Friendship University of Russia named after Patrice Lumumba (RUDN University), 6 Miklukho-Maklaya St., Moscow 117198, Russia
[e] Departamento de Recursos Ambientales, Facultad de Ciencias Agronómicas, Universidad de Tarapacá, Arica, Chile

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ABSTRACT

Attaining sustainable agriculture requires acknowledging the impact of human behavior. Despite the pivotal role of soils in agriculture, our understanding of the psychological drivers that motivate farmers to adopt soil conservation practices remains limited. Our objective was to explore the influence of soil science knowledge and connection to soil on farmers' soil conservation behavior. To achieve this goal, we developed scales capable of measuring farmers' soil knowledge, connection to soil, and soil conservation behavior. Our sample comprised 196 individuals from geographically and culturally distinct regions of Chile (the south, center, and north), highlighting the generalizability of our findings. Our target population consisted of farmers who were responsible for making soil management decisions on their farms. Farmers' soil conservation behavior was determined by the combination of their connection to soil ($r = 0.37$, $p < 0.001$) and their knowledge of soil science ($r = 0.37$, $p < 0.001$). The farmers who utilized ecological management practices exhibited better soil conservation behavior, a stronger connection to land, and a greater level of soil science knowledge (ANOVA, $p < 0.05$). Therefore, both motivational and cognitive factors are crucial in enacting effective soil conservation behavior. Furthermore, female farmers demonstrated a higher level of soil science knowledge, better soil conservation behavior, and stronger connection to soil than their male counterparts. Finally, pursuing professional studies in agriculture and formal education on soil management do not lead to the development of a stronger motivational connection to soil. This is a concerning outcome that calls for improvements in soil science education. Our study represents a significant contribution to the development of a comprehensive theory of soil conservation behavior, emphasizing the need for a holistic approach that acknowledges the multidimensional nature of farmers' motivational connection to soil and their knowledge of soil science.

1. Introduction

1.1. Intrinsic motivation for soil conservation behavior

It has long been recognized that the conventional agricultural paradigm has traditionally emphasized productivity (Beus and Dunlap, 1994), yet there is mounting pressure on agriculture to prioritize resource conservation and environmental protection. Due to the critical significance of soils in agriculture, several studies have focused on the concept of 'soil security', which parallels the notions of food, water, and energy security in relation to soils (McBratney and Field, 2015). The concept of soil security encompasses various related concepts, including soil conservation, soil care, soil quality, soil health, and soil protection (Koch et al., 2013; Morgan and McBratney, 2020). It is crucial to recognize that achieving soil security requires addressing the influence of human behavior (Napier, 2010). Consequently, several studies have explored the factors that drive farmers' motivation to adopt soil conservation and restoration practices.

For instance, Prager and Posthumus (2010) distinguished between the following three pathways for the adoption of soil conservation

* Corresponding author.
E-mail address: alexander.neaman@gmail.com (A. Neaman).

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practices by farmers: (1) an individual adopts a practice on their own initiative, (2) an individual enrolls in a soil conservation program and receives incentive payments, and (3) an individual complies with legislation requirements. Importantly, the first path represents an intrinsic motivation of an individual (Kaiser et al., 2017), whereas the second and third paths require extrinsic rules and incentives.

We argue that true success in the protection of natural resources will only be achieved when individuals are intrinsically motivated to prioritize the conservation of these resources over personal benefits such as commodities and convenience (Neaman et al., 2021a; Otto et al., 2014). One advantage of intrinsically motivated behavior is that it does not rely on additional incentives (such as financial, material, or social rewards) or external supervision, as individuals engage in such behavior voluntarily. Therefore, in the subsequent discussion, our focus will be on soil conservation practices that farmers adopt based on their own initiative.

Another crucial issue that requires further investigation within the current literature on soil conservation behavior is the limited scope of behaviors employed to gauge farmers' engagement, for instance, tillage practices (Ogieriakhi and Woodward, 2022). A narrow focus on specific behaviors overlooks the considerable variation in individual living circumstances, which may offer unique behavioral opportunities that differ from farmer to farmer and from context to context. Moreover, farmers possess a diverse array of behavioral options that they can choose to implement. Instead of exclusively concentrating on minimum tillage practices, a farmer may elect to embrace organic agricultural methods.

The constraint imposed by a restricted set of behaviors can be overcome by considering a farmer's soil conservation behaviors in multiple domains. This strategy offers a more comprehensive representation of a farmer's propensity to preserve soil resources, regardless of the specifics of each particular behavior. By focusing on this overarching predisposition, the emphasis is shifted from singular behaviors to a class of behaviors related to the farmer's overall outlook on agriculture and, consequently, the extent to which they adopt soil conservation practices. Therefore, in the present study on soil conservation behavior, we have opted for a multi-domain approach to capture farmers' overall propensity towards soil health.

1.2. Soil conservation education: insights from environmental education

Soils represent a vital component of the life-support system of human civilization (Yaalon and Arnold, 2000). Historical evidence reveals that the prosperity or collapse of ancient societies often hinged on their soil management practices (Diamond, 2011; Hillel, 1992). The authors analyzed the factors and techniques that determine the sustainability of long-term soil management practices. For example, cultivating sloping land contributes to water erosion, while irrigating poorly drained valleys leads to salinization. Given that the same age-old challenges still affect soils today but on a global scale (Editorial, 2004), multiple researchers have emphasized the need for improved soil conservation education to ensure sustainable development (Aytar and Ozsevgec, 2019; Sewilam et al., 2015).

The goal of soil science education is to elucidate the role of soil in human life and underscore the importance of soil conservation and sustainable land use (Muggler et al., 2006). It must be emphasized that soil science education has traditionally focused on psychomotor and cognitive learning, while giving relatively less attention to the motivational domain (Brevik et al., 2022a; Jelinski et al., 2020; Muggler, 2015).

