



Revista
Brasileira de
Ciência do Solo

Division - Soil Use and Management | Commission - Land Use Planning

Soil management practices adopted by farmers and how they perceive conservation agriculture

Tiago Santos Telles^{(1,2)*} , Thadeu Rodrigues de Melo^(1,2) , Ana Julia Righetto⁽¹⁾ ,
Elizeu Jonas Didoné⁽¹⁾  and Graziela Moraes de Cesare Barbosa^(1,2) 

⁽¹⁾ Instituto de Desenvolvimento Rural do Paraná, Londrina, Paraná, Brasil.

⁽²⁾ Universidade Estadual de Londrina, Departamento de Agronomia, Londrina, Paraná, Brasil.

ABSTRACT: In some rural properties of Brazil, soil and water conservation practices are partially or inappropriately implemented, intensifying soil erosion, even in no-tillage (NT) areas. This study aimed to check the farmer's understanding of conservation agriculture (CA) and assess whether they are using practices appropriate to soil conservation. A basin in the state of Paraná, in Southern Brazil, was selected. Surveys were conducted based on a structured questionnaire and in-person interviews of 234 farmers. Among these farmers, 67 % do not understand CA pillars adequately, and 68 % stated they have been using NT for over 12 years. However, 58 % stated that they carried out some kind of soil preparation. Furthermore, some of the farmers only partially implemented CA, adopting a low level of crop diversification. The main problems pointed out by the farmers to justify simplifying the CA approach were soil compaction, low production of plant biomass and resistance of weeds to herbicides. Most farmers in the study do not have enough knowledge of the pillars of CA. As a result, there is little diversification in crop rotation, and the soil is continually disturbed with chiseling. Furthermore, although most farmers use terracing, they drive sprayers crossing terraces and following the slope, a practice that can impair the capacity of terraces to control surface water runoff. These practices do not contribute to soil and water conservation and endanger the sustainability of agricultural production systems.

Keywords: soil conservation, soil use, no-tillage, crop rotation, soil cover.

* Corresponding author:



E-mail: telles@idr.pr.gov.br

Received: November 22, 2021

Approved: March 02, 2022

How to cite: Telle TS, Melo TR, Righetto AJ, Didoné EJ, Barbosa GMC. Soil management practices adopted by farmers and how they perceive conservation agriculture. Rev Bras Cienc Solo. 2022;46:e0210151.

<https://doi.org/10.36783/18069657/rbcs20210151>

Editors: José Miguel Reichert 
and Luciano da Silva Souza .

Copyright: This is an open-access article distributed under the terms of the Creative Commons Attribution License, which permits unrestricted use, distribution, and reproduction in any medium, provided that the original author and source are credited.



INTRODUCTION

Water erosion in agricultural areas is one of the main causes of soil and water degradation, leading to losses of agricultural lands and contamination of water resources. In Brazil, the economic impact of erosion on crops is estimated at around 2 billion dollars annually, caused by a loss of approximately 617 million metric tons of soil (Dechen et al., 2015). These erosive processes impair the sustainability of production systems, yields, and soil quality, which is further aggravated by low crop diversification and inadequate conservation practices (Derpsch et al., 2014). In addition to problems associated with hillside locations, where erosion begins, water resources are adversely affected by sediments and contamination with pesticides (Defersha and Melesse, 2012).

Brazil has pioneered the development and use of soil conservation techniques in tropical regions, especially in terms of no-tillage (NT) practices that are so important for conserving and improving the country's soil and water resources (Telles et al., 2013; Derpsch et al., 2014; Deuschle et al., 2019). No-tillage has been implemented on over 32 million hectares (Fuentes-Llanillo et al., 2021), producing about 60 % of the country's annual crops (IBGE, 2019). Three basic approaches, or pillars, form the foundations of Conservation Agriculture (CA): (i) the sowing system (i.e., no-tillage, except along the furrow); (ii) constant soil cover, keeping plant biomass on the soil surface; and (iii) crop rotation, with the emphasis on diversification, growing at least three species over a three-year cycle (Bolliger et al., 2006; Kassam et al., 2019). Given the high rainfall erosivity in Southern Brazil (Oliveira et al., 2013), NT alone is not sufficient to ensure soil conservation, and other practices must be implemented, such as level planting and agricultural terracing (Telles et al., 2019a).

However, not all the pillars of CA have been implemented according to the recommendations (Pittelkow et al., 2015; Telles et al., 2019a), and other conservation practices have been implemented partially (Didoné et al., 2015; Minella et al., 2017). This could increase soil erosion and degradation (Silva and De Maria, 2011). This is evidenced by the low amount of residual biomass covering the soil after harvesting, which is related to the adoption of production systems with low crop diversification (predominantly soybean in the spring-summer and corn in the autumn-winter). Many areas are still being left without soil cover between crops, intensifying exposure to rain, wind and sun radiation, increasing erosion and causing a drop in soil fertility and loss of yields (Kassam et al., 2009; Derpsch et al., 2014).

Even in southern Brazil, where over 90 % of the land cropped with soybean, corn, and winter cereals is managed under NT, there are soil erosion, degradation, and diffuse pollution. This is because of the low quality of NT practices and production systems used to mitigate environmental issues (Didoné et al., 2017). The main problems in terms of soil conservation in CA are (a) the misuse of terracing for managing flash flooding; (b) poor use of cover plants and crop rotation; (c) insufficient production of plant biomass for adequate soil cover; (d) excessive traffic of machinery and agricultural equipment; and (e) excessive use of pesticides. Consequently, environmental harm and economic losses have been inflicted on the land due to the reduction in water infiltration, significant losses of soil, water, and nutrients, wastage of pesticides, and pollution of water bodies (Londero et al., 2018).

This situation has raised issues regarding how much farmers know about CA, and whether they are adopting adequate soil conservation techniques. Our hypothesis is that farmers do not know CA principles and do not manage the land with soil conservation in mind. This study aimed to check whether farmers understand CA principles and assess which conservation practices have been adopted.

MATERIALS AND METHODS

Study area characterization

The study was carried out in southern Brazil, in the west of Paraná State, where we assessed how well farmers understand soil conservation practices. The current conditions of land use and management (partial adoption of conservation practices, knowledge, and technologies) increase the potential for sediment production that flows into the Paraná River. The area selected is sufficiently extensive to represent regional rather than local conditions.

