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Factors Associated with the Adoption of Soil Conservation Technologies in Brazilian Family Farming

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Abstract. This study aimed to investigate the factors associated with adopting technologies promoting soil conservation in Brazilian family farming in 2017. Structural Equation Modeling (SEM) was employed to identify these factors to achieve this aim, with the territorial unit of analysis being the 558 Brazilian microregions delineated by the Brazilian Institute of Geography and Statistics (IBGE) in 2017. The adoption of soil conservation technologies by Brazilian family farming represents a multidimensional phenomenon, which is positively influenced by factors within the socioeconomic context (including access to technical assistance services and credit facilities, as well as participation in collective farmer organizations), as well as characteristics of rural properties (such as water availability and the presence of productive machinery and equipment) and the education level of the farmer. It was observed that adopting such technologies has the potential to contribute to an increase in the country's Gross Production Value (GPV) of family farmers. The primary theoretical contribution of this study lies in validating factors associated with adopting soil conservation technologies within Brazilian family farming and the importance of family farmers' participation in collective organizations (cooperatives, technical meetings, and seminars) to access technical assistance and credit services. Furthermore, the practical implications suggest the need for specific public policies, including the establishment of cooperatives and the organization of technical meetings and seminars nationwide, the conservation and preservation of springs and water bodies in rural areas, and the provision of dedicated credit lines for the acquisition of machinery and equipment by family farmers.

Key words: climate change, gross production value, public policies, rural development, structural equation modeling, sustainability.

Introduction

The world population is estimated to reach 9 billion by 2050. Furthermore, improving living standards will increase the demand for food and energy. At the same time, the amount of productive land available (due to soil degradation in cultivable areas and forest preservation) for expanding food production is decreasing. Therefore, agricultural output growth should be guided by adopting technologies that increase the productivity of productive factors and promote soil conservation, aiming to ensure food and nutritional security for the world population (Reetz, 2017).

The demand for food is increasing as populations grow and gain wealth to purchase more varied diets with intensive resource use. There is increasing competition for land, water, energy, and other inputs in food production. Climate change poses challenges to the agricultural sector, especially in developing countries, and many farming practices are detrimental to the environment and a significant source of greenhouse gas emissions (Garnett *et al.*, 2013).

The effects of climate change on the agricultural sector are related to the increase in temperature, high concentrations of carbon dioxide (CO_2) (one of the greenhouse gases) in the atmosphere, increased frequency, and intensity of extreme weather events (droughts, heavy rains, heatwaves, and cold spells), and changes in rainfall patterns. For Brazil, average increases in climate temperature from 1.0°C to 5.8°C (Celsius) may reduce crop productivity levels of rice, sugarcane, beans, corn, and soybeans and promote a higher occurrence of diseases, pests, and weeds in crop cultivation areas and pastures in agricultural production systems (Oliveira, Gontijo Neto, & Nobre, 2018).

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Soil degradation primarily involves losing biological, physical, and chemical characteristics essential for plant development (Olsson *et al*., 2019). In 2017, approximately 11.86 million hectares of planted pastures were in poor condition of use (exhibiting some level of soil degradation, including issues such as erosion, presence of weeds and termite mounds, and lack of periodic maintenance of the pasture area) across Brazilian territory (IBGE, 2017).

The factors contributing to the increase in soil degradation levels in a region are related to poor management practices on rural properties (such as inappropriate land use according to its agricultural suitability), deforestation for the expansion of areas to be cultivated for crops and pastures, excessive soil preparation through mechanical activities (plowing and harrowing), lack or improper use of fertilizers and soil amendments, among others (Stuchi, 2022).

The definition of the family farmer was regulated by Law number 11,326 of July 24, 2006, and must simultaneously adhere to the following criteria: (a) not hold an area larger than four fiscal modules; (b) predominantly use family labor in the economic activities of the property; (c) have a minimum percentage of family income derived from economic activities on the property; and (d) manage the establishment with the family. In addition to these criteria, silviculturists, aquaculturists, extractivists, artisanal fishermen, indigenous peoples, and individuals from quilombola and traditional communities are also included (BRASIL, 2006).

In 2017, 3.89 million family farms were covering an area of 80.89 million hectares in Brazil. Among the Brazilian regions, the majority of family farms were concentrated in the Northeast, with 1.83 million (representing about 47.19% of the national total), followed by the Southeast with 688.94 thousand (about 17.68% of the national total), South with 665.76 thousand (about 17.08% of the national total), North with 480.57 thousand (about 12.33% of the national total), and Midwest with 223.27 thousand (about 5.73% of the national total) in the year 2017 (IBGE, 2017).

