

Theoretical foundations of sustainability and their contribution to innovation in the agricultural sector: a bibliometric analysis

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ABSTRACT

Objective: to gather knowledge of the behavior and trends of publications on the contributions from the dimensions of sustainability to innovation in the agriculture sector, based on their theoretical foundations.

Design/Methodology/Approach: a categorization of scientific papers was obtained through bibliometric analysis. In a first stage, the terms 'innovation', 'sustainability' and 'agricultural sector' were selected as search words. With which 161 papers were selected, all published during the analysis period. Then, information was classified in Excel[®] to generate bibliometric indicators in a second stage.

Results: main agricultural crops, in which innovation research related to sustainability was developed, were maize and beans; followed by rice and coffee. The most studied economic indicators were income, new markets, and production costs. Within the ecological dimension, the most recurrent indicators in research were biofertilization, nitrogen supply, carbon, crop rotation, coatings with organic matter, vermiculture, and climate change.

Limitations/Implications of the study: innovation is continuous, and results can vary if someone takes the articles that will be generated in the coming years. Therefore, our recommendation is to continue with other studies similar to this one, to give continuity and reveals new innovations.

Findings/Conclusions: about 30% of the works were focused on bacterial inoculation, biofertilizers and biostimulants. The search for soil fertility and its prompt recovery form the largest number of research aimed at technological and mainly biotechnological innovation in the agricultural sector worldwide.

Keywords: sustainability, innovation, bibliometric analysis.

Citation: Coutiño-Puchuli, A E., & Infante-Jiménez, Z. T. (2025). Theoretical foundations of sustainability and their contribution to innovation in the agricultural sector: a bibliometric analysis. *Agro Productividad*. <https://doi.org/10.32854/q4s3m078>

Academic Editor: Jorge Cadena Iñiguez

Associate Editor: Dra. Lucero del Mar Ruiz Posadas

Guest Editor: Daniel Alejandro Cadena Zamudio

Received: December 11, 2024.

Accepted: August 16, 2025.

Published on-line: October 24, 2025.

Agro Productividad, 18(9). September. 2025. pp: 133-141.

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INTRODUCTION

The Food and Agriculture Organization of the United Nations (FAO) recognizes four dimensions of food security; availability, access, utilization, and stability (Castañeda-Álvarez, 2022). For Ikerd (1990), sustainable agriculture is one capable of maintaining acceptable levels of biological and economic productivity, preserving the environment, and natural resources, satisfying at the same time a requirement of society.

In the second half of 1980s decade, the paradigm of sustainable development emerged as a result of the analysis of the World Commission on the Environment of the United Nations, through the document *Our Common Future*, which defined sustainability as the principle where human beings are at the center of concerns related to sustainable development. Humans have the right to a healthy and productive life in harmony with nature. The primer postulate is the satisfaction of the basic needs of world population for food, clothing, dwelling, and health (Badii, 2004). Sustainability can be understood as a paradigm for thinking about a future in which environmental, social and economic considerations are balanced in the search for development and a better quality of life (Oropesa-Casanova *et al.*, 2021).

The concept of sustainability is related to the principle of the scarcity of resources, the population that exists and the pressure they exert on the territory; through processes as pollution and depletion of natural resources, but also, with clean production strategies in any of the economic fields (Bravo & Bravo, 2016). Sustainable agriculture implies, among other things, long-term conservation of natural systems, optimal production with reduced production costs, adequate income and profit per unit of production. The World Commission on Environment and Development defines sustainable development as one that meets the needs of the present generation without compromising the ability of future generations to meet their own needs. In particular, the satisfaction of basic food needs, and sufficient supply to meet the demands and needs of rural families and communities (Liverman *et al.*, 1988).

On the other hand, bibliometric analyses are responsible for studying scientific activity in an area of study based on statistical and mathematical applications (Aleixandre, 2010). Bibliometrics makes it possible to identify patterns in publications and socialize the information generated on a specific topic (Rubilar-Bernal & Pérez-Gutiérrez, 2018).

The objective of this study was to gather knowledge of the behavior and trends of publications on the contributions from the dimensions of sustainability to innovation in the agriculture sector, based on their theoretical foundations.

MATERIALS AND METHODS

A critical analysis was done of the documents found on the subject 'innovations to agriculture sustainability' in the databases EBSCO and Redalyc in the period from 2019 to 2023. The methodology for bibliometric analysis was followed; in the first stage, 'innovation', 'sustainability' and 'agriculture sector' were used as search words.