The Paraná Basin 3 (PB3) covers an 8000 km² and accommodates 24,150 farms, distributed over 29 municipalities, 28 of which are located in the western mesoregion of Paraná State and one in the state of Mato Grosso do Sul (Figure 1).

According to Köppen classification system, the region's climate is predominantly subtropical humid (Cfa), with no dry season and moderately high temperatures, with average temperatures during summer reaching more than 22 °C and average temperatures during winter reaching about 18 °C (Alvares et al., 2014). The average annual rainfall is 1,792 mm. According to Waltrick et al. (2015), the average erosivity index for rainfall in this region is between 9,000 and 11,000 MJ mm ha⁻¹ h⁻¹ yr⁻¹.

Predominant soils in the basin are classified as *Latossolos Vermelhos*, *Nitossolos Vermelhos* and *Neossolos Regolíticos* (Santos et al., 2018), which corresponds to Hapludox, Rhodudults, and Psamments (Soil Survey Staff, 2014), or Rhodic Ferralsols, Rhodic Nitisols, and Regosols (IUSS Working Group WRB, 2015). The landscape in PB3 has elevations ranging from 80 to 725 m, reflecting the tendency towards rounded peaks, exhibiting average landscape dissection with undulating to gently undulating relief (Salamuni et al., 2003). The region is characterized by gentle slopes (5-9 %) at peaks and midway down hillsides and steeper slopes (10-14 %) close to drainage channels.

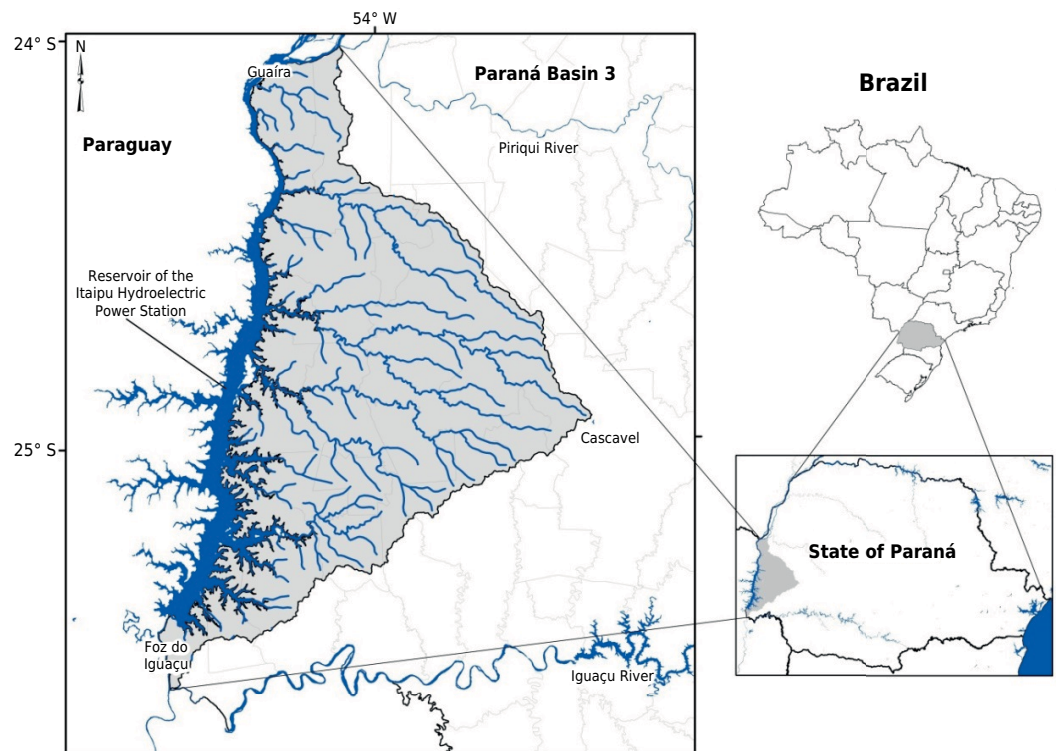


Figure 1. Location of the study area.

Land within the PB3 is mainly used for agriculture (92 %), producing grain such as summer soybean (*Glycine max*), summer and winter corn (*Zea mayz*), winter wheat (*Triticum* spp.), and winter oats (*Avena strigosa*). Oats are also used to lay down straw cover over the soil or produce winter pasture for beef and dairy production. Grain production soil management is based on NT, with some control over surface runoff (terraces and contour farming). The remaining 8 % of the area consists of forests, reservoirs, and urban areas (Telles et al., 2019b). The responses to the questionnaire regarding the time for which NT practices have been implemented are given in figure 2.

Description and application of the survey

To obtain the data for the analysis, about 234 farmers distributed along the PB3 were interviewed. The questionnaire used is titled “No-tillage system participatory quality index – IQP” (Telles et al., 2020). Farmers were interviewed in person during the 2016-2017 crop season. Each farmer was interviewed only once within this period. The questionnaire consisted of 30 questions and aimed to determine how farmers perceive CA and verify the implemented soil conservation practices.

A sample can produce accurate results using only a small fraction of the entire population when using survey techniques applied on large populations (Cochran, 1977). Our sample size was calculated based on Yamane (1967) and Cochran (1977) methodological procedures for sample proportions, which indicated a sample size of 204 observations for a confidence level of 95 % ($p = 0.05$). Some qualitative research methodologists present general guidelines for the sample size of interviews and recommend a minimum of 30 to 50 interviewees for this type of research (Marshall et al., 2013). Under these conditions, our sample of 243 interviews seems to be representative under the stipulated parameters and follows the methodological requirements established in the literature.

Procedures and statistics

Principal component analysis (PCA) was performed based on the correlation matrix of the data. The number of components plotted was defined by the Kaiser’s criterion, in which those with a variance greater than one were used. The chi-square (χ^2) adherence test was used to investigate whether the responses differed from the expected proportions, with random response selection. The significance was 5 %, and the analysis was run on R software, version 3.4.3.

