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Article

Economic and risk evaluation of crop rotation systems: literature review

Avaliação econômica e de risco de sistemas de rotação de culturas agrícolas: revisão de literatura

Fernando Pires Vieira[1]*; Alcido Elenor Wander[2]

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[1]Mestre em Agronegócio. Rua das Rosas, 316, Prolongamento Jardim América, 75902-410, Rio Verde, Goiás, Brasil

[2]Doutor em Ciências Agrárias. Empresa Brasileira de Pesquisa Agropecuária (Embrapa), Rodovia GO-462, Km 12 - Fazenda Capivara, 75375-000, Santo Antônio de Goiás, Goiás, Brasil

*Corresponding author: f.piresvieiraoficial@gmail.com

Abstract: In many countries, inadequate management of agricultural production has depleted soils to the point of compromising future production in these areas. Thus, crop rotation systems, one of the pillars of conservation agriculture, are presented as an alternative to prevent such losses while regenerating degraded lands. Verifying whether conservation agriculture practices can generate both agronomic and financial gains for producers is crucial for achieving sustainable agricultural production. The objective of this article was to evaluate the current panorama of scientific literature, identifying studies on crop rotation systems published in national and international databases between 2018 and 2023, which address economic and risk analysis aspects of these systems. Articles published in the databases Scientific Electronic Library Online, Science Direct, Scopus, Web of Science, CAPES Journals, and the Base de Dados da Pesquisa Agropecuária (BDPA) were analyzed. Twenty-five articles related to the topic and research objective were identified; 76% presented only studies on economic analyses, while 24% included risk analysis. Regarding the locations where the studies were conducted, 32% were studies conducted in Brazil and 68% in other countries. The year with the largest number of studies was 2019. Considering the theoretical framework presented, the findings of this study indicate that conservation agriculture practices, such as crop rotation systems, present both agronomic and economic benefits and can be strategies for reducing the risks inherent to agricultural activity.

Keywords: conservation agriculture; diversification of crops; profitability; sustainability.

Resumo: Em muitos países, o manejo inadequado da produção agrícola esgotou os solos a ponto de comprometer a produção futura nessas áreas. Assim, os sistemas de rotação de culturas, um dos pilares da agricultura conservacionista, se apresentam como uma alternativa que pode evitar tais perdas enquanto regenera terras degradadas. Para se alcançar uma produção agrícola sustentável é importante verificar se as práticas de agricultura conservacionista, além de ganhos agronômicos, podem gerar ganhos financeiros para os produtores. O objetivo deste artigo foi verificar o panorama atual da literatura científica sobre sistemas de rotação de culturas, identificando estudos que abordam aspectos de análise econômica e de risco desses sistemas, publicados em bases de dados nacional e internacional, entre 2018 e 2023. Foram analisados artigos publicados nas bases de dados Scientific Electronic Library Online, Science Direct, Scopus, Web of Science, Periódicos CAPES e Base de Dados da Pesquisa Agropecuária (BDPA). Foram identificados 25 artigos relacionados ao tema e à intenção de pesquisa; destes, 76% apresentaram apenas estudos sobre análises econômicas, enquanto 24% também agregaram análise de risco. Em relação aos locais onde os estudos foram realizados, 32% foram pesquisas realizadas no Brasil e 68% em outros países. O ano de 2019 foi o com maior número de estudos. Considerando o referencial teórico apresentado, os resultados deste estudo indicaram que práticas de agricultura conservacionista, como sistemas de rotação de culturas, apresentam benefícios tanto agronômicos quanto econômicos e podem ser estratégias para redução dos riscos inerentes à atividade agrícola.

Palavras-chave: agricultura conservacionista; diversificação de culturas; rentabilidade; sustentabilidade.

1. Introduction

According to data from the Food and Agriculture Organization of the United Nations, over the last 40 years, the world has lost one-third of its arable land - approximately 430 million hectares - due to inadequate agricultural production management. Given these facts, conservation agriculture (CA) is a cropping system that can prevent such losses while regenerating degraded land[1]. The conservation agriculture is based on three interconnected principles: minimal mechanical soil disturbance, permanent organic surface coverage with crop residues and/or cover crops, and species diversification through varied crop sequences and associations involving at least three species[1].

Since its implementation in Brazil, the No-Tillage System (NTS), as a CA technology, has presented numerous advantages in soil conservation. It allows better cultivation conditions for economically important crops, thus increasing productivity and profitability. These benefits have expanded the implementation areas and are associated with other conservation practices[2].

As one of the pillars of the NTS, Debiasi et al.[3] draw a distinction between crop rotation and succession. According to the authors, crop rotation is defined as the orderly alternation of different crops in a given space of time (cycle), in the same area and season of the year. In contrast, crop succession consists of the arrangement of two crops in the same agricultural area for an indefinite period, each cultivated in a season of the year.

Crop rotation diversification is economically competitive compared to specialized double cropping systems and has proven environmental conservation advantages (air, water, and soil). If well planned, it is an important strategy to reduce soil erosion, pesticide consumption, and greenhouse gas emissions and increase the efficiency of water and fertilizer use[4].

Economic and financial analyses help to verify whether a given activity will generate a return on investment and profit and, if carried out with adequate planning, can guarantee business continuity. In addition to feasibility and economic performance analyses, other complementary analyses are important in the decision-making process of rural property management, such as risk analysis[5].

Verifying whether CA practices can generate both agronomic and financial gains for producers is crucial for achieving sustainable agricultural production. Based on the results, farmers will have access to scientific information that can be considered when deciding whether to convert their conventional production system to a diversified one, in line with conservation agriculture.

Given this context, the present study proposed the following research question: Can crop succession and rotation systems be more profitable and offer lower economic risks to farmers than conventional cropping systems?