That search allowed selecting 161 papers in those databases during the period of analysis. We excluded those that did not report on an innovation related to at least one of the dimensions of sustainability in the agriculture sector. Then, information gathered was classified in Excel[®] to generate bibliometric indicators in a second stage.

Among the participants in innovation, the most representative are transnational private companies with national subsidiaries; followed by agribusiness, brokers or other commercial intermediaries; agricultural producers and public and private research centers. These participants were identified in the published papers on innovation.

RESULTS AND DISCUSSION

One of the important contributions, according to this bibliometric study, on sustainability towards innovation is the technological change in the form of conventional production towards organic production in commercially important crops. The highest costs in organic production are in inputs. This, according to personal interviews with avocado producers in Los Reyes (Michoacan) Mexico, and blackberry fruit producers in Ziracuaretiro, (Michoacan), as well as what was found in several of the articles reviewed in this study.

Innovation in the agriculture sector can be defined as that improvement in production technology that allows, with a certain group of inputs, to obtain more quantity or better quality at the level of production. It was found that biotechnological innovations

predominate in agriculture. Nowadays, the search for sustainability of resources such as soils leads to a large number of research on the inoculation of microorganisms to produce biofertilizers. According to the crop and the specific endogenous requirements of the agricultural production process.

Evolution in the application of science, technology and their innovations in agriculture by agriculture & livestock companies have given rise to major stages of transformation. Types of crops and machinery have made production occurs, in the living conditions of society, with less physical burdens (Zayas, 2018). Companies are mentioned as agriculture & livestock, since it was found that there are innovations centered on forage production, which is part of agriculture, to supply livestock systems.

Adoption of new technology is determined by the size of the farm, farmer experience, education, and industry participation associated with innovation (Zepeda, 1994), and property rights (Perret & Stevens, 2006). Another factor in sustainability that influences the adoption of technological innovations is the efficiency of agricultural production (Cabrini *et al.*, 2013). More than 30% of the papers found are centered on the study of new biofertilizers, mainly based on microorganisms. Another large number of studies focus on the search for efficiency in the use of mineral nutrients and efficiency in the use of water. Few studies deal with credits structure and financing for organic producers.

Another contribution of sustainability to innovation is the development actions associated with social aspects; such as organizing in associations, societies, or agricultural cooperatives that seek collective benefits. One more contribution is based in the creation or improvement of new products or production processes that are friendly to the environment. This can be seen in the studies of new varieties through in vitro production, genetic alterations, hybridization and mutations. All of those were found in a number of documents in this review.

Innovation systems integrate economic, ecological, social, political, cultural and organizational factors that compose, then, the dimensions of sustainability. Although they are generally included in only three, which are environmental, economic and social, this latter grouping the political, cultural and organizational dimensions. Some environmental problems of sustainability that drive innovations in the agriculture sector are climate change, environmental degradation, growing competition for land and water, or high fertilizer prices, due to the depletion of primary sources such as phosphate rock (phosphorite). For this reason, several studies have been directed towards carbon incorporation, nitrite filtration, carbon dioxide generation, and other greenhouse effect gases.

The economic dimension of sustainability is characterized by a production system that allows efficient use of productive factors, generates economies of scale, and increases productivity to levels that improve competitiveness in markets. Within the social dimension, institutions and values are the basis of the development process. While policy creates an environment to promote production and development of human populations. According to García (2018), one of the contributions of sustainability to agricultural innovation is that which refers to the social dimension and its determinants. For example, wages, the rights of rural workers, and other social relationships for production. The innovation he proposed, in terms of the production process, is “network production” where agricultural

capital resorts to service providers towards lowering costs. In such a network, the main participants are producers, also, agricultural service contractors and suppliers of services or inputs.

Innovation profile in the agriculture sector

Agriculture innovation is a process through which farmers improve the production and management practices of their farms. In other words, innovation means the implementation of new crop varieties; the combination of traditional practices with new scientific knowledge; the use of new technologies and machinery; the jointly application of old and new production and post-harvest practices; or participation in markets in a new and more profitable way, among other aspects (Bustamante-Lara & Schwentesius-Rindermann, 2018). However, innovation requires more than just farmer action. Agriculture innovation arises from the interaction between the different stakeholders related to the sector; this is, producers, processors, packers, distributors, consumers, organizations and government (OECD, 2013).