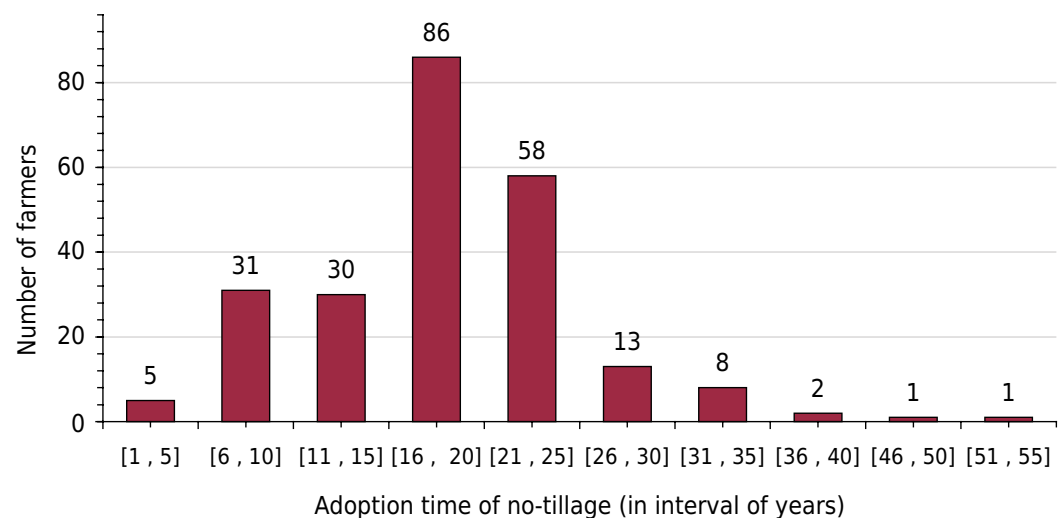


Figure 2. Farmers’ responses regarding the time for which no-tillage has been implemented.

RESULTS

Understanding on conservation agriculture

The majority of farmers (67 %) were not familiar with all three pillars of CA, and 12 % were unaware of any of them; 29 % were unaware of one pillar and 26 % two pillars (Figure 3a). Of the 67 % who were unaware of any of the three pillars of CA, crop rotation was the least known (49 %; Figure 3b), followed by constant soil cover (28 %) and no-tillage (23 %).

Most farmers self-assessed their NT management as “good” (Table 1), and all the benefits of CA were considered highly important (Figure 4a), especially mitigation of soil erosion risks (92 %), soil conservation (89 %), and time-saving on agricultural operations (84 %). However, half of the farmers did not think that CA cut production costs, increased yield, or reduced the risk of drought-induced losses.

Problems in adopting CA, in decreasing order of importance, were stated by farmers as follows: soil compaction on headlands, weed control, maintaining soil cover, and establishing crop rotation (Figure 4b). Half of the farmers interviewed thought that establishing crop rotation was very or moderately difficult (Figure 4b), corroborating the results regarding their lack of knowledge on this pillar of CA (Figure 3b).

Practices adopted

Among the farmers, 80 % carried out some operations in contour farming. Only one farmer did not sow in contour farming, and 50 % sowed and sprayed in contour farming. Furthermore, 97 % of farmers used terracing, a fact related to the low proportion of sowing following the slope (not in contour farming). However, these results also reveal that many farmers (41 %) drove spraying equipment crossing the terraces and following the slope, reducing the effectiveness of limiting soil and water losses.

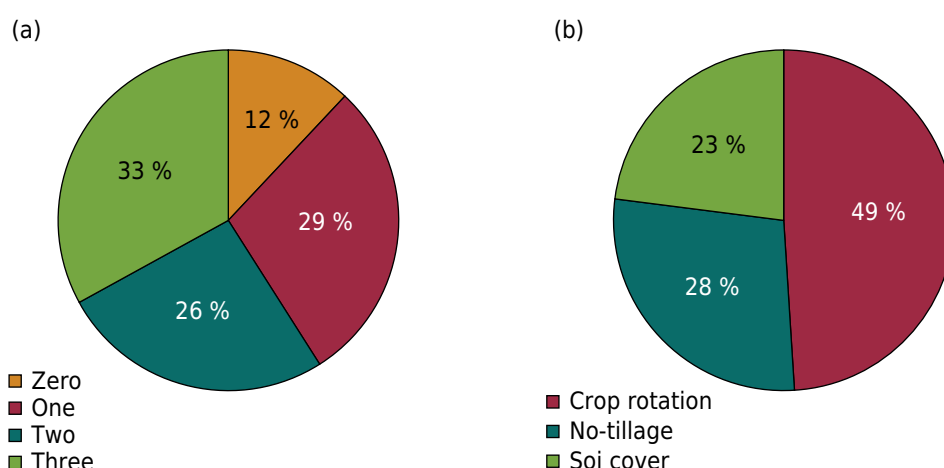


Figure 3. Proportion of farmers aware of the three pillars of CA (a) and proportion of pillars least known in the responses among the farmers who were not aware of all three pillars of CA (b). All proportions are significant at 0.1 % according to Chi-square (χ^2) adherence test.

Table 1. Farmers’ self-assessment on no-tillage system quality

Self-assessment of no-tillage system quality			
Poor	Reasonable	Good	Excellent
0.9 %	10.7 %	76.1 %	12.4 %

All proportions are significant at 0.1 % according to Chi-square (χ^2) adherence test.

Some 40 % of farmers observed soil erosion, whereas 74 % observed soil compaction. Among the farmers that observed soil compaction, 60 % thought the soil was compacted only on headlands and 14 % throughout the entire cropping area. Examination of the completed questionnaires showed that 58 % of farmers implemented some soil preparation. Of these, 49 % stated that they carried out soil preparation because of compaction on headlands (Figure 5). The most widely used soil preparation implements were the plow chisel (80 % of farmers), harrow (44 %), and plow (17 %).

Principal component analysis, containing the factors that might affect soil loss by water erosion is presented in figure 6. Our results followed the expected relationships between soil management and soil erosion. Farmers adopting no-tillage have a lower tendency to observe erosion in their soils. Also, farmers with compacted soil were more likely to have soil loss, as observed by the relative coincidence of the vectors representing soil erosion and compaction. To perform sowing and spraying operations in contour farming also contributed to reducing soil loss. The use of terraces presented a low correlation with the first two principal components. This probably happened because 97 % of farmers had terraces in their areas and, consequently, only a small variation on this variable was observed.