Thus, the objective of this article was to evaluate the current panorama of scientific literature, identifying studies on crop rotation systems published in national and international databases between 2018 and 2023, which address economic and risk analysis aspects of these systems.

2. Material and methods

Applied research was carried out, with an exploratory and descriptive objective, using the systematic literature review (SLR) methodology and working with national and international databases. The documents found were analyzed according to their economic and risk characteristics.

Galvão and Ricarte[6] define SLR as a type of research that follows specific protocols and seeks to understand and give some coherence to a large documentary corpus, especially by verifying what works and what does not work in each context. SLR focuses on reproducibility by other researchers, explicitly presenting the bibliographic databases that were accessed, the search strategies used in each database, the process of selecting scientific articles, the criteria for inclusion and exclusion of articles, and the process of analyzing each article.

The technical procedure of this article (Table 1) was carried out according to the protocol by Cronin et al.[7], which presents five steps: (I) formulate the research question; (II) set inclusion and exclusion criteria; (III) select and access the literature; (IV) assess the quality of the literature included in the review; and (V) analyze, synthesize and disseminate the findings.

Table 1. Steps of the implementation protocol of this Systematic Literature Review

Protocol steps	Article development
I) Formulate the research question	What articles have already been published, nationally and internationally, on economic and risk analysis in crop succession and rotation systems?
II) Set inclusion and exclusion criteria	The inclusion and exclusion criteria used in the searches were: Titles that contained the words in English (TI=crop rotation and economic analysis or feasibility analysis or risk analysis), Spanish (TI=rotación de cultivos and análisis económica or análisis de riesgo) or Portuguese (TI= rotação de culturas and análise econômica or análise de risco). Publication years: 2018-2023. Databases: Scielo, Science Direct, Scopus, Web of Science, Periódicos CAPES[1] and BDPA[2].
III) Select and access the literature	Advanced search in the selected databases according to the established inclusion and exclusion criteria and filtering through the titles and abstracts of the articles.
IV) Assess the quality of the literature included in the review	An initial reading of the selected articles in the previous stage to check whether they provided information that fit into the concept of economic and risk analysis of crop succession and rotation systems.
V) Analyze, synthesize, and disseminate the findings	The texts selected in the fourth step were rigorously analyzed and put into tables, charts, and flowcharts to better visualize and analyze the findings according to the topics of the research proposal.

Source: Adapted from Cronin et al.[7]
Note: [1]CAPES: Coordenação de Aperfeiçoamento de Pessoal de Nível Superior; [2]BDPA: Base de Dados da Pesquisa Agropecuária

Figure 1 shows the documents in the searches carried out in January 2023 and the articles selected by applying the inclusion and exclusion criteria and filtering by title, keywords, and abstract to exclude articles not specifically related to economic and risk analysis studies in crop succession and rotation systems. The organization of the article data and all the analysis were performed in Microsoft Excel® spreadsheets and in the Microsoft Word® text editor.

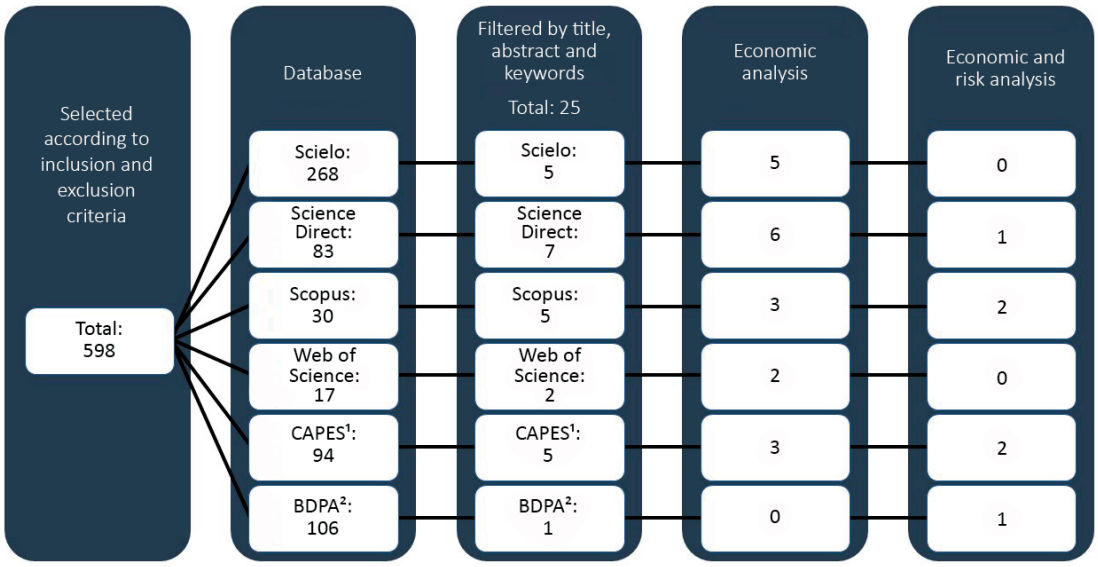

Figure 1. Number of documents selected from the systematic literature review filtering process
Source: Original search results
Note: [1]CAPES: Coordenação de Aperfeiçoamento de Pessoal de Nível Superior; [2]BDPA: Base de Dados da Pesquisa Agropecuária

Of the 598 articles identified in the search databases according to the inclusion and exclusion criteria adopted, 25 articles related to the topic and research objective were selected for analysis and discussion when filtered by title, abstracts, and keywords.

After selection, each article was analyzed in detail. Tables were created to facilitate the interpretation process, and the articles were organized by title, authors, year of publication, journal, country of publication and topic.