A classification of innovation is shown below, with some examples from agriculture sector:

- **Products innovation:** diversification of new crops for export (fruits, vegetables and grains), new and different varieties of crops, improved and hybrid seeds, seedlings generation, planting of organic and premium-quality crops, reforestation, use of rootstocks, payment of royalties for patents of new varieties, agro-industrial transformation.
- **Production innovations:** intensive-biotechnological production, fertigation; protected and precision agriculture, drones; better management of agrochemicals and fertilizers, organic production, better agricultural practices (safety, health and quality); agroclimatic monitoring; cold rooms and conservation chambers; automated packaging and sorters; greenhouses for seedling germination; fertilization with vermicompost; automation of pumping water from the subsoil; Smart machinery with GPS to make the planting and harvesting processes more efficient, design and construction of harvesting vehicles; computer systems for the management of the production process; use of fumigator planes, new plant growing systems (like pergola system); refrigerated transportation; integrated disease management (genetic, chemical, biological and cultural pest control); agroecological management.
- **Organizational innovation:** financial diversification; installation of computer systems for the management of the administrative and organizational processes the company; rental of agricultural machinery; new forms of flexible hiring of agricultural workers (day laborers), this is, hiring by the day or by the task.
- **Marketing innovations:** contract farming; direct marketing (without intermediaries); search for better market windows (summer and winter); promotional campaigns or agriculture fairs; improvements in presentation and packaging (bags and boxes); world quality certificates, website and management of social networks (Facebook, Twitter, blogs) with company information; search for government support.

To be able to affirm about a change in the degree of sustainability in the agricultural sector due to a technological innovation, it is necessary to compare it with another technology, taking into account time, scale of production and context. One of the main economic incentives to use an innovation that impacts agricultural sustainability is the surplus price for agricultural products in the organic market. Mainly at foreign markets, in the case of Mexico with the United States as the main destination for agricultural exports.

Undoubtedly, the search for soil fertility and soils quick recovery after production, form the largest number of research aimed at technological innovation. This, in order to impact towards greater productivity that results in better profitability, which is part of the ecological and economic dimensions of sustainability. Innovation is mainly biotechnological in the agriculture sector worldwide. There are multiple indicators that can be part of the dimensions in sustainability study that depend on the research objectives and interests to be considered in such studies.

Among the innovations found is conservation agriculture, which is a cultivation system that encourages a minimum of mechanical alteration in soils and the maintenance of permanent soil cover with crop diversification. This system of production enhances biodiversity and natural biological processes that contribute to the use of water and makes the use of nutrients more efficient. It also promotes the sustainability of agriculture production, and impacts profitability by reducing production costs.

In the 161 articles analyzed, 131 main authors were detected. The Cuban Ionel Hernández-Forte was identified as a leader with four articles of innovations in agriculture sustainability, in which he reported research on bacterial inoculation, specializing in rhizobia, in rice crops. He is followed by the also Cuban Carlos José Bécquer with three articles; with studies on inoculation of microorganisms such as *Trichoderma harzianum*, *Azospirillum brasilense* and *Glomus cubense*, to be used as biofertilizers and biostimulants.

According to the search completed in the Redalyc and EBSCO databases during the period 2019-2023, the withstanding countries in the number of research reports on innovations related to several dimensions of agriculture sustainability are Cuba, as the undisputed leader with 61 papers; Mexico with 25; Colombia with 20; Ecuador with 14; Argentina with 10; Brazil and Costa Rica both with 9.

Among the territories of the Mexican Republic that made the most contributions to research on innovations related to agricultural sustainability are the State of Mexico, Chiapas, Coahuila, and Sonora during the 2019-2023 study period. Michoacán is one of the 14 states of the Republic that implemented this type of research of great importance for the biotechnological development in Mexican primary sector.

During the period of analysis, in the 161 articles considered, a total of 32 different species of agricultural crops were studied. The main crops in which research on innovation related to sustainability were maize and beans with 14 and 13 articles during the period 2019-2023, followed by species such as rice, coffee and soybeans with eight documents each, cocoa tree and papaya with six; sugar cane, fodder and tomato with five; lemon and banana with four each. Since livestock production is linked to agriculture, fodder crops were included, and along with tomatoes, lemons and papaya were among the 12 crops with larger number of experiments reported.