Literature acknowledges the lack of emotional learning in soil science education and seeks solutions. For instance, McBratney et al. (2014) proposed the term "connectivity", posing the question, "Which new soil education approaches could be devised to connect land managers and the public appropriately to soil?" This notion of connectivity, also referred to as "connection to soil" (McBratney and Field, 2015), introduces a social dimension to soil, emphasizing the need to cultivate a relationship with the soil. This relationship is crucial to achieve soil security (Pino et al., 2022).

Furthermore, Lal et al. (2021) proposed the term "sensitization about soils", to awaken interest among non-farmers in urban areas. They also introduced the term "connection to land" and suggested that soil science education can enhance it by promoting an understanding of soil's importance. Similarly, other authors (Brevik et al., 2022a; Brevik et al., 2022b) suggested sharing soil information as a narrative with cultural and emotional relevance to the public, beyond presenting facts and figures. Some researchers have even proposed the term "spiritual connection to soil" (Charzynski et al., 2022). Despite these discussions, the potential for motivational learning in soil science education as a response to global soil degradation is not emphasized enough.

According to Muggler et al. (2006), soil science education can be approached in a manner similar to environmental education, which aims to help individuals achieve a more ecologically responsible way of life (Roczen et al., 2014). We agree with this view and believe that the ultimate goal of soil science education should be to promote soil conservation and restoration behaviors among farmers, in both intensive systems (such as fruit, vegetable, or cereal production) and less intensive systems (such as cattle grazing).[1] To achieve this objective, we will draw on insights from environmental education as we investigate the factors that drive soil conservation and restoration actions among farmers.

The existing environmental education literature indicates that individual ecological behavior is driven by environmental knowledge, and even more significantly, by an individual's connection to nature (Otto and Pensini, 2017; Roczen et al., 2014). These findings are consistent with the "knowledge-deficit theory", which proposes that inaction results from a lack of knowledge (Schultz, 2002b).

While certain authors perceive connection to soil as primarily an emotional bond (Charzynski et al., 2022), other scholars contend that connection to nature encompasses cognitive aspects as well (Schultz, 2002a). Hence, in this study, we choose to characterize "connection to soil" as a motivational determinant of soil conservation behavior, while considering "knowledge of soil science" as an intellectual determinant of such behavior. The division between intellectual and motivational determinants of nature conservation behavior has been recognized in previous studies by Roczen et al. (2014) and in our own research (Ermakov, 2008; Ermakov, 2021; Otto et al., 2020). Accordingly, environmental knowledge serves as the intellectual foundation, while an individual's connection to nature has been corroborated to be a motivational force associated with their overall ecological performance (Roczen et al., 2014). In essence, individuals' ecological behavior is underpinned by both the motivational (connection to nature) and the intellectual (environmental knowledge) determinants.

While past studies investigating the drivers of soil conservation behavior have made efforts to integrate concepts and theories from the field of environmental psychology (Bijani et al., 2017; Borkhani et al., 2023), a cohesive theory of soil conservation behavior has yet to be established. In the ensuing discourse, we will build upon the existing research and advance our understanding of this vital topic.

Our hypothesis drew from extant knowledge regarding drivers of ecological behavior. Specifically, we posited that the soil conservation practices of farmers are contingent upon both their cognitive grasp of soil science and their motivational disposition toward soil. Thus, the objective of our study was to investigate the extent to which knowledge and motivation of farmers influence the enactment of soil conservation behavior.

[1] This study does not consider non-agricultural use of soil (for example, for engineering purposes).

2. Materials and methods

2.1. Choice of research method

The natural sciences tend to apply quantitative methods, whereas the social sciences, such as rural studies, apply both qualitative and quantitative methods (Strijker et al., 2020). In the present study, we opted for a quantitative approach because it allows for the systematic and standardized measurement of the variables under study (Creswell, 2014). Further, the quantitative approach enabled us to collect survey data from a larger sample size, which in turn enhanced the generalizability of our conclusions. Moreover, the quantitative approach allows to examine the strength and statistical significance of the relationships between the variables under study. However, we acknowledge the potential for future studies to incorporate qualitative methods to explore the nuances of these relationships and gain a deeper understanding of the factors influencing soil conservation behavior.

2.2. Conceptual framework: the Campbell paradigm

The Campbell paradigm, a social psychology theory developed by Kaiser et al. (2010), builds upon the work of Campbell (1963), for whom the paradigm is named. This paradigm provides an explanatory framework for understanding individual engagement in ecological behaviors. According to the Campbell paradigm, behavior, such as commuting by bicycle, is typically the result of two factors: an individual's commitment to environmental protection (i.e., their environmental attitude) and the associated costs or challenges of a specific behavior (e.g., cycling in the rain). The strength of a person's attitude reflects the level of difficulty they are willing to overcome in order to align their actions with their environmental attitude.

Only if a person's attitude exceeds the costs of a behavior, will the behavior have a reasonable chance of manifesting. Behavioral costs include everything that makes behavior objectively more or less demanding: things such as effort, time, and financial costs, but also social norms and expectations, cultural practices, and the antagonistic social preferences that go hand in hand with certain behaviors (Kaiser and Wilson, 2019). In contrast to Campbell's deterministic model, which aimed to provide an explanation for behavior engagement, Kaiser et al. (2010) lowered their aspiration to explaining only the probability of behavior engagement. To achieve this, they adopted the Rasch model (Rasch, 1960).

According to the Campbell paradigm, individuals' attitudes are reflected in their behavior and in the extent to which they are willing to overcome the costs associated with that behavior. The paradigm challenges the common belief that human behavior is inherently complex and hard to manage. It also raises doubts about established theories in psychology, such as the theory of planned behavior, which posits that behavioral intentions are determined by three core factors (attitude, subjective norms, and perceived behavioral control) (Ajzen, 1991).