3. Results and discussion

In the sample texts selected for analysis, 76% of the papers presented studies on economic analyses of crop rotation systems, and 24% presented risk and economic analyses. Concerning the years of publication, 2019 was the year with the highest number of studies, with 3 articles on economic analysis and 4 with economic analysis combined with risk analysis (Figure 2).

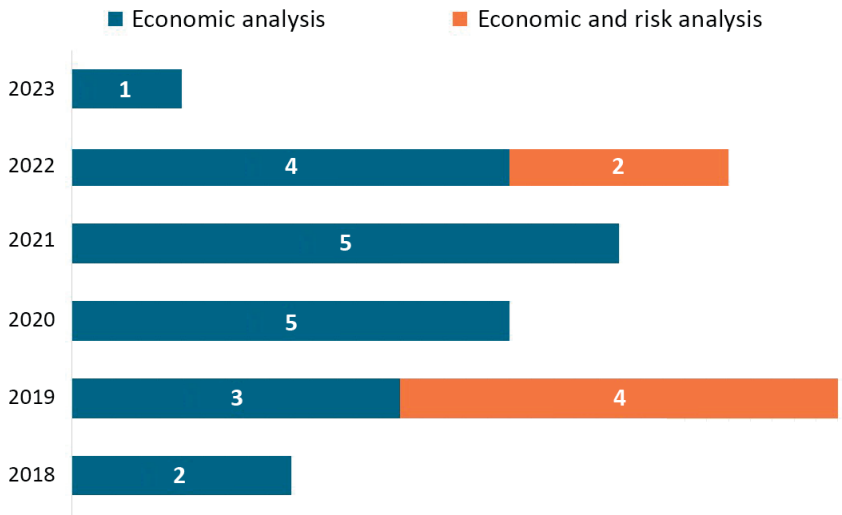

Figure 2. Selected articles classified by year of publication and study topics
Source: Original search results

Regarding the locations where the studies were done, 32% were conducted in Brazil and 68% in other countries, such as Canada, the United States of America, India, Morocco, Poland, Germany, Bangladesh, China, Costa Rica, Ghana and Switzerland (Figure 3). The diversity of nationalities in the origins of the studies in the sample confirms the interest in the scientific community for relevant information capable of supporting the decision-making process in adopting conservation agriculture practices, such as crop rotation.

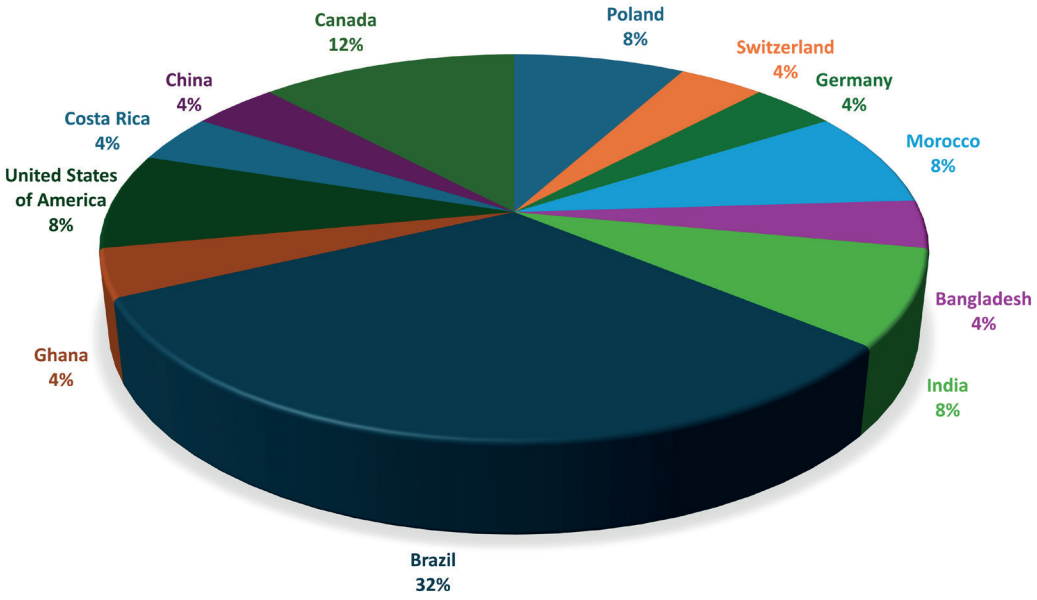

Figure 3. Article classification by countries
Source: Original search results

Table 2 shows the articles that present only economic analyses of crop rotation systems.

Table 2. Articles that address economic analysis

Title	Can productivity and profitability be enhanced in intensively managed cereal systems while reducing the environmental footprint of production? Assessing sustainable intensification options in the breadbasket of India
Author (Year)	Kumar et al.[8]
Journal	Agriculture, Ecosystems & Environment
Country	India
Topic	Identification of a new generation of high-yielding and resource-efficient cereal systems based on conservation and precision agriculture principles

Title	Profitability of no-till grain production systems
Author (Year)	Fuentes-Llanillo et al.[9]
Journal	Semina: Ciências Agrárias
Country	Brazil
Topic	Verification of profitability in grain cropping in no-tillage systems that follow the precepts of conservation agriculture

Title	Economic analysis of soil management systems and crop rotation
Author (Year)	Santos et al.[10]
Journal	Ambiência
Country	Brazil
Topic	Assessment of economic viability, using the net revenue from soil management systems and crop rotation for grain production in winter and summer over approximately twenty years

Title	Legume-based rotations have clear economic advantages over cereal monocropping in dry areas
Author (Year)	Yigezu et al.[11]
Journal	Agronomy for Sustainable Development
Country	Morocco
Topic	Analysis of the effects of the individual and simultaneous adoption of broad bean-wheat rotation and improved broad bean varieties on yields, agricultural income, and food and nutritional security