In 2017, most family farms had a low Gross Production Value (GPV) for the year, with around 2.27 million having an annual GPV of up to US$ 3,022.97, accounting for 58.44% of the national total. Additionally, the adoption of soil conservation technologies by family farmers is low. Out of the total of 3.8979 million producers, approximately 741.02 thousand utilized crop rotation (representing 19.01% of the national total), 429.19 thousand employed no-till farming (representing 11.01% of the national total), 1.63 million used fertilizers (representing 42.03% of the national total), and 497.92 thousand used soil amendments (about 12.77% of the national total) (IBGE, 2017).

Adopting technology in the agricultural sector is a complex phenomenon influenced by environmental, cultural, economic, institutional, political, and social factors. These factors can group into categories: (a) characteristics of the rural property, (b) characteristics of the socioeconomic environment in which the rural property located, (c) characteristics of the rural producer, and (d) characteristics of the technology itself (Mungia & Llewellyn, 2020; Tey & Brindal, 2012).

The literature on the determinants of technology adoption in the agricultural sector has made little effort to synthesize results in ways that are particularly useful for policymakers (Pannell & Claassen, 2020). Empirical research on the technology adoption process in the field needs to incorporate the characteristics of the socio-institutional context of the analyzed region, especially the social, political, and economic aspects related to the phenomenon. This type of assessment is essential for promoting policies of Inclusive Agricultural Development and poverty reduction in rural populations (Jones-Garcia & Krishna, 2021).

There is a need for more studies discussing the factors associated with technology adoption in countries where most rural producers have a low production level (Pannell & Zilberman, 2020). Therefore, the investigative question of the present research was: "Which factors related to the socioeconomic environment and the characteristics of rural properties and farmers are associated with the adoption of soil conservation technologies among Brazilian family farmers?". Additionally, another research question investigated was: "Can the adoption of soil conservation technologies contribute to an expansion of the Gross Production Value (GPV) among Brazilian family farmers?".

The objective of this research was to investigate the factors associated with the adoption of technologies that promote soil conservation in Brazilian family farming in the year 2017. Structural Equation Modeling (SEM) was used to determine the factors, and the territorial analysis unit was the 558 microregions in Brazil delimited by the Brazilian Institute of Geography and Statistics (IBGE) (2017).

Materials and Methods

Conservation agriculture and determinants of technology adoption

Conservation agriculture is conducted under the protection of a complex of systemic technologies aimed at preserving, maintaining, and restoring (or recovering) natural resources through integrated management of soil, water, and biodiversity (Denardin *et al.*, 2014). The diffusion of sustainable practices in the agricultural sector contributes to maintaining long-term food production and conserving natural resources (Ngaiwi *et al.*, 2023).

Water erosion is the main factor leading to soil degradation, involving the detachment and transport of soil particles by rainwater (Bertol *et al.,* 2014; Zonta *et al*., 2012). In Brazil, water erosion is one of the main forms of soil degradation on rural properties. Nutrients and organic matter from cultivated areas are transported in surface runoff. The erosive process can alter the soil's biological, physical, and chemical characteristics and reduce fertility levels, affecting the productive capacity of rural properties (Telles, 2015).

Promoting soil conservation in agricultural activities should be encouraged through the dissemination of technologies that lead to a reduction in soil erosion processes (Bertol *et al*., 2014). Technologies such as crop rotation (Baumhardt, Johnson, & Schwartz, 2012), no-till farming systems (Merten *et al.*, 2015; Ofstehage & Nehring, 2021; Somasundaram *et al.*, 2020), as well as the use of fertilizers (Li *et al*., 2022) and soil amendments (Konstadinou *et al*., 2023), contribute to the reduction of soil erosion on rural properties.

Crop rotation is the alternating cultivation of different types of plants within a productive area of a rural property over time. It can provide benefits such as increased organic matter content, promoting greater nutrient flow, and reducing soil erosion processes (ISGA, 2010). It also leads to a reduction in greenhouse gas emissions (Carvalho *et al*., 2014).