2.3. Methodological challenge

When we set out to investigate our research question, we encountered a methodological challenge. The field of soil conservation behavior research suffers from a lack of comprehensive scales for collecting empirical data. Although educators in soil science frequently evaluate the knowledge of their students by means of written examinations, there is a dearth of standard scales for precise measurement of soil science knowledge. Furthermore, existing scales for assessing farmers' connection to soil are often designed to measure the perspectives of particular types of farmers, such as those cultivating coconut (Herath and Wijekoon, 2013) or rice (Ashoori et al., 2016; Borkhani et al., 2023), and are not readily applicable to other populations. Similarly, the soil conservation behavior scale introduced by Bijani et al. (2017) is also confined to rice cultivators. Without a reliable tool to measure analytical concepts, it is impossible to test academic assumptions or establish theoretical foundations for research on soil conservation behavior. To address this gap, we have developed appropriate scales in the present study.

2.4. Measures used in the study

The data was obtained through surveys utilizing three distinct scales. These scales were:

1) The scale of soil conservation behavior (Appendix A, Supplementary Table 1), which evaluated behaviors related to various domains of soil management, including organic matter and soil biological activity, compaction, aggregate stability and erosion, contamination, and general soil conservation. It is worth noting that the soil conservation behavior scale utilized in the present study featured a "not applicable" option. This allowed farmers to skip a question if it did not apply to their specific farming situation.
2) The scale of connection to soil (Appendix B, Supplementary Table 2) was based on our previous investigation (Neaman et al., 2021b). During that study, a substantial number of the items were identified as too simple for agronomy students. Thus, in the present research, we endeavored to include more difficult items.
3) The soil science knowledge scale (Appendix C, Supplementary Table 3) was designed to measure veridical knowledge and modeled after environmental knowledge scales (Geiger et al., 2019). This scale consisted of true/false and multiple-choice questions. Although previous studies have attempted to identify the types and domains of soil science knowledge (Charzynski et al., 2022; Field et al., 2011; Field et al., 2017), there is no consensus on this matter. Nevertheless, we incorporated the perspectives of the latter authors and focused our soil science knowledge scale on the following three domains:
   (a) The assessment of conceptual knowledge pertaining to soil science encompassed queries relating to the scientific domains of soil chemistry, soil physics, soil biology, and general soil science.
   (b) The appraisal of knowledge concerning global soil degradation consisted of inquiries spanning several domains, namely (Editorial, 2004):
   - degradation of organic matter and reduction in soil biological activity,
   - sodification and salinization,
   - compaction, erosion, and loss of aggregate stability,
   - acidification, and
   - contamination.

   (c) The evaluation of practical knowledge of soil science was conducted through a series of questions targeting various aspects of soil management aimed at preventing the types of soil degradation previously mentioned. However, strategies to mitigate the impact of soil contamination (Ulriksen et al., 2021) are not known for the majority of farmers, so they were not included in our questionnaire.

2.5. Geographical and cultural diversity of the study areas

To effectively address our research question, a deliberate focus on a specific geographic area was necessary. Consequently, for the purposes of this study, we have elected to concentrate our efforts on Chile. To bolster the universality of our proposed model, our research analyzed populations in three distinct geographic and cultural regions of Chile, namely, the Arica and Parinacota Region (north), Valparaíso Region and Metropolitan Region (center), and Los Ríos Region (south).

One point to consider is that the areas under study differ significantly in terms of the proportion of indigenous populations, namely Mapuche and Ayumara (INE, 2023). This is pertinent to the objective of the study since both the Mapuche (Quintriqueo et al., 2014) and Aymara (Eisenberg, 2013) indigenous populations are known to hold a respectful

Table 1
Sociodemographic characteristics of participants.

Variable		
Age, years	Mean ± SD	49 ± 16
	Range	21—82
Gender, %	Female	23
	Male	75
	Prefer not to specify	2
Education level, %	Incomplete high school education	27
	High school completed	36
	Technical professional	19
	University level professional	17
	Postgraduate degree	2
Profession, %	Independent farmer	69
	Field manager in an agricultural company	8
	Administrator of an agricultural enterprise	3
	Manager of an agricultural enterprise	3
	Owner of an agricultural enterprise	3
	Other	15
Professional degree, %	Without formal professional degree	53
	Agricultural technician or similar	25
	Agronomist or similar	11
	Other	11
Formal education on soil management, %	University	14
	Professional institute	12
	Agricultural college	13
	Training course(s) or similar	25
	Other	5
	No formal education on soil management	32
Ecological farm management, %	Yes	64
	No	36
Geographical origin, %	Northern Chile	24
	Central Chile	57
	Southern Chile	14
	Online	5
Product, %	Vegetables, flowers and/or industrial crops	48
	Fruit trees	50
	Livestock	2

attitude toward soil. The Arica and Parinacota Region (north) has a substantial Aymara population (26%), while the Mapuche population is minimal (3%). Conversely, the Los Ríos Region (south) has a significant Mapuche population (24%), while the Aymara population is negligible. Finally, the indigenous population in the Valparaíso and Metropolitan Regions (center) is minimal (~10%).

Furthermore, the study areas differed greatly in climate, with the north of Chile experiencing extreme desert aridity, the center a Mediterranean-type climate, and the south a rainy oceanic climate. Soil types also varied considerably, with Aridisols predominant in the north, Alfisols and Mollisols in the center, and Andisols and Ultisols in the south (Casanova et al., 2013). In addition, the types of soil degradation differed in the study areas, such as sodification and salinization in the north (Torres and Acevedo, 2008) and acidification in the south (Herrera-Huerta et al., 2012). As a result, soil management practices varied significantly in the study areas.

2.6. Sample population

Our sample size comprised 196 individuals, whose sociodemographic characteristics are presented in Table 1. Our target population consisted of farmers who were responsible for making decisions related to soil management on their respective farms. To elicit the necessary information, the participants were queried with the following question: “Do you make decisions pertaining to soil management on your farm?” If an affirmative response was provided, the surveyor conducted a pencil-and-paper survey, verbally presenting the questions to the farmer.

Table 2
Pearson correlation coefficients (r) between self-reported behavior and observed (real) behavior in farmers as used in the study. Here and below, items in *italics* indicate negatively formulated behaviors; their scores were inverted for analysis. In all cases, the p values were <0.001. Also, the number of data (n) is shown.