Title	Yield and economic results of spring barley grown in crop rotation and in monoculture
Author (Year)	Woźniak et al.[12]
Journal	Polish Journal of Environmental Studies
Country	Poland
Topic	Evaluation of yield and economic results of spring barley, sown in crop rotation and monoculture under different soil preparation systems

Title	Cost and benefit analysis of adopting climate adaptation practices among smallholders: The case of five selected practices in Ghana
Author (Year)	Williams et al.[15]
Journal	Climate Services
Country	Ghana
Topic	Assessment of the economic effectiveness of smallholder vegetable farmers in two counties in Ghana using the cost-benefit analysis model of the five climate adaptation strategies

Title	Long-term productive, competitive, and economic aspects of spring cereal mixtures in integrated and organic crop rotations
Author (Year)	Klima et al.[16]
Journal	Agriculture
Country	Poland
Topic	Analysis of yield, competitiveness, leaf area index, and economic indicators of spring cereals in pure or mixed sowing in crop rotations over nine years in the mountainous area of southern Poland

Table 2. Continued

Title	Production and profitability of diversified agricultural systems
Author (Year)	Volsi et al. [17]
Journal	Anais da Academia Brasileira de Ciências
Country	Brazil
Topic	Verification of the economic performance of more diversified crop rotation systems
Title	Economic optimization for the cultivation of potatoes, carrots and onions in Cartago, Costa Rica
Author (Year)	Barboza-Navarro et al.[18]
Journal	Tecnología en Marcha
Country	Costa Rica
Topic	Optimization of the economic profitability of planting potatoes, onions, and carrots in northern Cartago through a linear programming model to contribute to and strengthen the generation of knowledge in agricultural research in Costa Rica
Title	The agronomic and economic viability of innovative cropping systems to reduce Fusarium head blight and related mycotoxins in wheat
Author (Year)	Drakopoulos et al.[19]
Journal	Agricultural Systems
Country	Switzerland
Topic	Investigation of the agronomic and economic viability of two innovative cropping systems to reduce the risk of fungal diseases in subsequent wheat
Title	Economic analysis of organic cropping systems under different tillage intensities and crop rotations
Author (Year)	Dayananda et al.[20]
Journal	Renewable Agriculture and Food Systems
Country	Canada
Topic	Comparison of the impact of two crop rotation sequences (simplified and diversified) and two levels of cropping intensity (high and low) on the cost of production, gross return, and gross margin of crops when grown under organic management in a semiarid brown soil zone of the Canadian prairies
Title	Crop rotation enhances agricultural sustainability: From an empirical evaluation of eco-economic benefits in rice production
Author (Year)	He et al.[21]
Journal	Agriculture
Country	China
Topic	Assessment of the economic, social, and ecological effects of data generated from fields with different rice cultivation systems during two consecutive years to develop a more profitable, effective, and ecological rice production strategy
Title	Diversified crop rotations increase the yield and economic efficiency of grain production systems
Author (Year)	Garbelini et al.[4]
Journal	European Journal of Agronomy
Country	Brazil
Topic	Verification of grain productivity and profitability of agricultural production systems with different levels of plant diversity in southern Brazil
Title	Perception and level of soil and water conservation practices adoption by farmers in a watershed
Author (Year)	Melo et al.[22]
Journal	Revista Ciência Agronômica
Country	Brazil
Topic	Verification of the perception and level of soil and water conservation practices adopted by farmers with annual crops in a specific river basin. And verification of the relationship between the adoption of conservation practices and the socioeconomic characteristics of farmers

Table 2. Continued

Title	Conservation agriculture improves agronomic, economic, and soil fertility indicators for a clay soil in a rainfed Mediterranean climate in Morocco
Author (Year)	Devkota et al.[23]
Journal	Agricultural Systems
Country	Morocco
Topic	Systematic evaluation of agronomic, economic, and soil fertility indicators under conservation agriculture and conventional tillage using field experimentation and simulation modeling for a clay soil of a dryland region in the Mediterranean environment
Title	Enhancing farm income through boundary plantation of poplar (*Populus deltoides*): An economic analysis
Author (Year)	Chavan et al.[24]
Journal	Sustainability
Country	India
Topic	Determination of the economic viability of adjacent poplar plantations in a field experiment from planting to harvest
Title	Reduced tillage and crop diversification can improve productivity and profitability of rice-based rotations of the Eastern Gangetic Plains
Author (Year)	Hoque et al.[25]
Journal	Field Crops Research
Country	Bangladesh
Topic	Evaluation of conservation agriculture and alternate cropping versus conventional farming under six cropping systems, double and triple, in terms of grain yield, grain protein, caloric yields, labor use, and gross margin of different crops and cropping systems

Source: Original search results

Kumar et al.[8] aimed to identify integrated management options to improve productivity and profitability by rationalizing resource use and reducing environmental externalities based on diversification, precision management, and conservation agriculture principles. In 2009, a long-term field study was established in India to evaluate four scenarios with different strategies and crop combinations. The system's net returns and cost-benefit ratio were calculated for the economic analysis. The results demonstrated that to overcome the emerging problems of labor and water shortages and increasing production costs, direct-seeded rice cultivation appears to be an economically viable alternative to conventionally transplanted rice (flooded soil). The results also indicated that maize under CA-based management appears to be a suitable and profitable alternative to rice, with significant reductions in irrigation water quantity, energy use, and pollutant emissions and higher profitability than conventionally transplanted rice (flooded soil).