Regarding public or private technical assistance, only six farmers did not receive any kind of technical advice on how to work their land. Of those who received advice, 2 % received it from public institutions only, and 85 % from cooperatives or private organizations; 13 % received advice from public and private organizations. It is also interesting to highlight that the time of NT adoption was neither correlated to the farmers' knowledge on the pillars of CA (Figure 7a) nor with their decision to prepare the soil (Figure 7b).

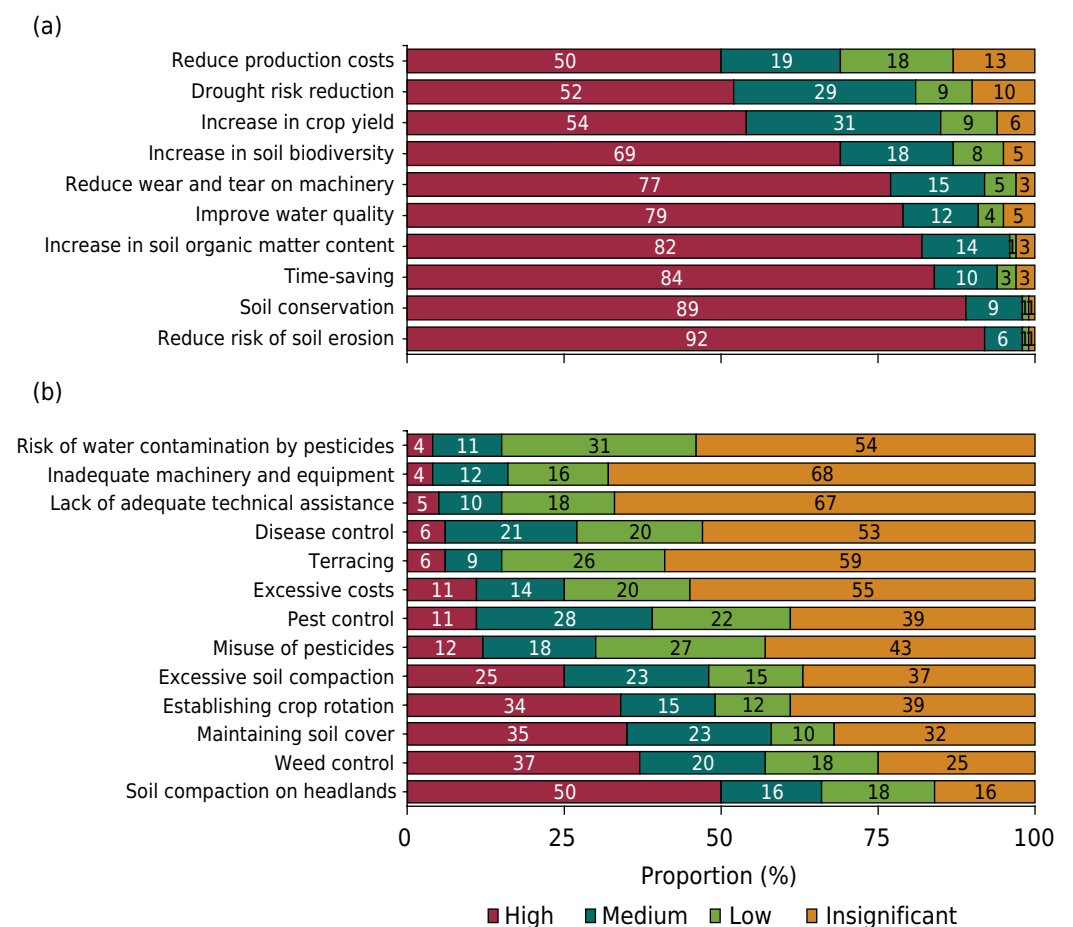


Figure 4. Benefits of no-tillage perceived by farmers (a) and difficulties reported by farmers in using Conservation Agriculture (b). All proportions are significant at 0.1 % according to Chi-square (χ^2) adherence test.

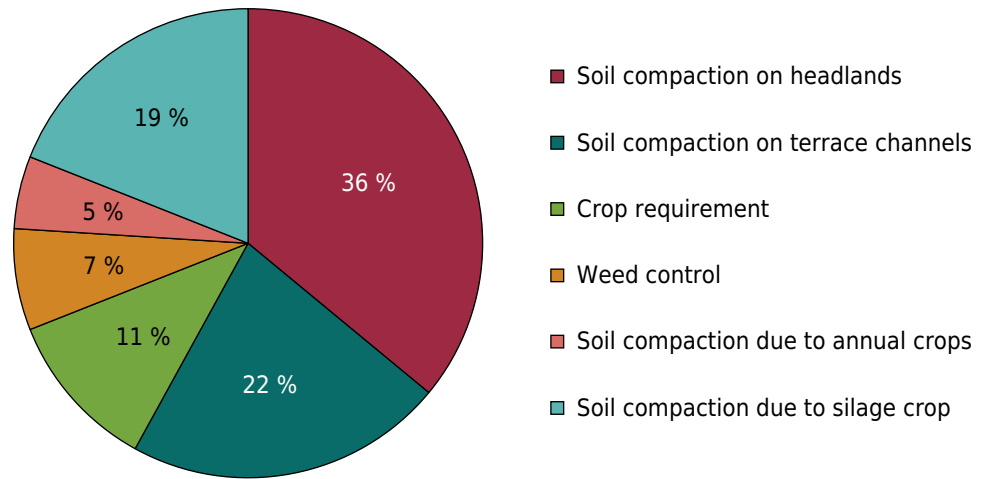


Figure 5. Reasons why farmers prepared the soil.