Observed (real) behavior	Self-reported behavior	r	n
The use of cover crops on the property is observed	I maintain cover crops on my land	0.43	138
The use of mulch (organic or inorganic) is observed	I apply mulch (organic or inorganic material) to the soil surface	0.68	141
The use of fallow land is observed	I leave fallow land on my property, i.e., I leave land unused for at least one year	0.27	132
Eroded and/or abandoned soil is observed	*When the soil erodes, I abandon it without trying to restore it*	0.62	137
Garbage piles with plant debris are observed	*I throw away the agricultural waste generated on my property.*	0.57	126
There are areas with composting plant materials	I compost agricultural waste on my farm	0.44	139
Soil disinfection by solarization is evident	I disinfect the soil on my farm using heat generated by solar energy (solarization)	0.79	124
Farmer uses different conventional agrochemicals (pesticides, herbicides, fungicides, nematicides)	*I apply various conventional agrochemicals (pesticides, herbicides, fungicides, or nematicides) to the soil on my farm.*	0.34	141
Farmer uses organic agrochemicals.	I use more organic agrochemicals than conventional ones on my farm.	0.74	133

After conducting the survey, the surveyor requested a tour of the farm from the farmer, conducting a discrete observation of the property while inquiring about specific areas of interest. Upon conclusion of the visit, the surveyor documented their observations on a supplementary page, detailing nine distinct behaviors readily apparent during the farm tour (as outlined in Table 2), noting whether each behavior was observed or not during the visit. Subsequently, the surveyor affixed this supplementary page to the corresponding survey.

2.7. Data analysis

In the present study, a Rasch-type model was employed to compute individual scores for each participant. The infit mean square (*MS*) values were used to assess the goodness of fit of the model, with values of ≤1.2 deemed to be indicative of good fit, and *MS* values ≤1.3 considered to be acceptable (Wright et al., 1994). The selection of a Rasch-type model over classical test theory was preferred as the latter often results in a restricted range of item difficulty, making it hard to differentiate between individuals with varying levels of the measured variable. On the contrary, Rasch models enable a broader range of item difficulties, allowing for more nuanced distinctions between participants. To achieve this objective, all the scales used in this study were designed to display a wide range of item difficulties. As a result, we were able to discern significant differences in the behavior, attitude, and knowledge of the participating farmers.

The reliability and item fit of the scales measuring soil conservation behavior, connection to soil, and knowledge of soil science were found to be good, with only a few items displaying low fit (Table 3). Furthermore, Table 2 showcases the correlations between the behaviors that were observed by the surveyor at the farm (commonly referred to as real behaviors) and their corresponding self-reported behaviors. Finally, Table 4 presents the results of the analysis of variance (ANOVA) for the effects of socio-demographic variables on knowledge of soil science, connection to soil, and soil conservation behaviors.

A post-hoc power analysis was conducted using the R-package pwr (Champely, 2020). For the ANOVAs with gender, formal education,

Table 3
Descriptive statistics for the scales used.

Scale	Number of items	Mean ± SD	Range	Reliability	Items with1.2 < *MS* ≤ 1.3	Items with *MS* > 1.3
Soil conservation behavior	19	0.5 ± 1.0	−2.9–4.0	0.68	2	1
Connection to soil	22	0.6 ± 1.2	−2.7–3.6	0.77	1	0
Knowledge of soil science	43	1.5 ± 1.2	−1.5–3.9	0.81	0	1

MS = mean square, SD = standard deviation.

Table 4
Effects of sociodemographic variables on knowledge of soil science, connection to soil, and soil conservation behavior, expressed as logits. Larger logit values indicate better knowledge, behavior, and connection, while smaller values indicate the opposite. Mean ± standard deviation, ranges and number of observations (n) are shown. Different letters in the same column, for the same variable indicate statistically significant differences between variable categories. (ANOVA, $p < 0.05$).

Category of the variable	n	Soil conservation behavior	Connection to soil	Knowledge of soil science
Gender				
Feminine	41	0.9 ± 1.1 A	1.0 ± 1.1 A	1.1 ± 0.7 A
Masculine	149	0.4 ± 1.0B	0.5 ± 1.2B	0.8 ± 0.9B
Formal education on soil management				
Yes	153	0.6 ± 1.0 A	0.6 ± 1.2 A	1.1 ± 0.8 A
No	42	0.1 ± 0.9B	0.6 ± 1.2 A	0.4 ± 0.8B
Ecological farm management				
Yes	135	0.7 ± 1.0 A	0.7 ± 1.2 A	1.1 ± 0.8 A
No	59	0.0 ± 0.8B	0.3 ± 1.1B	0.6 ± 0.8B
Professional degree				
Agricultural degree	80	0.5 ± 1.1 A	0.5 ± 1.2 A	1.3 ± 0.8 A
Other degree	114	0.5 ± 1.0 A	0.7 ± 1.2 A	0.7 ± 0.8B
Origin				
Central Chile	55	0.8 ± 1.2 A	0.6 ± 1.2 A	1.0 ± 0.7 A
Southern Chile	99	0.4 ± 0.8 AB	0.6 ± 1.0 A	1.1 ± 1.0 A
Northern Chile	30	0.1 ± 0.7B	0.8 ± 1.1 A	0.5 ± 0.8B

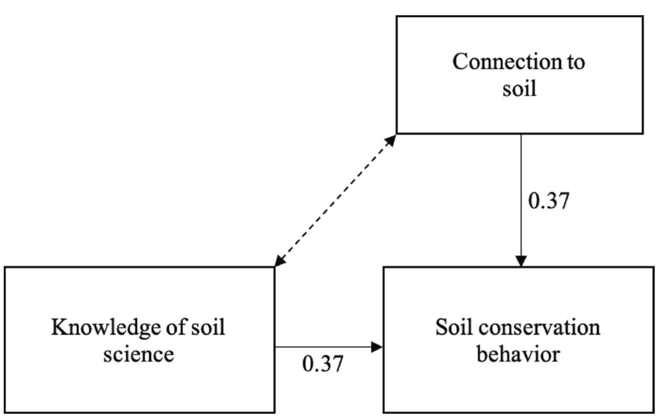

Fig. 1. The Pearson correlations between the measured variables ($p < 0.001$ in all the cases). The dashed line indicates a marginally significant correlation ($r = 0.13$, $p = 0.07$) between soil science knowledge and the connection to soil.