Fuentes-Llanillo et al.[9] investigated whether no-tillage grain cropping systems that followed the precepts of CA were economically profitable. The research used the methodology of a quantitative and qualitative multi-case study focusing on 13 farms in the state of Paraná. Technical and economic data were compiled for each farm, and variable costs, gross revenue, and gross margin per hectare of useful agricultural areas were calculated from 1998/1999 to 2003/2004. The authors found that higher gross margins were associated with a longer time using the no-tillage system, ownership of machinery and equipment, specialization in grains, rotation of commercial crops used, and higher variable costs. Lower gross margins were associated with outsourcing sowing, small-scale cultivation, and lack of crop rotation. Therefore, the findings indicated that no-tillage grain production systems in northern Paraná were economically profitable.

Santos et al.[10] evaluated the economic viability using the net revenue of soil management and crop rotation systems for grain production in winter and summer over approximately 20 years. The treatments consisted of four soil management systems - NTS, minimum tillage, conventional tillage with disc and moldboard plows - and three crop rotation systems - involving wheat, soybean, vetch, corn, white oats, and sorghum. The results showed that in

terms of net revenue, over an average of 18 harvests, NTS was more profitable per hectare (US$ 315.29)[1] than the other soil management systems - minimum tillage: US$ 255.34[1]; conventional tillage with disc plow: US$ 190.45[1]; and conventional tillage with moldboard plow: US$ 188.95[1]. The findings also indicated that crop rotation in three harvests, with a two-year interval, was economically more efficient per hectare than wheat/soybean.

Yigezu et al.[11] documented the effects of individual and simultaneous adoption of rotation with broad bean and wheat and the use of improved broad bean varieties on productivity, farm income, and food and nutrition security. Economic analyses were performed using endogenous switching regression applied to 2-year production data from a sample of 1,230 Moroccan farming households. The results showed that the joint adoption of rotations and improved broad bean varieties led to a two-year average gross margin of US$ 537 ha^{-1} (48%) higher than wheat monoculture. This was the largest economic benefit of all the available cropping options. However, a surprising result was that contrary to common expectations, rotation adopters did not use lower amounts of nitrogen fertilizers than wheat monocultures, thus reducing the ecological benefits of broad bean-wheat rotations.

The study by Woźniak et al.[12] aimed to evaluate the productivity and economic results of spring barley sown in crop rotation and monoculture under different soil preparation systems. The experiment was conducted between 2015 and 2017 on an experimental farm in Poland. The treatments involved two production systems: monoculture and crop rotation with soybeans, peas, spring barley, and winter wheat. The soil preparation systems were conventional, reduced, and herbicide treated. The gross margin, profit, profitability ratio, unit cost, and economic efficiency ratio were calculated. The research found spring barley grain production was significantly higher in crop rotation than in cereal monoculture. In addition, the yield was significantly higher in reduced tillage than in conventional and herbicide-treated tillage. The economic analysis showed a clear competitive advantage of reduced tillage treatments with crop rotation over the others. The proof was the highest gross margin and profit and the lowest unit production cost.

Volsi et al.[13] verified whether no-tillage crop rotation systems were economically profitable in a Caiuá sandstone area in the northwestern region of Paraná state (Brazil). The crops of black oats, rye, soybeans, forage radish, sorghum, triticale, corn, crambe, canola, safflower, lupine, corn with brachiaria, common beans, and buckwheat were used in the four treatments evaluated. For the economic analysis, the farm's net revenue was calculated by subtracting the operating cost of each treatment from its gross revenue. Only the rotation system with the greatest crop diversification (lupine/corn with brachiaria – common beans/corn – buckwheat/soybean) was profitable, with a positive net agricultural income. Despite having the second highest production cost, it was also the one that generated the highest revenue, showing that the higher cost of this cropping system can be more than offset by its revenue. The results obtained in this study indicated that more diversified production systems with crop rotation are more profitable, which is an important indicator to promote and accelerate the adoption of more sustainable technologies.

The objective of the study by Fortini et al.[14] was to analyze the effects of adopting different conservation practices on land productivity and the profits of farms in Brazil. Using microdata from the 2006 Agricultural Census, the Entropy Balancing technique was used to obtain groups of adopters and non-adopters of conservation practices. Unlike the results presented so far, the study's results showed that the adoption of conservation practices on profit was not statistically significant for crop rotation and pasture recovery practices. However, the authors argued that one of the reasons for the failure of crop rotation, considering the loss of productivity, is performing the rotation incorrectly, that is, using an order of crops that do not complement each other adequately and, consequently, do not result in a physical, chemical and biological balance of the soil. Thus, although this study found lower land productivity for those who adopt crop rotation, this practice does not lose its importance in other aspects.

The study by Williams et al.[15] sought to assess the economic effectiveness of smallholder horticultural farmers in two counties in Ghana using the cost-benefit analysis model of the five climate adaptation strategies. The following strategies were considered: intercropping, mixed cropping, crop rotation, irrigation, and fertilization. 180 smallholder households implementing the identified practices in two horticultural growing counties were surveyed. Profitability indicators and assessment of environmental and social externalities were used to estimate the practices' cost-effectiveness. The findings indicated that mixed cropping and crop rotation are low-cost practices, and intercropping, irrigation, and mixed cropping require relatively high investment costs. While mixed cropping and crop rotation required, on average, two years to amortize the investment costs, the other three practices required more than three years and presented higher risks of failure if adopted. The results also indicated that implementing any of the five adaptation practices would generate positive benefits from a private and public

[1]The mentioned values were converted using the average exchange rate for 2016, equivalent to R$3.48. These data were obtained from the historical series of IPEADATA (Exchange Rate History – R$/US$ Basis). Available at: http://www.ipeadata.gov.br/ExibeSerie.aspx?stub=1&serid=38590&module=M. Accessed on: Dec 05, 2024.

perspective. However, considering the capital required, the payback period of the investments made, and the risks of implementation, mixed cropping and crop rotation, among the five practices, are particularly suitable choices for smallholders.