The no-till farming system encompasses three general aspects that should be adhered to (a) minimal soil disturbance (reduction of mechanical activities during soil preparation, such as plowing and harrowing); (b) maintenance of vegetative cover on the soil through the retention of plant residues (mulch) throughout the cultivation area; and (c) implementation of crop rotation (Passos, Alvarenga, & Santos, 2018; Telles *et al.*, 2021). It provides benefits such as improvement in the biological, physical, and chemical structure of the soil (Passos *et al*., 2018) and reduces greenhouse gas emissions (Somasundaram *et al*., 2020; Weidhuner *et al*., 2022).

Fertilizer and soil amendments should be employed based on technical recommendations to respect rural property's soil and climatic conditions (such as soil characteristics, climate, topography, etc.) and the type of economic activity being pursued (each plant has specific nutrient and water requirements during the production cycle) (ISGA, 2010).

The process of technology adoption in the rural sector is complex and multidimensional, influenced by various factors related to the socio-economic environment and the characteristics of the property and rural producer (Mungia & Llewellyn, 2020; Tey

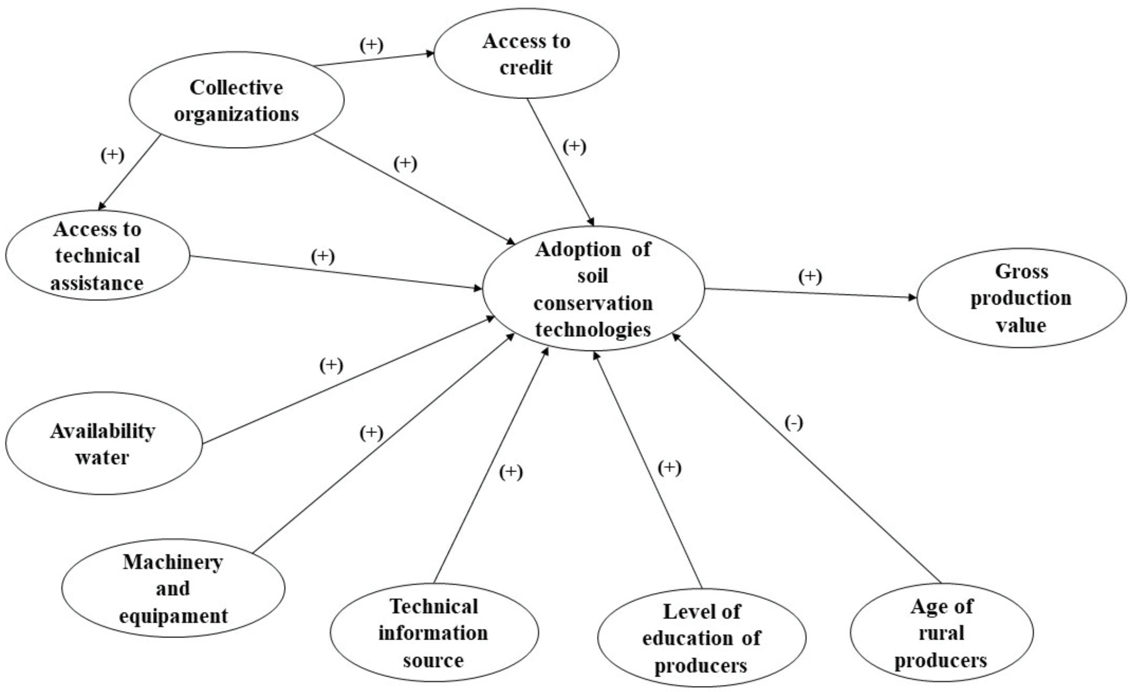

Figure 1. Factors associated with adopting technology in the agricultural sector.

Source: Adapted from Procópio (2023).
Note: (+) positive influence of one construct on another; (-) negative influence on another.

& Brindal, 2012). The following theoretical constructs can represent these factors: (a) socio-economic environment, access to technical assistance services and credit, and the participation of rural producers in collective organizations; (b) characteristics of the rural property: availability of water, existence of productive machinery and equipment, and sources of technical information (newspapers, magazines, devices with internet connection, etc.); and (c) characteristics of rural producers: level of education and age of individuals (Figure 1) (Procópio, 2023; Procópio, Binotto, & Pereira, 2024).