ecological farm management, and professional degree, a minimum sample size of $n = 41$ in each group, a power of 0.8, and a significance level of $\alpha = 0.05$ were employed. These parameters allowed for the detection of effects of at least $f = 0.31$, indicating a medium to large effect. Similarly, for the ANOVA with "Origin", a sample size of $n = 30$ in each group, a power of 0.8, and a significance level of $\alpha = 0.05$ were used, enabling the detection of effects of at least $f = 0.33$.

The Pearson correlations between the measured variables are depicted in Fig. 1. Pearson's correlation is a widely-used statistical method used to assess the strength of the relationship between two variables (Field, 2013, p. 881). In the domain of environmental education, the use of Pearson's correlation is widely recognized and accepted (Kollmuss and Agyeman, 2002). Hence, our selection of this method is consistent with established research practices in this field.

A statistical power of 0.99 was observed for the smallest correlation between connection to soil and soil conservation behavior, based on an $r = 0.37$ and a sample size of 196, with a significance level of $\alpha = 0.05$. The sample size of $n = 196$ allowed us to detect effects with a minimum

Appendix A

Soil conservation behavior scale as used in the study. Here and below, items in *Italics* indicate negatively formulated behaviors; their scores were inversed for analysis. These items should be read as 'I refrain from…'. Item difficulties (delta) are expressed in logits, the basic units of Rasch scales. Larger logit values indicate higher score on the respective scale. Conversely, a smaller logit value indicates smaller score on the respective scale. Infit MS (mean square) reflects the relative discrepancy in the variation between model prediction and observed data independent of the sample size. Perfect model prediction is expressed by a MS value of 1.0. MS values above 1.0 indicate excessive variation (e.g., a value of 1.2 indicates 20% excessive variation). A commonly acceptable upper value is 1.2, however, values between 1.2 and 1.3 are still acceptable.

N°	Item	MS infit	Delta
BD3	*I apply various conventional agrochemicals (pesticides, herbicides, fungicides, or nematicides) to the soil on my farm*	1.12	1.52
BD12	I conduct chemical analysis of the irrigation water I use on my property	1.26	0.86
BD11	I disinfect the soil on my farm using the heat generated by solar energy (solarization)	1.38	0.64
BD4	I compost agricultural waste on my farm	0.78	0.60
BD8	I talk to farmers about soil degradation problems	0.83	0.40
BD18	I have attended classes or training courses on soil management to be more informed	0.91	0.39
BD14	I use more organic agrochemicals than conventional ones on my farm	0.83	0.36
BD10	I leave fallow land on my property, i.e., I leave land unused for at least one year	1.24	0.33
BD6	I am looking for information about soil conservation technologies	0.85	0.28
BD2	I maintain cover crops on my land	1.00	0.20
BD16	I have let other farmers know that they have behaved in an anti-ecological way, damaging the soil resource	0.89	0.19
BD5	I apply mulch (organic or inorganic material) to the soil surface	1.08	0.12
BD1	*I burn the stubble on my land*	0.97	−0.34
BD7	I try to avoid fertilizer leaching on my farm	0.92	−0.37
BD17	I have tried to persuade other farmers to be more respectful of the soil resource	0.88	−0.49
BD15	*I throw away the agricultural waste generated on my property*	1.10	−0.63
BD19	I learn about soil resource issues from the media (newspapers, magazines, websites, etc.)	0.92	−1.14
BD13	I avoid running machinery over the soil on my property excessively	0.98	−1.27
BD9	*When the soil erodes, I abandon it without trying to restore it*	0.79	−1.65

Appendix B
Connection to soil scale as used in the study.

N°	Item	MS infit	Delta
AD17	I like paintings made from natural earth materials	0.83	2.87
AD9	I consider soil to be the most important environmental resource	1.20	1.16
AD2	I like to talk to the soil	1.14	0.95
AD5	Soil must be sanctified	1.06	0.92
AD13	I like to observe the different components of the soil	0.79	0.87
AD22	*The soil is dirty*	1.10	0.63
AD10	*Beings that live in the soil are disgusting*	0.86	0.36
AD15	*Soil is not important to plants; all nutrients can be added through fertilizers*	1.00	0.33
AD1	I think of the soil as my family	1.05	0.28
AD11	*I don't mind if soil is eroded*	0.89	0.27
AD20	I think it is important to protect the soil from agrochemicals	0.86	0.26
AD18	The life forms in the soil are beautiful	0.88	0.20
AD12	I like to touch the soil with my hands	0.85	0.05
AD16	*All soils are the same*	0.97	−0.31
AD21	I think it is important to know about the soil	0.84	−0.40
AD19	*The only purpose of the soil is to serve as a walking surface.*	0.97	−0.48
AD14	*Soil is an irrelevant resource for the environment*	0.92	−0.60
AD4	Soil is a sacred resource	1.01	−0.88
AD7	*I believe that there is no life in the soil*	1.21	−1.12
AD6	I like to smell the soil	1.05	−1.21
AD3	I like the different colors of soil	1.13	−1.61
AD8	I am concerned about soil contamination or degradation	0.94	−2.54

$r = 0.20$, with a statistical power of 0.80 and a significance level of $\alpha = 0.05$. Consequently, it is possible that the correlation between connection to soil and soil science knowledge could have been significant in a larger sample. Nonetheless, it should be noted that this correlation would still be considered weak ($r < 0.20$).