Klima et al.[16] analyzed the yield, competitiveness, leaf area index, and economic indicators of spring cereals in pure or mixed cropping in integrated or organic crop rotations over nine years (three crop rotations) in southern Poland. The treatments evaluated two factors: the first was between integrated and organic systems, and the second was composed of crop rotations involving potatoes, spring cereals, and spring vetch. Economic indicators such as gross margin and direct profitability index were calculated. It was found that, on average, cereals in pure and mixed sowings yielded 18% less in organic rotations compared to integrated ones. However, crops of spring cereal mixtures produced more than pure sowings and had a higher leaf area index and land equivalent ratio. The average gross margin without subsidies was almost twice as high in organic rotations as in integrated rotations, mainly influenced by barley cultivation in pure sowing. In summary, cultivating spring cereal mixtures in the mountainous areas of southern Poland was recommended, considering productive and economic factors.

Volsi et al.[17] proposed to verify whether more diversified crop rotation systems present better economic performance. To this end, they carried out an experiment located at the headquarters of the Agronomic Institute of Paraná, in Londrina-PR (Brazil). There were six treatments, five highly diversified crop rotation systems and one less diversified crop rotation system, in a three-year cycle. For the economic analysis, the relationship between revenue and cost, or net return, for each production system was used. The findings indicated that the production systems that practiced a more diversified crop rotation presented higher profit and revenue. Specifically, the best revenue result was found in the treatment with the combination corn/corn and brachiaria – canola/corn – common bean/soybean. Despite the higher cost, diversified systems with a greater number of commercial crops in the winter presented higher profits.

Barboza-Navarro et al.[18] sought to optimize the economic profitability of planting potatoes, onions, and carrots in Costa Rica using a linear programming model. This study used data from primary and secondary sources from institutions linked to the agricultural sector to determine revenues and costs. The profitability of each crop was calculated, and two optimization scenarios of the profitability function were applied based on restrictions on useful area, market capacity, and budget. The mathematical linear programming model, in the first scenario, demonstrated that the economic optimization of the productive rotation system for potato, onion, and carrot crops was achieved by planting them in April, August, and September, for harvesting in July, November, and December. However, the most profitable solution was presented in the second scenario, in which producers sow each crop only once a year, that is, in rotation, and use all the available land.

Drakopoulos et al.[19] investigated the agronomic and economic feasibility of two innovative cropping systems to reduce the risk of fungal diseases in wheat. The systems were corn intercropped and cover cropped with different plant species before the wheat growing season under reduced tillage practices. The field experiment was conducted over two years (2016–2017) in two different fields in Switzerland. An economic evaluation was performed by calculating each cropping system's revenues, operating costs, and gross margin. The findings indicated that intercropping with corn or intercropping cover crops in a corn-wheat rotation under reduced tillage decreased mycotoxins in wheat grains while maintaining crop yield. However, this agronomic benefit due to increased operating costs was economically offset by a reduction in gross margin from 7% to 25% across the rotation.

The objective of the research developed by Dayananda et al.[20] was to compare the impact of two crop rotation sequences (simplified and diversified) and two levels of cropping intensity (high and low) on the production cost, gross revenue and gross margin of crops when grown under organic management, in the semiarid brown soil zone of the Canadian prairies, for six years. The treatment involved crops such as field peas, hard red wheat, flax, lentils, and yellow mustard, and the gross revenue from the sale of the crops was calculated. The results confirmed the hypothesis raised in the article that a diversified crop rotation would result in greater agricultural profitability than a simplified crop rotation. The five-year average gross revenues and gross margins, with and without organic price premiums, were significantly higher for the high-intensity cropping treatments than the low-intensity cropping treatments. Furthermore, the rotation sequences did not significantly affect the five-year average gross margins.

He et al.[21] sought to evaluate the economic, social, and ecological effects of data generated from fields with different rice cropping systems in China in 2017 and 2018 to develop a more profitable, efficient, and environmentally friendly rice production strategy. Each field experiment contained treatments including two rice cultivars and four cropping systems involving rice, potato, and watermelon crops. The benefit evaluation indicators, including profit, profit margin, revenue, yield, among others, were determined. The results showed that increasing agricultural diversity through rotations, particularly potato-rice rotation, significantly increased rice production's social, economic, and ecological benefits. Yields, profits, profit margins, weighted dimensionless values of soil chemical and physical characteristics, and heavy metals, benefits, and externalities generated by

potato-rice rotation and other rotations were generally higher than successive rice crops. These results suggested that implementing agricultural diversity through rotations proved to be advantageous.

The paper by Garbelini et al.[3] was based on results obtained during the 2009–2017 harvests through a long-term field experiment carried out since 1985 in Campo Mourão-PR (Brazil), which aimed to analyze grain productivity and profitability of agricultural cropping systems with different levels of plant diversity. The treatments consisted of five systems involving soybean, corn, wheat, white oat, black oat, forage radish, and radish crops. The results proved that diversified crop rotations increased the grain productivity of soybean, corn, and wheat while reducing production costs. All four-year diversified crop rotation systems generated a higher cumulative operating profit and gross margin than specialized double cropping systems.