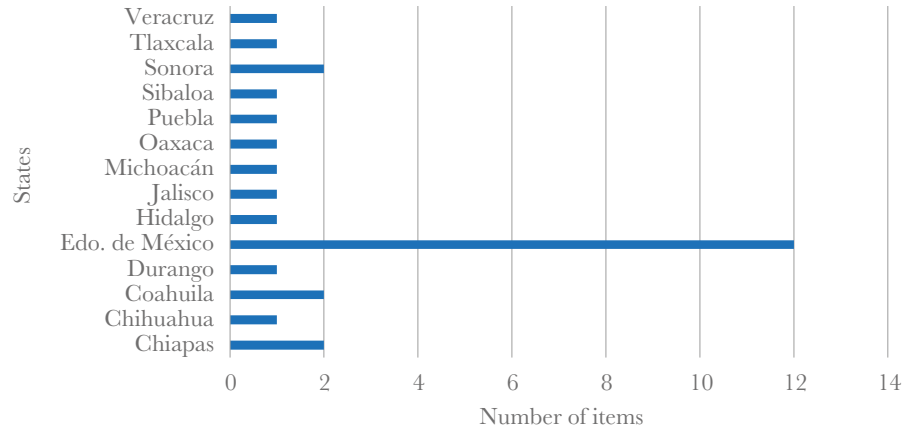


Figure 1. Federation Entities (states) in Mexico with innovations related to agricultural sustainability during 2019-2023. Source: original with data from Redalyc and EBSCO.

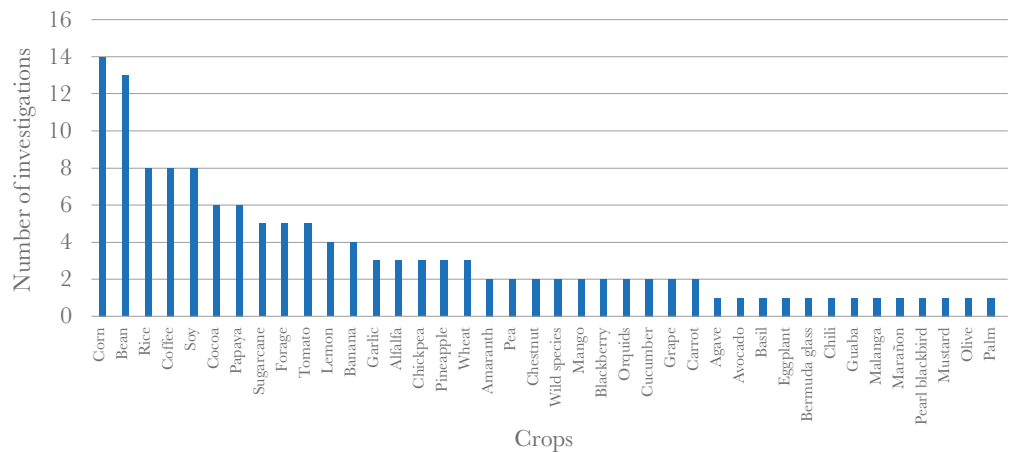


Figure 2. Main crops where sustainability-related innovations were made in the agriculture sector. Source: original based on data from Redalyc and EBSCO (2019-2023) databases.

In regard to the dimensions of sustainability analyzed in this research with their indicators, Economic includes income, new markets, production costs; followed by price, labor costs, input costs, technical assistance, study on clusters, credits, certification and determination of the break-even point. In the Ecological dimension, biofertilization, nitrogen contribution, carbon; crop rotation, organic matter mulch; vermiculture; climate change; protected agriculture; dead and living barriers; crop association (all of which are centered on the recovery of the fertility of agricultural soils and water conservation).

Those main dimensions were followed not so closely by innovations towards other human-related dimensions, cultural, social and political. Here we found education, health, equity, dwelling; recognition of the empowerment of rural women, quality of life for producers, work quality, identification of key participants and production networks.

This means, that mainly, innovations were more technological and biotechnological in nature. In terms of technology, the innovations were mostly in new products, *in vitro* propagation, integrated and post-harvest technology, irrigation technology,

green technologies, labeling systems, multi-scale precision systems, new machinery and equipment, hydroponics, new cultivation systems, mechanized transplantation, thermotherapy, spectroscopic index, use of Single Nucleotide Polymorphism markers with a high degree of precision; nutrient injection, remote sensing, chromatography, weather radar, and molecular markers (Figure 3).

In regard to biotechnological innovations, about 30% of the research papers reported on bacterial inoculation, biofertilizers and biostimulants; 13 articles with focus on the search for new varieties, 5 on new hybrids, 4 on biological control of pests, bioinputs and in vitro cloning, followed by studies of dehydration, plant biomass coverage, organic matter mulch, bacterial DNA extraction and genomics, genetic improvement, nanobiotechnology, mutations, and cross-pollination. Regarding processes, we found few studies; two referring specifically to food sufficiency and one, in the study of rural community-owned enterprises.