For the calculation of Pearson correlations, it is ideal to have a normal distribution present. However, research by Bishara and Hittner (2012) has demonstrated that the Pearson correlation coefficient remains robust even when this assumption is violated. As the sample size increases, the impact of violating the normal distribution assumption on the calculation of this correlation coefficient diminishes. With the sample size of $n = 196$ in the present study, the Pearson correlation coefficient provides a reliable estimate of the relation between the variables being investigated.

3. Results and discussion

3.1. Validity of the soil conservation behavior scale

The validity of the soil conservation behavior scale was confirmed through various approaches:

1) The self-reported behaviors of the farmers were found to have a statistically significant correlation with the real behaviors observed by the surveyor at the farm, as indicated in Table 2.
2) An analysis presented in Table 4 revealed that the soil conservation behavior of female farmers was statistically superior to that of their male counterparts (Table 4). This finding is consistent with previous research. For example, Karami and Mansoorabadi (2008) measured sustainable agricultural behaviors of rice growers and found that women showed better practices in the use of agrochemicals and methods of weed and pest control. Similarly, Unay-Gailhard and Bojnec (2021) reported a greater tendency of female farmers toward environmentally friendly farming activities. Furthermore, Dolisca et al. (2009) demonstrated that female farmers were more positive about participating in forest conservation activities compared to their male counterparts.

Appendix C
Knowledge of soil science as used in the study.

N°	Item	MS infit	Delta
TK13	What is the relationship between soil calcium and soil pH?	1.31	2.13
PK2	How can sodic soil be remediated?	1.25	2.05
PK13	Can over-application of agricultural lime (calcium carbonate) cause soil salinization?	1.09	1.73
TK14	What conditions prevail in a soil that is permanently saturated with water?	1.11	1.72
PK16	Can the addition of materials with a high carbon/nitrogen ratio to the soil (e.g., grass stubble or pruning residues) temporarily reduce the availability of nitrogen to plants?	1.26	1.60
TK8	Do insoluble salts (e.g., calcium carbonate) increase soil electrical conductivity the most?	1.09	1.59
TK12	What property of the soil determines its water holding capacity?	0.99	1.44
PK6	How can the accumulation of salts in the soil be reduced?	1.00	1.32
PK14	Is sulfuric acid useful for washing out salts in saline soils?	1.20	1.25
TK16	Which of the following soil properties cannot be changed by agriculture?	1.05	1.22
GD10	What activity is the main cause of nitrate contamination of surface water in the central regions of Chile?	0.79	1.16
TK4	In acid soils, are K^+, Na^+, Ca^{+2}, and Mg^{+2} the dominant cations of the exchangeable cation complex?	1.12	0.97
PK15	Can soil drainage be improved by adding a layer of sand to the surface?	0.83	0.96
GD8	What is the possible effect of phosphorus fertilizers on soil cadmium concentrations?	1.25	0.88
TK2	Can very porous soils have a bulk density less than that of water?	1.17	0.88
TK15	In calcareous soils (soils with the presence of calcium and/or magnesium carbonates), which element is usually deficient in crops?	0.94	0.44
GD11	What is the process of gravitational entrainment of soil particles at lower altitudes called?	0.91	0.42
TK7	Do mineral soils in arid regions typically have an acidic pH?	0.90	0.35
PK8	What is the effect of ammonium fertilizers (e.g., ammonium nitrate or urea) on soil pH?	0.87	0.32
PK7	What amendment is useful to increase the pH of excessively acidic soil?	1.00	0.22
GD6	What is the effect of agriculture on soil salinity in arid and semi-arid areas?	1.04	0.11
GD7	Does soil acidification occur naturally in the southern regions of Chile?	1.17	0.01
GD1	What chemical element is harmful to the soil when present in excess in the irrigation water?	0.86	−0.02
GD14	If there is little or no biological activity in the soil, what is the expected long-term effect?	1.01	−0.07
TK10	What information about soil drainage conditions is provided by the presence of mottling (a mixture of gray and orange-red colors) in the deep layers of the soil profile?	1.19	−0.12
TK5	Were most of the soils in Chile formed *in situ* from rocks?	0.98	−0.15
GD15	What are the environmental and societal impacts of soil organic matter degradation?	1.10	−0.22
PK12	What is the expected time for organic amendments to change soil structure?	1.09	−0.22
TK1	Do lighter colored soils have more organic matter?	1.06	−0.30
TK3	Can soil organic matter trap nutrients, making them less available to plants?	0.96	−0.30
TK6	In terms of land capability classification, class III soil refer to soil with no agricultural value?	0.94	−0.32
PK17	Is acidifying irrigation water with sulfuric acid to pH 2.0 beneficial to the soil?	0.91	−0.46
GD12	What is the effect of sodium on soil properties?	0.86	−0.55
GD3	What is the effect on soil erosion of fruit orchards on steep ridges?	0.83	−0.56
PK3	How to prevent soil erosion on sloping terrain?	0.82	−0.73

(*continued on next page*)

Appendix C (*continued*)

N°	Item	MS infit	Delta
GD9	What is the effect of soil structure degradation on soil agricultural productivity?	0.84	−0.84
PK5	What are the effects of agricultural burning (stubble burning) on the soil and the environment?	0.81	−0.87
PK9	Under what conditions can soil erosion by rainfall erosion occur on the property?	0.77	−1.00
GD4	What are the effects of soil erosion on human activities?	0.82	−1.23
TK11	What is the major element in the soil organic matter structure?	0.90	−1.28
PK1	What is needed to make compost?	0.86	−1.34
GD5	What is the effect of soil compaction on agricultural productivity?	0.84	−1.43
GD2	What is the effect of excessive nitrate fertilization on the environment?	0.83	−1.65
TK9	What is the importance of naturally occurring soil organic matter in terms of plant nutrition?	0.81	−1.69
PK4	How does adding organic matter to the soil affect its biological activity?	0.81	−1.69
PK11	On an agricultural property, what is the effect of frequent passage of heavy machinery over the soil?	0.79	−1.70
GD13	What is the effect of salt accumulation in the soil on plant growth?	0.88	−1.91
PK10	What is the effect of organic matter application on the stability of soil aggregates?	0.91	−2.08

3) Farmers who reported utilizing ecological management practices on their farm exhibited superior soil conservation behavior compared to their non-ecologically minded counterparts, as supported by data in Table 4. Similarly, farmers who disclosed holding organic certification for their farm demonstrated better soil conservation behavior compared to those without certification.