The study by Melo et al.[22] verified the perception and level of soil and water conservation practices adopted by farmers with annual crops in a river basin in Paraná (Brazil) and the relationship between the adoption of conservation practices and the socioeconomic characteristics of farmers. This survey was carried out on 41 rural properties during the 2019-2020 harvest, where the predominant production system is annual crops, mainly with soybean and corn in double cropping under no-tillage. The results show that adopting conservation practices was important for 10.5% of the owners to reduce production costs. The owners' or tenants' point of view determines whether crop rotation is important for maintaining production. Approximately 58% of the owners and 87% of the tenants understand that maintaining production is the most important reason for adopting crop rotation. In contrast, crop rotation was the only conservation practice with the lowest level of adoption among farmers, adopted by 30.4% of landowners and 33.3% of tenants. The authors stated that even though farmers were aware of the importance of crop rotation in maintaining the level of agricultural production yield, they were very reluctant to adopt this practice. The main reason for the low adoption was the uncertainty in obtaining profits from growing alternative crops to double cropping - growing soybeans in the spring/summer followed by corn. This is probably due to a limited view of the profitability of the agricultural production system, which is sometimes restricted to short-term analysis. Improvements to agricultural systems, including their economic benefits, with the adoption of crop rotation occur only in the medium and long term. This is one of the main bottlenecks for the sustainable intensification of agricultural production and needs to be addressed in public and private actions, especially through technical assistance.

The study by Devkota et al.[23] aimed to systematically evaluate agronomic, economic, and soil fertility indicators under CA and conventional tillage, using medium-term field experimentation and long-term simulation modeling, for a dryland clayey soil in Morocco. The experiment was conducted from 2015 to 2019, and four crops were adopted: barley, chickpea, lentil, and wheat. The economic analysis considered the total cost of cultivation and gross return. The results showed that over the five years of contrasting rainfall, compared to conventional tillage, CA had greater stability and increased wheat grain yield by 43%, barley by 8%, lentil by 11%, and chickpea by 19%. In addition, over the five-year cereal-legume rotation cycle, CA resulted in a 20% increase in system yield and a 40% increase in total benefits, a 13% increase in rainwater use efficiency and a 14% increase in soil water availability, with a 14.5% reduction in production costs. Therefore, the field experiment and long-term simulation results suggested that adopting CA improves a series of agronomic, economic, and soil fertility indicators compared to conventional tillage in the clayey soil of Morocco, in a Mediterranean environment cultivated under rainfed conditions.

The study by Chavan et al.[24] focused on determining the economic viability of poplar (*Populus deltoides*) plantations in a field experiment from planting to harvest. The research was carried out in India from 2008 to 2016. The experiment was designed by planting poplar in various orientations to determine the yield potential, economic viability, and its effect on sorghum-wheat crop rotations until harvesting of the trees. The economic analysis of the boundary systems indicated that adopting a tree-based system would help farmers increase total income in a semi-arid environment where traditional cropping is not economically viable. Therefore, the findings indicated that intercropping of sorghum-wheat crop rotation in east-west boundary plantings was more beneficial in increasing farm income than traditional cropping in northern India.

The research by Hoque et al.[25] aimed to evaluate conservation agriculture and crop rotation against conventional tillage regarding grain yield, grain protein and caloric yields, labor input, and gross margin. The study was conducted between 2013 and 2016 in northern Bangladesh. The treatments evaluated were three tillage options and six cropping sequences involving rice, mung bean, wheat, and maize crops. The study showed that rice-maize and rice-mung bean systems could increase the main crop (rice) yield and the caloric and protein yields of the systems by 50%, 5%, and 27%, respectively, while providing 133% higher gross margins than the rice-rice monoculture system. In conclusion, CA outperformed conventional tillage in different winter crops and cropping systems. The results further demonstrate the multiple benefits of CA-based partial and full cropping practices employed with appropriate crop diversification to achieve sustainable food security with increased calorie and protein intake while maximizing the agricultural profitability of intensive rice-based rotation systems.

Table 3 presents articles with Original search results that carried out risk analyses in addition to economic analyses.

Table 3. Articles that address economic and risk analysis

Title	Avaliação de sistemas de rotação de culturas na análise econômica e de risco, nas décadas de 1980 a 2010
Author (Year)	Santos et al.[5]
Journal	Chapter in a Book by Embrapa
Country	Brazil
Topic	Dissemination of the results of long-term experiments related to economic and risk analysis in different crop rotation systems
Title	Stability analysis for grain yield of winter wheat in a long-term field experiment
Author (Year)	Macholdt and Honermeier[26]
Journal	Archives of Agronomy and Soil Science
Country	Germany
Topic	Investigation on the yield stability of winter wheat as a function of crop rotation systems with different nitrogen fertilization and under different annual meteorological conditions over 25 years
Title	Economic Performance of Long-term Organic and Conventional Crop Rotations in the Mid-Atlantic
Author (Year)	White et al.[27]
Journal	Agronomy Journal
Country	United States of America
Topic	Survey of five cropping systems' costs, yields, and net returns between 2006 and 2014
Title	Agronomic and economic benefits of rotating corn with soybean and spring wheat under different tillage in eastern Canada
Author (Year)	Gagnon et al.[28]
Journal	Agronomy Journal
Country	Canada
Topic	Identifying the best crop rotation system concerning grain yield, soil aggregation, and economic return under different soil preparation managements.
Title	Evaluating the climate resilience in terms of profitability and risk for a long-term corn-soybean-wheat rotation under different treatment systems
Author (Year)	Eeswaran et al.[29]
Journal	Climate Risk Management
Country	United States of America
Topic	Assessment of the climate resilience of three alternative treatment systems regarding profitability and long-term risks compared to the conventional system
Title	Pulse-included diverse crop rotations improved the systems economic profitability: evidenced in two 4-year cycles of rotation experiments
Author (Year)	Khakbazan et al.[30]
Journal	Agronomy for Sustainable Development
Country	Canada
Topic	Evaluation of the profitability and performance of various legume rotations compared to wheat monoculture over an 8-year study period and examination of the risk of rotations with different types and frequencies of legume crop

Source: Original search results

Santos et al.[5] presented the economic analysis and assessment of the risks inherent in the different crop rotation systems for wheat, barley, and triticale under conventional soil preparation and NTS or even grain production systems with crop + livestock integration, also involving wheat crops. The findings indicated that the crop rotation system has always been more profitable than species monoculture. In addition to reducing crop production costs, increasing grain yield promoted crop diversification and, consequently, reduced the risk of farmer failure.