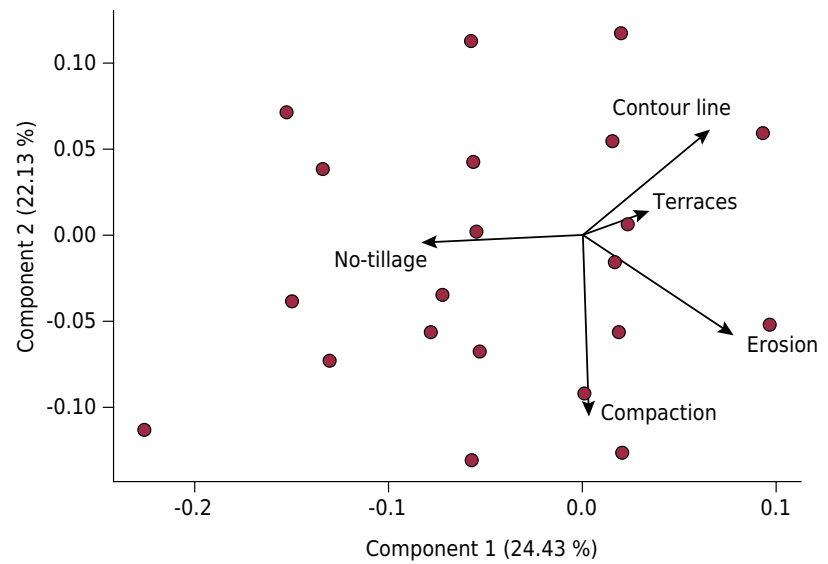


Figure 6. Principal component analysis of the practices adopted by farmers and soil loss by water erosion.

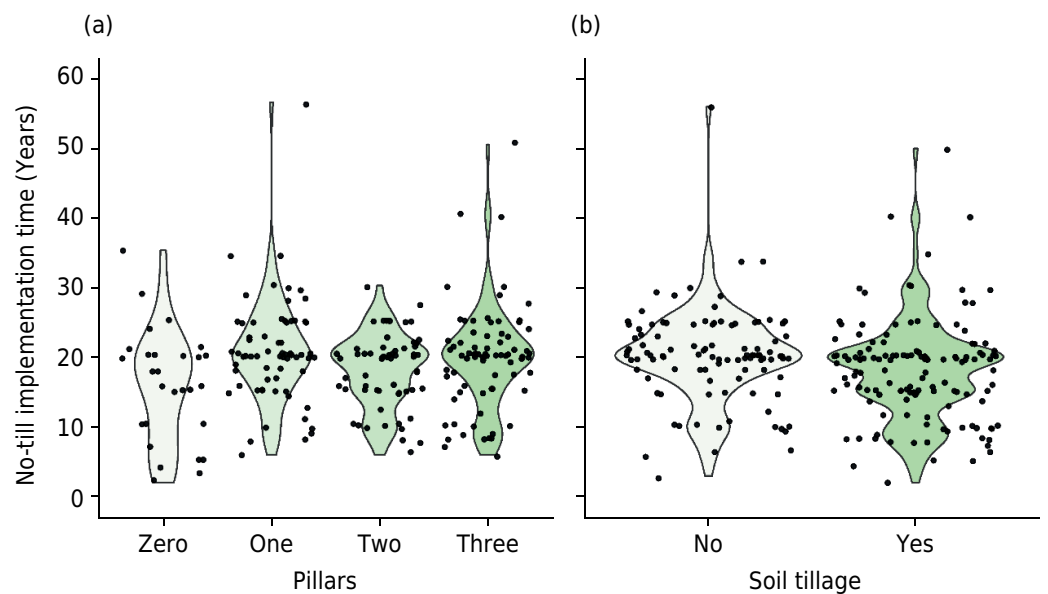


Figure 7. No-tillage implementation time as a function of farmers' knowledge on the pillars of (a) Conservation Agriculture and (b) soil tillage.

DISCUSSION

Most of the farmers were not fully aware of the three pillars of CA. The main gaps in their knowledge related to crop rotation and no-tillage. This reveals that the farmers' understanding of CA is still in the early stages, probably because of insufficient dissemination. In addition, agricultural terracing was incorrectly managed in many cases, as sprayers were conducted crossing the terraces and following the slope.

Most of the interviewees considered their practices are of good quality (Table 1). However, in terms of the three pillars of CA, it was evident that most interviewees ignored crop rotation (Figure 3). This is contradictory, given that most of them point out that the main advantages of CA are reduced risk of soil erosion and soil conservation (Figure 4a), benefits that are boosted by crop rotation. Furthermore, crop rotation increases the level of organic matter in the soil and boosts nutrient cycling, decreasing losses caused by leaching and erosion, as well as increasing cation exchange capacity and soil aggregation (Melo et al., 2019).

Lack of knowledge on crop rotation as one of the pillars of CA appears to severely limit its adoption on rural properties (Figure 3). However, the difficulty of inserting crop rotation into the productive system also presents an obstacle associated with the cost of operations and the low availability of seeds of the species necessary for rotation. These factors are aggravated by the use of cover crops with little economic return in the short term (Garbelini et al., 2020). Especially considering the economic pressure on subsistence farmers, mainly those who farm leased land. This indicates the low quality of the current conservation system, which falls short of the desired CA (Pittelkow et al., 2015; Telles et al., 2019a).

In the study region, two crops are grown per year. These crops usually consist of soybean in the spring-summer and corn in the autumn-winter. Silage production areas for animal feed are also common, with three crops per year, consisting mainly of corn and oats. Double crop or specialized farming contributes little to the establishment of sustainable CA (Kassam et al., 2019; Hufnagel et al., 2020). Given that the climate is adequate for more than one crop per year, it suggests that the absence of crop rotation is conditional on immediate economic interests, and is not considered strategically as a way of cutting input costs and increasing yields and profitability.

With regard to crop rotation, most farmers reported problems with NT and classified as medium to high the problems they encountered in controlling compaction and weeds, and in establishing cover crops (Figure 4b). Crop yield increases in systems with diversified crop rotation compared to systems with little diversification (Nascente and Stone, 2018; Zhao et al., 2020). Consequently, adopting CA could help farmers overcome the difficulties that they are currently experiencing.

Many farmers associate minimal tillage with NT (Figure 3b). However, over half of these farmers stated that they tilled the soil. This contradiction suggests that the concept of NT is being incorrectly applied because farmers believe there are performing NT even chiseling the soil. The adoption of NT implies in avoiding any mechanical disturbance to the soil by the use of implements, such as harrow and plow chisel, and minimizing soil disturbance during sowing. The main reasons for tilling the soil are associated with perceived soil compaction (Figure 5). However, farmers rarely quantify the level of soil compaction, which is perceived by indirect observation of phenomena, such as the resistance of the soil during sowing and crop development.