3.2. Validity of connection to soil scale

The discriminative validity of the connection to soil scale was substantiated by the following findings:

1) Farmers who reported utilizing ecological management practices on their farm exhibited statistically superior connection to soil in comparison to conventional farmers, as indicated in Table 4. Adopting ecological management practices necessitates a motivational incentive, with farmers feeling remorseful for employing harmful chemicals and more contented upon transitioning to ecological agriculture (Mzoughi, 2011). Ecological farming has been found to enhance farmer life satisfaction and happiness (Mzoughi, 2014). Similarly, the research of Bouttes et al. (2019) discovered that interviewed farmers become increasingly hesitant to employ conventional farming practices, particularly regarding the spreading of chemicals on their fields. These findings provide evidence that adopting ecological farming requires a motivational connection to natural resources, particularly to soil resources.
2) The analysis presented in Table 4 revealed that female farmers' connection to soil were statistically superior to those of their male counterparts (Table 4). This finding is consistent with previous research in the field of environmental psychology (Zelezny et al., 2000), and the underlying mechanisms are discussed in detail in the study by Desrochers et al. (2019).

3.3. Validity of soil science knowledge scale

The validation of the soil science knowledge scale was accomplished through several methods:

1) Farmers possessing a professional degree in agriculture, including agronomists and agricultural technicians, exhibited a statistically higher level of knowledge of soil science, in comparison to farmers without such credentials, as indicated in Table 4.
2) Farmers who declared receiving formal education in soil management, whether at university, professional institute, high school, or through training courses, demonstrated a statistically higher level of knowledge of soil science, compared to those who have not received any formal education in this domain, as supported by data in Table 4.
3) The knowledge of soil science was significantly correlated with the educational level of farmers, ranging from incomplete high school education to postgraduate degrees (Table 1), as evidenced by a statistically significant correlation coefficient ($r = 0.28$, $p < 0.001$). This observation is consistent with the findings in other studies, which suggests that more highly educated individuals possess a greater level of environmental knowledge (Díaz-Siefer et al., 2015).

3.4. Relationship between the knowledge of soil science and connection to soil

In the sample under study, the relationship between soil science knowledge and connection to soil was not statistically significant (Fig. 1). However, as mentioned above, the correlation between connection to soil and soil science knowledge might have been significant in a larger sample. In any case, this correlation would still be considered weak ($r < 0.20$). Similar results were obtained in the study of Roczen et al. (2014), in which the relationship between connection to nature with different types of environmental knowledge was either statistically insignificant or weak (r values in the range of 0.09–0.14).

It is important to note that farmers' acquisition of knowledge in soil science may stem not only from a stronger connection to soil, but also from a legitimate interest in augmenting their income (Davis et al., 2021; Van den Berg and Jiggins, 2007). This conjecture may serve as an explanation for the absence of a statistically significant correlation between the farmers' comprehension of soil science and their connection to soil.

However, in our previous study (Neaman et al., 2021b), Pearson's correlation between the knowledge of soil science and connection to soil came to $r = 0.29$ in a sample of undergraduate students of an introductory soil science course. While the correlation appears low, it is actually close to that between knowledge and attitude in the field of environmental education (Liefländer and Bogner, 2018). Thus, students who had a stronger connection to soil were more enthusiastic learners and thus obtained greater knowledge during the semester. Nonetheless, it can be argued that students with greater knowledge about soil were predisposed to have a stronger connection to soil.

Furthermore, it is noteworthy that farmers who declared utilizing ecological management practices on their farm displayed superior soil conservation behavior, compared to their counterparts who did not employ such practices (Table 4). Importantly, the farmers who utilized ecological management practices also exhibited a stronger connection to soil and a greater level of knowledge in soil science. This finding corroborates our hypothesis that both motivational and cognitive factors are necessary for inducing behavioral change in soil conservation. However, establishing a definitive cause-and-effect relationship can be challenging. It is possible that farmers who possessed a strong connection to soil were more motivated learners and thus acquired a more profound knowledge of soil science. Conversely, farmers who had a more extensive knowledge of soil may have been more inclined to develop a strong connection to soil.

3.5. Effects of the knowledge of soil science and connection to soil on behavior

As hypothesized, farmers' soil conservation behavior was determined by the combination of their connection to soil and their level of knowledge of soil science (Fig. 1). Therefore, both motivational and cognitive factors are crucial in enacting effective soil conservation behavior. Although the correlations shown in the Fig. 1 may appear weak at first glance, they are in fact similar to those observed in other studies. For example, Díaz-Siefer et al. (2015) reported a correlation coefficient (r) of 0.34 ($p < 0.001$) between environmental knowledge and ecological behavior. Likewise, Bijani et al. (2017) reported a correlation coefficient (r) of 0.42 ($p < 0.05$) between social pressure and soil conservation behavior.

It is worth noting that farmers from all three regions under study exhibited similar connection to soil (Table 4) despite the aforementioned differences in the proportion of indigenous populations and their cultural reverence for soil. However, this study did not collect data on the ethnic identity of the participants. Therefore, future research is needed to elucidate the attitudes toward soil of different ethnic groups of farmers. Nevertheless, farmers from the north of Chile showed less commitment to soil conservation practices, which is consistent with their lower soil science knowledge, compared to their counterparts from the center and south of Chile (Table 4). This highlights the need for government programs to educate farmers about soil conservation practices.

In addition to superior soil conservation behaviors and a stronger connection to soil, female farmers demonstrated higher levels of soil science knowledge compared to their male counterparts. These findings highlight the importance of gender considerations in designing effective interventions to promote sustainable soil management practices.