The adoption of technology in the agricultural sector positively influenced when individuals have access to credit services (H1) (Kumar *et al*., 2021; Tesfay & Moral, 2021) and technical assistance (H2) (Nasereldin *et al*., 2023; Ngaiwi *et al*., 2023). The participation of rural producers in collective action entities enables the exchange and acquisition of technical information and experiences regarding the use of technologies in agricultural production systems, which contributes to the technology adoption process (H3) in the field. It also aids in accessing technical assistance services (H4) and credit (H5), as well as markets, and in reducing production costs (Souza Filho *et al*., 2011; Wossen, Berger, & Falco, 2015).

Water availability on rural properties contributes to the technology adoption process in the rural sector (H6) (Kharel, Raut, & Dahal, 2023; Yang, Zhu, & Wang, 2021). The presence of productive machinery and equipment (H7) (Jones-Garcia & Krishna, 2021; Pannell *et al*., 2006; Souza Filho *et al*., 2011), as well as sources of technical information (newspapers, magazines, devices with internet connection etc.) (H8)

Table 1

Hypotheses of the theoretical model

Hypothesis	Description	Expected relationship
Influence on the technology adoption construct		
H1	Access to credit positively influences the adoption of technologies that promote soil conservation.	Positive
H2	Access to technical assistance positively influences the adoption of technologies that promote soil conservation.	Positive
H3	Rural producers’ participation in collective organizations positively influences the adoption of technologies that promote soil conservation.	Positive
H6	Water availability on rural properties positively influences the adoption of technologies that promote soil conservation.	Positive
H7	The presence of machinery and equipment on rural properties positively influences the adoption of technologies that promote soil conservation.	Positive
H8	The existence of sources of technical information on rural properties positively influences the adoption of technologies that promote soil conservation.	Positive
H9	Higher education levels among rural producers positively influence the adoption of technologies promoting soil conservation.	Positive
H10	The older age bracket of rural producers negatively influences the adoption of technologies aimed at soil conservation.	Negative
Influence on the constructs of access to technical assistance services and credit		
H4	The participation of rural producers in collective organizations exerts a positive influence on access to technical assistance.	Positive
H5	The participation of producers in collective organizations exerts a positive influence on access to credit.	Positive
Influence on the GPV construct		
H11	The adoption of technologies promoting soil conservation exerts a positive influence on the GPV of family farming.	Positive

Source: Developed by the author.

(Filippini *et al*., 2020; Giua, Materia, & Camanzi, 2021), also exert a positive influence on the technology adoption process in the agricultural sector. Regarding individual characteristics, the level of education has a positive influence on technology adoption in the field (H9) (Emongor, Katungi, & Uside, 2023; Mulwa, Muyanga, & Visser, 2021).

Individuals' age negatively influences the technology adoption process in the rural sector (H10). Older rural producers may exhibit less energy, have a shorter planning horizon (compared to younger individuals), and show greater resistance to changes needed in the production system when implementing new technology (Souza Filho *et al*., 2011).

The use of technologies such as crop rotation (Volsi *et al*., 2022), no-till farming systems (Foloni *et al*., 2023; Somasundaram *et al.*, 2020), fertilizers (Ejigu, Selassie, & Elias, 2023; Foloni *et al*., 2023), and soil amendments (Ejigu *et al*., 2023) can contribute to increased productivity of production factors and, consequently, exert a positive influence on the Gross Value of Production (GVP) in the agricultural sector (H11).

In Table 1, the relationship of hypotheses from the theoretical model for evaluating the adoption process of soil conservation-promoting technologies among Brazilian family farmers is presented, along with whether the use of such practices and productive inputs can contribute to an expansion of the Gross Value of Production (GVP) for family producers in the country.

Structural equation modeling (SEM)

Structural Equation Modeling (SEM) encompasses a set of multivariate data analysis techniques that combine aspects of multiple regression and factor analysis to estimate a series of dependency relationships simultaneously. A pre-defined theoretical model is necessary to construct a structural equation model to determine the multiple dependency relationships (or causal relationships) between the theoretical constructs (Hair *et al*., 2009).

The approach utilized was PLS-SEM, which stands for Partial Least Squares Structural Equation Modeling, where the parameters are estimated through a series of partial least squares regressions. The term "partial" arises from the procedure of interactive parameter estimation in blocks (by latent variable), as opposed to the entire model simultaneously. In SEM, two models are evaluated: the measurement model (outer model) and the structural model (inner model). The measurement model considers the relationship between constructs and indicators (observable variables). The structural model evaluates the relationship between constructs (validating the hypotheses proposed in the theoretical model) (Nascimento & Macedo, 2016).