Terraces increase infiltration rates and reduce runoff and sediment yield (Londero et al., 2018). Although 97 % of the farmers use terracing, 41 % observed erosion. In addition to low water infiltration, common in agricultural systems, the use of sprayers crossing terraces and following the slope by many farmers, renders terracing less efficient, resulting

in erosion because of the left trails that the machinery passing over the terraces causes ruts that channel runoff and intensify erosion.

Surface water runoff under NT system does not necessarily cause excessive erosion if the hillsides are terraced (Londero et al., 2018). Terracing prevents concentrated water flows in the event of low to medium intensity rainfall. However, even with reduced runoff rates, furrows can be eroded in specific hillside regions. Concentrated water flows provide sufficient energy to remove the soil biomass cover, leaving exposed gaps subject to erosion under high-intensity rainfall (Minella et al., 2017).

Soil compaction increases water and sediment delivery, boosting sediment runoff in particularly sensitive regions (Evrard et al., 2007). Because of the high volume of water and sediment generated by surface runoff, farmers feel the need to chisel terrace channels to increase water infiltration. Chiseling aims to minimize runoff and terrace rupturing due to the low infiltration of water into the soil induced by perceived compaction (Figure 5).

Soil management practices aimed at controlling compaction, based on periodic chiseling, have been tested in several studies (Silva et al., 2012; Cortez et al., 2019; Peixoto et al., 2020). However, the residual effect of interventions, such as plowing or chiseling, on the physical properties of the soil has been shown to disappear after a few crop cycles or over periods of less than six months (Silva et al., 2012). In contrast, soils under no-tillage tend to exhibit better structural characteristics if properly managed. This suggests that the attempt to recover structural soil quality by using implements contributes to erosive processes and soil degradation.

Establishing soil conservation strategies can significantly impact landscapes that affect soil erosion and hillside connectivity with channels, resulting in reduced erosion (Bezak et al., 2015). The efficiency of no-tillage in reducing soil loss is related to better soil protection by the straw on soil surface against raindrop impact, but isolated conservation strategies do little to mitigate erosive processes during medium to heavy rainfall events (Didoné et al., 2017; Deuschle et al., 2019). Especially in Brazil, where water precipitation is voluminous, these practices help to reduce surface runoff. Therefore, CA involving NT, crop rotation, and soil cover leads to a better soil environment and crop yield with minimal impact on the environment (Busari et al., 2015). For this reason, adopting CA combined with adequate terracing is more effective in reducing erosion and maintaining production system sustainability.

There is no evidence that the farmers' knowledge of the three pillars of CA increases over time and as more system experience is acquired (Figure 7a). The experience of the farmers with the no-tillage does not influence the decision to prepare the soil (Figure 7b), indicating that the origin of such practices is associated with other factors, such as soil compaction, crop's requirement and weeds control (Figure 5).

The farming practices currently used, with little crop diversification, could be the result of agricultural advice that does not take into account sustainability-related issues, with the emphasis only on short-term economic aspects. The resulting low level of added plant biomass leads to the germination of weeds (Pires et al., 2008; Osipitan et al., 2019) and boosts erosive processes (Derpsch et al., 2014; Merten et al., 2015), raising production costs. Note that most of the farmers receive technical assistance from private companies and cooperatives (85 %), while only 2 % of the farmers receive assistance from public organizations.



Since technical assistance is one of the relevant aspects that influences the adoption of technologies, it is of fundamental importance that the conservationist approach is disseminated in technical assistance, diffusion, and technology transfer actions from public and private initiatives. Thus, disseminating information on the pillars of CA and its benefits and soil and water conservation practices still poses a challenge to the sustainability of agricultural production systems.




As well as in Brazil, particularly in the region in this study, misunderstanding, and non-adoption of conservation agriculture practices have also been shown in other regions around the world, such as Africa (van Hulst and Posthumus, 2016; Lalani et al., 2021), Middle East (Chalak et al., 2017), United States of America (Reimer et al., 2012) and Asia (Halbrendt et al., 2014). It shows that CA is very little understood and applied by farmers worldwide. It may be due to their low knowledge and information about sustainable agriculture practices.




CONCLUSIONS



Most farmers in the study do not have enough knowledge of the pillars of CA. As a result, there is little diversification in crop rotation, and the soil is continually disturbed with chiseling. Furthermore, although most farmers use terracing, they drive sprayers crossing terraces and following the slope, a practice that can impair the capacity of terraces to control surface water runoff. These practices do not contribute to soil and water conservation and endanger the sustainability of agricultural production systems.



AUTHOR CONTRIBUTIONS




Conceptualization:  Graziela Moraes de Cesare Barbosa (equal) and  Tiago Santos Telles (equal).



Data curation:  Ana Julia Righetto (equal),  Thadeu Rodrigues de Melo (equal) and  Tiago Santos Telles (equal).



Formal analysis:  Ana Julia Righetto (equal),  Thadeu Rodrigues de Melo (equal) and  Tiago Santos Telles (equal).

Funding acquisition:  Graziela Moraes de Cesare Barbosa (equal) and  Tiago Santos Telles (equal).




Investigation:  Ana Julia Righetto (equal) and  Thadeu Rodrigues de Melo (equal).

Methodology:  Ana Julia Righetto (equal),  Thadeu Rodrigues de Melo (equal) and  Tiago Santos Telles (equal).

Project administration:  Graziela Moraes de Cesare Barbosa (equal) and  Tiago Santos Telles (equal).

Validation:  Graziela Moraes de Cesare Barbosa (lead) and  Tiago Santos Telles (equal).

Writing - original draft:  Ana Julia Righetto (equal),  Elizeu Jonas Didoné (equal),  Thadeu Rodrigues de Melo (equal) and  Tiago Santos Telles (equal).

Writing - review & editing:  Elizeu Jonas Didoné (equal),  Thadeu Rodrigues de Melo (equal) and  Tiago Santos Telles (equal).