3.6. Effect of formal education on knowledge, connection, and behavior

What is the purpose of education? In our opinion (Ermakov, 2008), education is intended to advance competences, i.e., abilities and skills that allow students to handle real-life challenges. In other words, education is expected to help people to attain real-life tasks, and not just to increase factual knowledge. Along with the idea of education for sustainable development (UNESCO, 2020), sustainability is proposed to be a driver of professional education to develop competences required to achieve the 17 goals of sustainable development (Ermakov, 2021). In this respect, it is anticipated that education for sustainable development will result in a behavior change, with attitude change serving as an important prerequisite for such change to occur (Arbuthnott, 2009).

Along with these ideas, formal education on soil management is expected to teach people soil conservation and protection practices, and not just to increase theoretical knowledge of soil science. However, as mentioned above, soil science education primarily emphasizes psychomotor and cognitive learning, disregarding the motivational domain (Brevik et al., 2022a; Jelinski et al., 2020; Muggler, 2015).

It is noteworthy that farmers who reported receiving formal education on soil management demonstrated superior soil conservation behavior and greater soil science knowledge, in comparison to farmers who did not receive any formal education on soil management (Table 4). However, there was no significant association between formal education on soil management and connection to soil among the studied population. This indicates that, while formal education may have increased farmers' knowledge of soil science, it did not facilitate the development of motivational connection to soil, which is required to produce a behavior change in soil conservation (Fig. 1).

Similarly, we observed that farmers holding professional degrees in agriculture, such as agronomists and agricultural technicians, outperformed those without such credentials solely in terms of their knowledge of soil science, while their soil conservation behavior and connection to soil remained unaffected (Table 4). In other words, the pursuit of professional studies in agriculture does not guarantee the development of connection to soil among students. As a result, students were not obtaining competences required to achieve soil conservation behavior in their real professional life.

The present findings imply that, among the examined population, agronomists and agricultural technicians do not effectively apply their advanced knowledge of soil science to promote soil conservation. Instead, it is likely that these professionals leveraged their expertise to optimize crop yield and promote farm profitability, potentially at the expense of soil conservation efforts. To confirm this conjecture, additional investigations are necessary.

4. Practical implications and future research needs

Soil stewardship is a philosophy that guides conservation actions that farmers take on their farms, emphasizing managing soils to maintain their health in the context of ecosystems (Chouinard et al., 2008). It involves caring for something that has been entrusted to us by nature and whose benefits are there to be enjoyed down through generations. Soil stewardship involves not only carefully tending to the soil but also guarding and protecting it from harm, as it is a non-renewable resource (Ogieriakhi and Woodward, 2022). A soil stewardship ethic may help farmers resolve the apparent trade-off between short-term productivity goals and long-term conservation goals (Roesch-McNally et al., 2018). Studies suggest that at least some producers have a direct stewardship motive to undertake some level of conservation practices, and they are willing to forgo some profits to adopt these practices (Chouinard et al., 2008).

Lal et al. (2021) posited that soil science education has the potential to strengthen humanity's connection to soil. However, our findings suggest that achieving this goal is not a straightforward task. For example, at the university level, students enrolled in soil science courses receive instruction over the course of a semester, but the degree to which this instruction affects their connection to soil is seldom measured. Furthermore, it remains unclear which types of soil knowledge should be imparted to students to engender the desired shift in their attitudes. Instead, the focus is often on teaching students what they need to know to meet the industry's demand for high-yield crops (Field et al., 2017). Despite students being the future stewards of the soil, our current understanding of how to foster their adoption of soil conservation practices is surprisingly limited. This issue is particularly pressing given that many students of agriculture lack a strong connection to soil (Hartemink et al., 2014) due to the increasing urbanization of the world. For instance, in a previous study of Chilean agriculture students, we found that 70% of them hailed from urban areas (Neaman et al., 2021b).

The findings of the present study suggest that a comprehensive soil science education should encompass both motivational and cognitive components, to elicit behavioral changes that promote soil conservation. One effective strategy for achieving this is through methods that cultivate fascination with the subject of learning (Otto et al., 2020), which in the case of soil science is soil itself. This can be achieved through, for instance, artistic engagement and soil mapping (Hartemink et al., 2014) or storytelling and narratives (Brevik et al., 2022a) with a purpose to create a sense of wonder about the soil.

It is well established that certain soil science concepts are easily addressed in the classroom, while others remain distant and abstract until students gain personal, hands-on experience with them (Hartemink et al., 2014). For example, traditional teaching approaches such as lectures have been shown to be inadequate in facilitating soil science learning (Amador, 2019). Conversely, laboratory studies and field work may be instrumental in increasing fascination with soil resources. Nevertheless, the effects of various teaching strategies on soil science knowledge and attitude toward soil have not been thoroughly quantified (Neaman et al., 2021b). Thus, further research is necessary in this regard.

5. Conclusions

The results of this study highlight the complex interplay between farmers' connection to soil, their knowledge of soil science, and their soil conservation behavior. Specifically, it is evident that the successful implementation of soil conservation practices requires a balance between motivational and intellectual components, represented by connection to soil and soil science knowledge, respectively. These findings emphasize the significance of considering both motivational and cognitive factors in designing effective interventions for promoting sustainable farming practices. Ultimately, this study highlights the need for a holistic approach to soil conservation behavior research that takes into account the multifaceted nature of farmers' motivational disposition toward soil and their knowledge of soil science.

The present study is also an important step in developing valid scales capable of measuring farmers' soil science knowledge, connection to soil, and soil conservation behavior. Without a reliable instrument to gauge these analytical concepts, it is impossible to test academic hypotheses or establish theoretical frameworks for research on soil conservation behavior. It is noteworthy that the efficacy of the developed scales was demonstrated across three regions characterized by distinct geographical and cultural features. This underscores the universality of the proposed scales and implies their potential usefulness for diverse farmer populations.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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Appendix A

Appendix B. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.geoderma.2023.116583.

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