Initially, 42 observable variables from the 2017 Agricultural Census were selected, representing different theoretical constructs of the theoretical model (Figure 1). The variables were standardized relative to the total number of establishments (NT), total area of establishments (AE), or occupied personnel (OP) (Lobão & Staduto, 2020). The unit of analysis was the 558 Brazilian microregions, and the software used was SMARTPLS®.

Results and Discussion

The first step of SEM is validating the measurement model by evaluating Convergent and Discriminant Validity and Composite Reliability. Convergent validity was assessed by analyzing the Average Variance Extracted (AVE), which should be greater than 0.50. Discriminant Validity aims to verify the distinction of a construct from others by evaluating the cross-loadings of indicators with their respective constructs. Fornell and Larcker (1981) criterion was used to compare the square root of AVE values with the correlations of other constructs. The square root of the AVE for each latent variable should be greater than the correlations of the constructs within the model. Composite Reliability (CR) of the constructs is conducted to ensure the sample is free from biases and should assume a value greater than 0.70 (Hair *et al.*, 2017).

The initial model with 42 observable variables was not deemed adequate according to the measurement model's criteria. Therefore, adjustments were made to the model until it became satisfactory (AVE > 0.50 and CR > 0.70) (Table 2). Adjustments were made by removing some observable variables and applying a logarithmic transformation to those representing the GPV. Logarithmic transformation of a variable is important for reducing issues of data distribution skewness (Fávero *et al.*, 2014).

Table 3 presents information from the adjusted measurement model, indicating the observable variables and their factor loadings (ranging from a minimum of 0.439 to a maximum of 0.927) (Table 3).

It is recommended that the factor loadings of observable variables be greater than 0.70 for the discriminant validity of the measurement model (Hair *et al*., 2017). However, variables AC3 (0.439), AW2 (0.697), TIS1 (0.619), TIS2 (0.556), LEP3 (0.686), and LEP8 (0.663) presented factor loadings below 0.70. In such situations, it is advisable to retain as many indicators as possible in the measurement model to maintain the content validity of the constructs (Bido & Silva, 2019). Therefore, it was decided to keep these observable variables in the measurement model.

Table 2

Correlation Matrix of Latent Variables

Constructs	AC	ATA	AT	AW	TIS	ARP	ME	LEP	OC	GPV
AC	**0.723**									
ATA	0.602	**0.833**								
AT	0.597	0.687	**0.775**							
AW	0.292	0.403	0.432	**0.831**						
TIS	0.656	0.758	0.765	0.387	**0.897**					
ARP	0.447	0.646	0.529	0.480	0.647	**0.723**				
ME	-0.194	-0.314	-0.247	-0.105	-0.276	-0.428	**0.848**			
LEP	0.245	0.586	0.500	0.470	0.538	0.681	-0.438	**0.722**		
OC	0.719	0.748	0.748	0.392	0.825	0.616	-0.281	0.472	**0.896**	
CPV	0.206	0.445	0.525	0.385	0.456	0.439	-0.27	0.532	0.426	**0.789**
AVE	0.523	0.694	0.601	0.691	0.804	0.522	0.719	0.522	0.803	0.622
CR	0.755	0.818	0.857	0.814	0.943	0.842	0.884	0.844	0.891	0.767

Source: Research findings.

Note: AVE - average variance extracted; CR - composite reliability. Constructs: AC - access to credit; ATA - access to technical assistance; AT - adoption of soil conservation technologies; AW - availability of water; TIS - technical information source; ARP - age of rural producers; ME - machinery and equipment; LEP - level of education of producers; OC - collective organizations; GPV - gross production value.

Table 3

Observable variables of the adjusted measurement model

Constructs	Observable variables	Factor loadings
AT – Adoption of Soil Conservation Technologies	AT2 – fertilizers	0.790
	AT3 – crop rotation	0.851
	AT4 – amendments	0.714
	AT5 – no-till farming system	0.740
AC – Access to Credit	AC1 – banks (including financial resources from rural credit lines like PRONAF, PROCERA, etc.)	0.786
	AC2 – credit cooperatives	0.872
	AC3 – governments (federal, state, and municipal) (other types of resources provided outside rural credit lines)	0.439
ATA – Access to Technical Assistance	ATA2 – rural producer (or contracted)	0.768
	ATA3 – cooperatives	0.893
OC – Collective Organizations	OC1 – cooperatives	0.917
	OC5 – technical meetings/seminars	0.874
AW – Availability of Water	AW1 – springs	0.947
	AW2 – rivers/streams	0.697
ME – Machinery and Equipment	ME1 – tractors	0.875
	ME2 – seeders/planters	0.927
	ME3 – harvesters	0.875
	ME4 – fertilizer spreader and lime spreader	0.91
TIS – Technical Information Source	TIS1 – television	0.619
	TIS2 – radio	0.556
	TIS3 – devices with internet connection	0.831
	TIS4 – magazines	0.786
	TIS5 – newspapers	0.781