REFERENCES

- Alvares CA, Stape JL, Sentelhas PC, Gonçalves JLM, Sparovek G. Köppens's climate classification map for Brazil. *Meteorol Z.* 2014;22:711-28. <https://doi.org/10.1127/0941-2948/2013/0507>
- Bezak N, Rusjan S, Petan S, Sodnik J, Mikoš M. Estimation of soil loss by the WATEM/SEDEM model using an automatic parameter estimation procedure. *Environ Earth Sci.* 2015;74:5245-61. <https://doi.org/10.1016/j.jhydrol.2010.07.010>
- Bolliger A, Magid J, Carneiro A, Telmo J, Skora Neto F, Ribeiro MFS, Calegari A, Ralisch R, Neergaard A. Taking stock of the Brazilian "Zero-Till Revolution": A review of landmark research and farmers' practice. *Adv Agron.* 2006;91:47-64. [https://doi.org/10.1016/S0065-2113\(06\)91002-5](https://doi.org/10.1016/S0065-2113(06)91002-5)

- Busari MA, Kukal SS, Kaur A, Bhatt R, Dulazi AA. Conservation tillage impacts on soil, crop and the environment. *Int Soil Water Conserv.* 2015;3:119-29. <https://doi.org/10.1016/j.iswcr.2015.05.002>
- Chalak A, Chaaban J, Bashour I, Seyfert K, Smoot K, Abebe GK. Farmers' willingness to adopt conservation agriculture: New evidence from Lebanon. *Environ Manage.* 2017;60:693-704. <https://doi.org/10.1007/s00267-017-0904-6>
- Cochran WG. Sampling techniques. 3rd ed. New York: John Wiley and Sons; 1977.
- Cortez JW, Pusch M, Silva RP, Rufino MV, Anghinoni M. Management systems: Soil cover and compaction, longitudinal distribution, and yield of soybean crop. *Eng Agr.* 2019;39:490-7. <https://doi.org/10.1590/1809-4430-eng.agric.v39n4p490-497/2019>
- Dechen SCF, Telles TS, Guimarães MF, De Maria IC. Losses and costs associated with water erosion according to soil cover rate. *Bragantia.* 2015;74:224-33. <https://doi.org/10.1590/1678-4499.0363>
- Defersha M, Melesse AM. Field-scale investigation of the effect of land use on sediment yield and surface runoff using runoff plot data and models in the Mara River basin, Kenya. *Catena.* 2012;89:54-64. <https://doi.org/10.1016/j.catena.2011.07.010>
- Derpsch R, Franzluebbers AJ, Duiker SW, Reicosky DC, Koeller K, Friedrich T, Sturny WG, Sá JCM, Weiss K. Why do we need to standardize no-tillage research? *Soil Till Res.* 2014;137:16-22. <https://doi.org/10.1016/j.still.2013.10.002>
- Deuschle D, Minella PGM, Hörbe TAN, Londero AL, Schneider FJA. Erosion and hydrological response in no-tillage subjected to crop rotation intensification in southern Brazil. *Geoderma.* 2019;340:157-63. <https://doi.org/10.1016/j.geoderma.2019.01.010>
- Didoné EJ, Minella JPG, Evrard O. Measuring and modelling soil erosion and sediment yields in a large cultivated catchment under no-till of Southern Brazil. *Soil Till Res.* 2017;174:24-33. <https://doi.org/10.1016/j.still.2017.05.011>
- Didoné EJ, Minella JPG, Merten GH. Quantifying soil erosion and sediment yield in a catchment in Southern Brazil and implications for land conservation. *J Soil Sediment.* 2015;15:2334-46. <https://doi.org/10.1007/s11368-015-1160-0>
- Evrard O, Persoons E, Vandaele K, van Wesemael B. Effectiveness of erosion mitigation measures to prevent muddy floods: A case study in the Belgian loam belt. *Agr Ecosyst Environ.* 2007;118:149-58. <https://doi.org/10.1016/j.agee.2006.02.019>
- Fuentes-Llanillo R, Telles TS, Soares Junior D, Melo TR, Friedrich T, Kassam A. Expansion of no-tillage practice in conservation agriculture in Brazil. *Soil Till Res.* 2021;208:104877. <https://doi.org/10.1016/j.still.2020.104877>
- Garbelini LG, Franchini JC, Debiasi H, Balbinot Junior AA, Betioli Junior E, Telles TS. Profitability of soybean production models with diversified crops in the autumn-winter. *Agron J.* 2020;112:4092-103. <https://doi.org/10.1002/agj2.20308>
- Halbrendt J, Gray SA, Crow S, Radovich T, Kimura AH, Tamang BB. Differences in farmer and expert beliefs and the perceived impacts of conservation agriculture. *Glob Environ Change.* 2014;28:50-62. <https://doi.org/10.1016/j.gloenvcha.2014.05.001>
- Hufnagel J, Reckling M, Ewert F. Diverse approaches to crop diversification in agricultural research. A review. *Agron Sustain Dev.* 2020;40:14. <https://doi.org/10.1007/s13593-020-00617-4>
- Instituto Brasileiro de Geografia e Estatística - IBGE. Censo agropecuário 2017: Resultados definitivos. Rio de Janeiro: IBGE; 2019.
- IUSS Working Group WRB. World reference base for soil resources 2014, update 2015: International soil classification system for naming soils and creating legends for soil maps. Rome: Food and Agriculture Organization of the United Nations; 2015. (World Soil Resources Reports, 106).
- Kassam A, Friedrich T, Derpsch R. Global spread of Conservation Agriculture. *Int J Environ Stud.* 2019;76:26-51. <https://doi.org/10.1080/00207233.2018.1494927>
- Kassam A, Friedrich T, Shaxson F, Pretty J. The spread of Conservation Agriculture: Justification, sustainability and uptake. *Int J Agr Sustain.* 2009;7:292-320. <https://doi.org/10.3763/ijas.2009.0477>