A study by Macholdt and Honermeier[26] investigated the yield stability of winter wheat as a function of crop rotation systems with different nitrogen fertilization under different annual weather conditions over 25 years. The study was based on a long-term field experiment conducted in Germany. The treatments included six different crop

rotation systems involving cultivars of winter rye, winter wheat, winter barley, spring oats, rapeseed, sugar beet, field beans, and silage corn. The three methodological approaches used were: Ecovalence, Biplot analysis, and Risk analysis. Based on the field experiment investigated, clear effects of crop rotation and nitrogen fertilization on the yield stability of winter wheat were determined. In the three nitrogen fertilization treatments, the safest crop rotation systems were with field beans as the preceding crop, which showed the highest probability of winter wheat exceeding the average grain yield. These are important factors to consider in agronomic management decisions under the increasingly difficult environmental conditions caused by climate change.

White et al.[27] surveyed the costs, yields, and net returns of five cropping systems in a Beltsville (United States) agricultural systems project between 2006 and 2014. The project analyzed consisted of two conventional and three organic cropping systems, consisting of rotations of vetch, corn, rye, soybean, wheat, and alfalfa. A risk assessment model was used to assess the risk for the complete crop rotations in each system. Annual returns for each crop and average returns for each system were calculated. This economic analysis demonstrated that long, diversified rotations in organic farming systems increase returns for individual crops within the rotation and for the system itself. In addition, including a multi-year perennial forage crop stabilized overall returns, particularly in poor years for grain crops, and reduced risk relative to shorter organic rotations and conventional no-till and plow systems. Organic system returns competed with no-till and conventional tillage systems regardless of rotation length, although returns from shorter rotations were more variable and had greater risk associated with production.

Gagnon et al.[28] sought to identify the best crop rotation system in the humid temperate region of eastern Canada under two tillage management for grain yield, soil aggregation, and economic return. The experiment lasted six years and included tillage treatments: minimum and conventional tillage with moldboard plowing. Six crop rotation systems were evaluated: 1) continuous corn; 2) continuous soybean; 3) corn-soybean; 4) corn-corn-soybean; 5) corn-soybean-spring wheat; and 6) corn-spring wheat–soybean. An economic analysis was performed to find the rotation with the highest net return among the years with the lowest economic risk. This was done with a stochastic simulation in which the distribution of annual net returns for each rotation system was described in terms of their respective means, variances, and fractal values. The findings indicated that the crop rotation system affected the yield and economic performance of the cultivated grain crops. Corn grown in rotation had higher grain yield than continuous corn or corn-corn-soybean, regardless of soil tillage. Soybeans grown once every three years consistently produced higher yields than continuous soybeans, while the inclusion of spring wheat to diversify the corn-soybean rotation increased the grain yield of corn and soybean compared to continuous cropping. Continuous soybean, corn-soybean, and corn-soybean-spring wheat and corn-spring wheat-soybean rotations, with wheat straw being sold, were the most efficient rotation systems, i.e., they had high net returns and low adverse risk. Thus, it may be advisable to adopt minimum tillage under comparable climatic and soil conditions due to its benefits on soil quality without compromising crop yield and profitability.

Eeswaran et al.[29] were designed to assess the effects of climate variability on farm net returns under different production and treatment systems, and the level of risk for adapting these alternative treatments. This study was conducted in Michigan (USA), where the climate resilience of three alternative treatment systems implemented in a long-term corn-soybean-wheat rotation was assessed compared to a conventional treatment. Gross margin and annual change in gross margin were used as economic risk assessment metrics. The modeled results demonstrate that USDA-certified organic net revenues were expected to exceed conventional treatment net revenues, i.e., organic showed greater annual stability in revenues. The results indicated that the no-till treatment dominates conventional and reduced-input practices in expected annual net revenues, with a relatively lower risk for these revenues due to climate extremes. Furthermore, organic and no-till treatments were suitable for serving a range of farmers with different risk preferences. Therefore, organic treatments and no-till farming were found to be climate resilient, and this finding may motivate the expansion of agricultural conservation practices.

Khakbazan et al.[30] aimed to evaluate the profitability and performance of a variety of legume rotations compared to wheat monoculture over an 8-year study period, in addition to examining the risk of rotations with different types and frequencies of legume crops. The experiments were conducted at three sites in Canada, where the treatments consisted of 13 diversified crop rotations with cultivars of yellow peas, chickpeas, red lentils, oriental mustard, and a continuous wheat crop. Net revenue was estimated, and a simulation model was used for the risk-return analysis. The results showed that rotations with high frequencies of lentils or diversified crops generated significantly higher net revenues than wheat monoculture systems. The risk analysis showed the same trend, and, in addition, the study showed that adding legumes to crop rotations can reduce the need for nitrogen fertilizers by 38%, thus saving money.

The results presented in this study support the idea that conservation agriculture practices, such as crop rotation systems, can provide agronomic benefits and economic gains. In addition, they are strategies that can reduce the various risks inherent to agricultural activity.

4. Conclusion

Considering the theoretical framework presented within the sample evaluated, conservationist agriculture practices, such as crop rotation systems, not only present agronomic but also economic benefits and are strategies that can reduce the various risks inherent to agricultural activity. The data collected in this literature review are important because they demonstrate new possibilities for studies on economic and risk analyses to assist rural producers in the decision-making process regarding the adoption of conservationist agriculture practices.

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