LEP – Level of Education of Producers	LEP3 – former primary school (elementary)	0.686
	LEP4 – former middle school (junior high)	0.804
	LEP8 – regular high school	0.663
	LEP9 – technical high school	0.732
	LEP11 – higher education	0.718
ARP – Age of Rural Producers	IP1 – less than 25 years old	0.865
	IP2 – 25 to less 35 years old	0.883
	IP3 – 35 to less than 45 years old	0.792
GPV – Gross Production Value	lGPV_nt – Natural logarithm of gross production value divided by total establishments	0.793
	lGPV_ae – Natural logarithm of gross production value divided by establishment area	0.785

Source: Research findings.
Note: the observable variable AT1 (contour planting) was removed from the model due to poor fit in the measurement model. Except for GPV, the other observable variables were normalized by the total number of establishments (NT) in the analyzed microregion.

The structural model was assessed through Pearson's determination coefficients (R2), multicollinearity analysis, effect size f2, and the significance of structural coefficients (Bido & Silva, 2019; Ringle, Silva, & Bido, 2014) (Table 4). The R2 evaluates the portion of the variance of the endogenous latent variables (which were the constructs AT, AC, ATA, and GPV) explained by the structural model (Ringle *et al*., 2014). The adjusted R2 considers the model's complexity and the sample size, and values can range from 0 to 1 (which can be evaluated in percentage terms) (Henseler, Hubona, & Ray, 2016).

The model was able to explain 65.40% (0.654) of the variance in the adoption of soil conservation-promoting technologies (AT) in Brazilian family agriculture (adjusted R-squared). In the constructs of access to technical assistance services (ATA) and credit (AC), the adjusted R-squared values were 55.90% (0.559) and 51.60% (0.516), respectively. Finally, for the construct of Gross Value of Production (GVP) in family agriculture, the achieved value was 27.40% (0.274) in 2017 (Table 4).

The collinearity analysis evaluated the value of the latent variables' VIF (variance inflation factor). In the context of PLS-SEM, it is recommended that the VIF value be between 0.20 and 5.00 to avoid collinearity issues (Hair *et al*., 2017). The absence of multicollinearity in the model was confirmed, as all

Table 4

Results of the structural model

Relationships between constructs	Hypotheses	VIF	f^2	Structural coefficient	Standard error	Significance (p-value)	Adjusted R-squared
AC -> AT	H1	2.312	0.008	0.078	0.042	0.061***	0.654
ATA -> AT	H2	3.081	0.015	0.125	0.050	0.012**	
OC -> AT	H3	4.175	0.050	0.267	0.059	0.000*	
AW -> AT	H6	1.447	0.029	0.119	0.032	0.000*	
ME -> AT	H7	3.954	0.104	0.375	0.055	0.000*	
TIS -> AT	H8	2.665	0.018	-0.128	0.048	0.008*	
LEP -> AT	H9	2.433	0.014	0.107	0.045	0.018**	
ARP -> AT	H10	1.343	0.000	-0.009	0.032	0.775	
OC -> AC	H5	1.000	1.069	0.719	0.026	0.000*	0.516
OC ->ATA	H4	1.000	1.271	0.748	0.029	0.000*	0.559
AT ->GPV	H11	1.000	0.380	0.525	0.031	0.000*	0.274

Source: Research findings.
*Note: * 1% significance level; ** 5% significance level; *** 10% significance level. Constructs: AC – access to credit; ATA – access to technical assistance; AT – adoption of soil conservation-promoting technologies; AW – availability of water; TIS – source of technical information; ARP – age of rural producers; ME – productive machinery and equipment; LEP – level of education of producers; OC – collective organizations; GVP – Gross Value of Production. P-values of structural coefficients achieved through the bootstrapping resampling technique with 5.000 repetitions.*

VIF values were greater than 0.20 and less than 5.00 (Table 4).