- Lalani B, Aminpour P, Gray S, Williams M, Büchi L, Haggart J, Grabowski P, Dambiro J. Mapping farmer perceptions, Conservation Agriculture practices and on-farm measurements: The role of systems thinking in the process of adoption. *Agr Syst.* 2021;191:103171. <https://doi.org/10.1016/j.agry.2021.103171>
- Londero AL, Minella JPG, Deuschle D, Schneider FJA, Boeni M, Merten GH. Impact of broad-based terraces on water and sediment losses in no-till (paired zero-order) catchments in Southern Brazil. *J Soil Sediment.* 2018;18:1159-75. <https://doi.org/10.1007/s11368-017-1894-y>
- Marshall B, Cardon P, Poddar A, Fontenot R. Does sample size matter in qualitative research? A review of qualitative interviews in is research. *J Comput Inform Syst.* 2013;54:11-22. <https://doi.org/10.1080/08874417.2013.11645667>
- Melo TR, Pereira MG, Barbosa GMC, Silva Neto ECS, Andreello AC, Tavares Filho J. Biogenic aggregation intensifies soil improvement caused by manures. *Soil Till Res.* 2019;190:186-93. <https://doi.org/10.1016/j.still.2018.12.017>
- Merten GH, Araújo AG, Biscaia RCM, Barbosa GMC, Conte O. No-till surface runoff and soil losses in southern Brazil. *Soil Till Res.* 2015;152:85-93. <https://doi.org/10.1016/j.still.2015.03.014>
- Minella JPG, Merten GH, Barros CAP, Ramon R, Schlesner A, Clarke RT, Moro M, Dalbianco L. Long-term sediment yield from a small catchment in southern Brazil affected by land use and soil management changes. *Hydrol Process.* 2017;32:200-11. <https://doi.org/10.1002/hyp.11404>
- Nascente AS, Stone FS. Cover crops as affecting soil chemical and physical properties and development of upland rice and soybean cultivated in rotation. *Rice Science.* 2018;25:340-9. <https://doi.org/10.1016/j.rsci.2018.10.004>
- Oliveira PTS, Wendland E, Nearing MA. Rainfall erosivity in Brazil: A review. *Catena.* 2013;100:139-47. <https://doi.org/10.1016/j.catena.2012.08.006>
- Osipitan OA, Dille JA, Assefa Y, Radicetti E, Ayeni A, Knezevic SZ. Cover crop for early season weed suppression in crops: Systematic review and meta-analysis. *Crop Sci.* 2019;59:833-42. <https://doi.org/10.2135/cropsci2018.09.0589>
- Peixoto DS, Silva LCM, Melo LBB, Azevedo RP, Araújo BCL, Carvalho TS, Moreira SG, Curi N, Silva BM. Occasional tillage in no-tillage systems: A global meta-analysis. *Sci Total Environ.* 2020;45:140887. <https://doi.org/10.1016/j.scitotenv.2020.140887>
- Pires FR, Assis RL, Procópio SO, Silva GP, Moraes LL, Rudovalho MC, Bôer CA. Manejo de plantas de cobertura antecessoras à cultura da soja em plantio direto. *Rev Ceres.* 2008;55:94-101.
- Pittelkow C, Liang X, Linquist B, van Groenigen KJ, Lee J, Lundy ME, van Gestel N, Six J, Venterea RT, van Kessel C. Productivity limits and potentials of the principles of conservation agriculture. *Nature.* 2015;517:365-8. <https://doi.org/10.1038/nature13809>
- Reimer AP, Weinkauff DK, Prokopy LS. The influence of perceptions of practice characteristics: An examination of agricultural best management practice adoption in two Indiana watersheds. *J Rural Stud.* 2012;28:118-28. <https://doi.org/10.1016/j.jrurstud.2011.09.005>
- Salamuni E, Ebert HD, Borges MS, Hasui Y, Costa JBS, Salamuni R. Tectonics and sedimentation of the Curitiba Basin. *J S Am Earth Sci.* 2003;15:901-10. [https://doi.org/10.1016/S0895-9811\(03\)00013-0](https://doi.org/10.1016/S0895-9811(03)00013-0)
- Santos HG, Jacomine PKT, Anjos LHC, Oliveira VA, Lumbreiras JF, Coelho MR, Almeida JA, Araújo Filho JC, Oliveira JB, Cunha TJF. Sistema brasileiro de classificação de solos. 5. ed. rev. ampl. Brasília, DF: Embrapa; 2018.
- Silva RL, Maria IC. Erosão em sistema plantio direto: influência do comprimento de rampa e da direção de semeadura. *Rev Bras Eng Agr Amb.* 2011;15:554-61. <https://doi.org/10.1590/S1415-43662011000600003>
- Silva SGC, Silva AP, Giarola NFB, Tormena CA, Sá JCM. Temporary effect of chiseling on the compaction of a Rhodic Hapludox under no-tillage. *Rev Bras Cienc Solo.* 2012;36:547-55. <https://doi.org/10.1590/S0100-06832012000200024>
- Soil Survey Staff. Keys to soil taxonomy. 12th ed. Washington, DC: United States Department of Agriculture, Natural Resources Conservation Service; 2014.

- Telles TS, Dechen SCF, Guimaraes MF. Institutional landmarks in Brazilian research on soil erosion: A historical overview. *Rev Bras Cienc Solo*. 2013;37:1431-40. <https://doi.org/10.36783/18069657rbcs20210113>
- Telles TS, Lourenço MAP, Oliveira JF, Costa GV, Barbosa GMC. Soil conservation practices in a watershed in Southern Brazil. *An Acad Bras Cienc*. 2019b;91:e20180578. <https://doi.org/10.1590/0001-3765201920180578>
- Telles TS, Righetto AJ, Costa GV, Volsi B, Oliveira JF. Conservation agriculture practices adopted in southern Brazil. *Int J Agr Sustain*. 2019a;17:338-46. <https://doi.org/10.1080/14735903.2019.1655863>
- Telles TS, Righetto AJ, Lourenço MAP, Barbosa GMC. No-tillage system participatory quality index. *Rev Bras Eng Agr Amb*. 2020;24:128-33. <https://doi.org/10.1590/1807-1929/agriambi.v24n2p128-133>
- Van Hulst FJ, Posthumus H. Understanding (non-) adoption of Conservation Agriculture in Kenya using the reasoned action approach. *Land Use Policy*. 2016;56:303-14. <https://doi.org/10.1016/j.landusepol.2016.03.002>
- Waltrick PC, Machado MAM, Dieckow J, Oliveira D. Estimativa da erosividade de chuvas no Estado do Paraná pelo método da pluviometria: atualização com dados de 1986 à 2008. *Rev Bras Cienc Solo*. 2015;39:256-67. <https://doi.org/10.1590/01000683rbcs20150147>
- Yamane T. *Statistics: An introductory analysis*. 2nd ed. New York: Harper and Row; 1967.
- Zhao J, Yadong Y, Zhang K, Jeong J, Zeng Z, Zang H. Does crop rotation yield more in China? A meta-analysis. *Field Crop Res*. 2020;245:107659. <https://doi.org/10.1016/j.fcr.2019.107659>