The statistical significance of the structural coefficient represents the theoretical validation of the analyzed hypothesis (causal relationship between the constructs of the theoretical model) (Hair *et al*., 2017). Meanwhile, the effect size (f^2) indicates the practical importance of the achieved result (Cohen, 1988). Cohen's effect size indicates public policies for disseminating soil conservation-promoting technologies among family farmers across the Brazilian territory.

The effect size (f2), or Cohen's indicator, evaluates how much each construct is considered "useful" for the model. Values of 0.02, 0.15, and 0.35 indicate small, medium, and large effects, respectively (Cohen, 1988; Hair *et al*., 2017; Ringle *et al*., 2014). Out of the eight hypotheses related to the adoption process of soil conservation-promoting technologies by family farmers (crop rotation, no-till farming system, and the use of soil amendments and fertilizers), six were confirmed (H1, H2, H3, H6, H7, H9). One had an inverse relationship to what was advocated in the literature (H8) (Table 3).

The first hypothesis (H1) that access to credit exerts a positive influence on the adoption of soil conservation-promoting technologies in Brazilian family agriculture was confirmed (=0.078, p<0.061) (Table 4). Access to credit was necessary for adopting fertilizers in Ethiopia (Tesfay & Moral, 2021) and genetically improved rice, corn, and wheat seeds in India (Kumar *et al*., 2021).

Hypothesis 2, which relates to the positive influence of access to technical assistance services on adopting soil conservation-promoting technologies in Brazilian family agriculture, was confirmed (=0.125, p<0.012) (Table 4). Access to technical assistance services contributed to the adoption of a set of soil conservation practices (crop rotation, agroforestry systems, green cover, and no-till farming) in Cameroon (Ngaiwi *et al*., 2023) and new cultivars of oil palm in Thailand (Nasereldin *et al*., 2023).

The third hypothesis (H3) concerning the positive influence of rural producers' participation in collective organizations on the adoption of soil conservation-promoting technologies was confirmed for Brazilian family farming (=0.267, p<0.000), with a small effect (f^2 equal to 0.050) (Table 4). The participation of producers in collective organizations was significant for adopting genetically improved seeds in India (Kumar *et al*., 2021) and fertilizers in Kenya (Mulwa *et al*., 2021). In the context of Brazilian family farming, developing public policies that promote the creation of cooperatives and the organization of seminars and technical meetings may contribute to disseminating soil conservation technologies among family farmers across Brazilian territory.

The sixth hypothesis (H6) concerning the positive influence of water availability on rural properties on the adoption of soil conservation technologies was confirmed for Brazilian family farming (=0.119, p<0.000), with a small effect (f^2 equal to 0.029) (Table 4). Water availability on rural properties has contributed to the adoption of fertilizers in China (Yang *et al*., 2021) and Nepal (Kharel *et al*., 2023). Governmental actions promoting the conservation and preservation of springs, rivers, and streams in rural areas can contribute to disseminating soil conservation technologies among Brazilian family farmers.

The seventh hypothesis (H7) regarding the existence of productive machinery and equipment (tractors, seeders/planters, harvesters, fertilizer spreaders, and lime distributors) on rural properties exerting a positive influence on the adoption of soil conservation-promoting technologies was confirmed for the context of Brazilian family farming (=0.375, p<0.000), with a small effect (f^2 equal to 0.104) (Table 3). The presence of productive machinery and equipment on rural properties is crucial for implementing productive practices such as no-till farming (Telles *et al*., 2021) and using fertilizers (Zonta *et al*., 2012). The development of public policies that provide access to credit for the modernization of rural family properties can contribute to the country's greater adoption of soil conservation technologies.

The ninth hypothesis (H9), which is that higher levels of education among rural producers positively influence the adoption of soil conservation-promoting technologies, was confirmed for Brazilian family farming (=0.107, p<0.018) (Table 4). The educational attainment of rural producers has been significant for using fertilizers (Mulwa *et al*., 2021) and integrated soil fertility practices (Emongor *et al*., 2023) in Kenya.

The eighth hypothesis (H8) yielded results contrary to those anticipated in the literature. In Brazilian family farming, access to technical information had a negative relationship with adopting soil conservation technologies (=-0.128, p<0.008) (Table 4). In 2017, Brazil had 3.89 million family farmers, of which 1.02 million (representing 26.38% of the total national) were unable to read or write, and 699.51 thousand (representing 17.49% of the total national) had never attended school (IBGE, 2017). This implies that a portion of Brazilian family producers have a minimal level of education but have not been able to adequately develop the learning process for acquiring new technical knowledge.

Using soil conservation technologies on rural properties requires producers to acquire new management skills (Knowler & Bradshaw, 2007). For instance, when applying fertilizers and amendments, it is necessary to adhere to technical recommendations following soil analysis (Linquist, Phengsouvanna, & Sengxue, 2007). Adopting no-till farming demands proper preparation of machinery and equipment for soil preparation and seeding (Telles, 2015), while crop rotation necessitates adequate planning of cultivation areas (ISGA, 2010).

Hypotheses H4 (the participation of producers in collective organizations has a positive influence on access to technical assistance) (=0.748, p<0.000; f^2 of 1.271, classified as a large effect) and H5 (the participation of rural producers in collective organizations has a positive influence on access to credit) (=0.719, p<0.000; f^2 of 1.069, classified as a large effect) were confirmed for Brazilian family agriculture (Table 4). The participation of rural producers in collective organizations has been found to contribute to access to credit in Ethiopia (Wossen *et al*., 2015) and to technical assistance services in Ghana (Zakaria *et al*., 2020). The development of public policies promoting the creation of cooperatives and the organization of technical meetings and seminars can contribute to expanding family farmers' access to technical assistance and credit services.

The eleventh hypothesis (H11) concerning the positive influence of adopting soil conservation technologies (crop rotation, no-till farming, and the use of amendments and fertilizers) on the GPV confirmed for Brazilian family agriculture (=0.525, p<0.000), with a large effect size (f^2 equal to 0.380) (Table 3). The utilization of soil conservation technologies can enhance the productivity of rural properties, exemplified by crop rotation (Volsi *et al*., 2021), no-till farming (Foloni *et al*., 2023), amendments (Ejigu *et al*., 2023), and fertilizers (Foloni *et al*., 2023). The formulation of public policies aimed at disseminating soil conservation technologies can contribute to expanding the GPV of family-owned properties across the national territory.

Conclusions

This research aimed to identify factors associated with adopting soil conservation technologies in Brazilian family agriculture in 2017 and assess whether adopting such technologies could contribute to expanding the GPV of Brazilian family farmers. The main theoretical contribution of this study was validating factors related to the adoption of soil conservation technologies in Brazilian family agriculture.

The adoption of soil conservation technologies in Brazilian family agriculture is a complex and multidimensional phenomenon, positively influenced by factors in the socioeconomic environment (access to technical assistance and credit services and the participation of rural producers in collective organizations) as well as the characteristics of the rural property (availability of water and the existence of productive machinery and equipment) and the producer (level of education). Conversely, it is negatively influenced by the absence of technical information sources on the rural property. The theoretical validation of the importance of family farmers' participation in collective organizations (cooperatives, technical meetings, and seminars) to access technical assistance and credit services was also conducted, demonstrating how adopting soil conservation technologies can contribute to expanding the GPV of family farmers in the country.

The main practical contributions relate to indicating public policies for promoting rural development in Brazil. Regarding the adoption of soil conservation technologies, the following proposals are suggested: (a) the establishment of cooperatives and the organization of technical meetings and seminars across Brazil, (b) the conservation and preservation of springs and rivers/streams in rural areas, and (c) specific credit lines for the purchase of machinery and equipment by family farmers. Implementing such actions can also contribute to expanding Brazil's GPV of family agriculture. Furthermore, incentivizing the participation of family producers in collective organizations (cooperatives, technical meetings, and seminars) can contribute to expanding access to technical assistance and credit services throughout the Brazilian territory.

One of the main limitations of this study was the unintentional exclusion of factors that may be related to the adoption of soil conservation technologies in Brazilian family agriculture. The theoretical model (Figure 1) could be expanded to include other factors, as the adjusted R2 was 0.654. Another limitation was the non-inclusion of other soil conservation technologies in the structural model, such as minimum tillage and fallow or soil rest, variables in the 2017 Agricultural Census database.

It recommended that studies be conducted for regions and states with the unit of analysis at the municipal level. Evaluating regions and federative units can contribute to developing more specific public policies tailored to the different contexts throughout the Brazilian territory.

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