The reason behind placing biofertilizers as an innovative bioproduct is they cause a significant impact on each of the dimensions of sustainability. Such innovations are implemented in traditional crops such as basic crops (staplers); maize, beans, rice; also

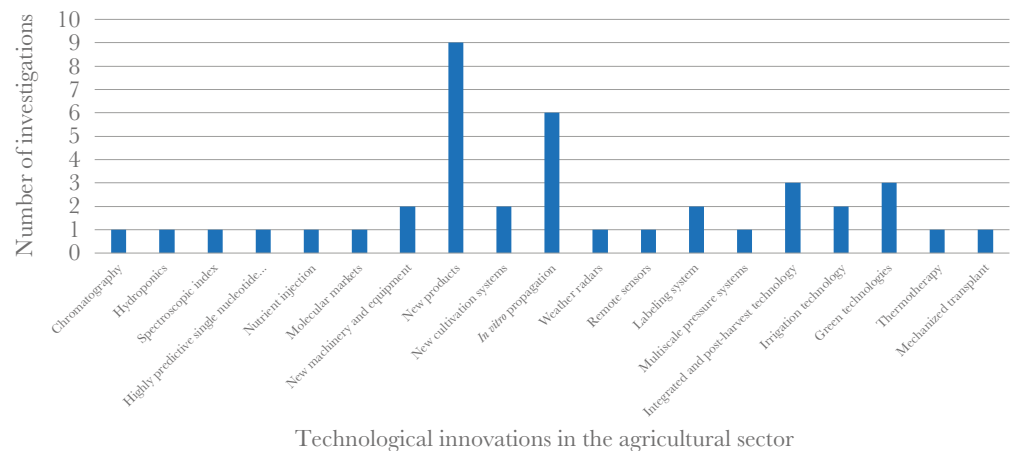


Figure 3. Main types of technological innovations in agriculture during 2019-2023.

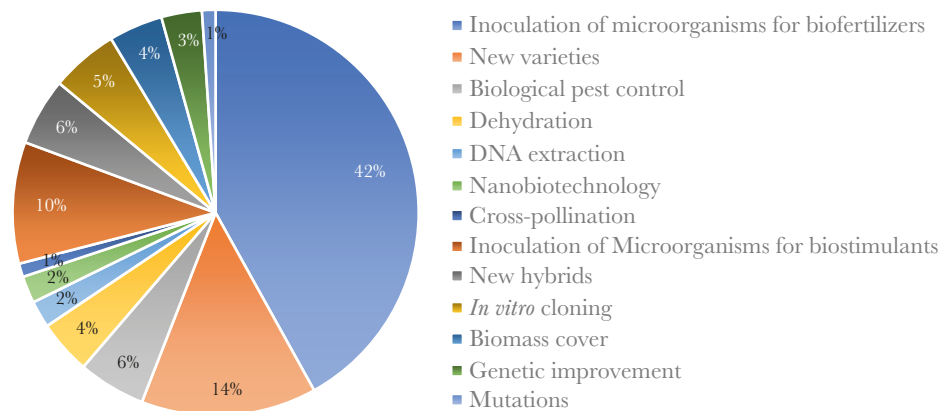


Figure 4. Main biotechnological innovations in Agriculture during 2019-2023.

coffee and cocoa tree generate important innovations in agriculture. As well as other products of great commercial interest such as sugar cane, banana, lemon, as well as berries and avocado that are also part of the findings in this bibliometric study.

Those figures that are taken as indicators of the dimensions of sustainability in agriculture vary according to the subject and the goals pursued by the research. Some additional indicators of the environmental dimension can be erosion risks, productive diversity, management of pests and diseases with biotechnological and conventional methods, health status, waste management, waste reuse, just to mention a few. In the economic sphere are diversification of production, percentage of products destined for sales or for self-consumption, income level, social security, dependence on inputs, production costs, search for the internal rate of return (IR) or break-even point, among many others. Some indicators developed for the political, social and cultural dimensions are type of land ownership, level of education, access to health systems, access to primary services, social integration, training; even others found in this study with focus on the empowerment of rural women, among others.

CONCLUSIONS

There were more than 30 different innovations found, which indicates the great interest in innovation in scientific research in agriculture, mainly for maize, beans, rice, coffee and cocoa tree; also, sugarcane, banana, lemon, berries and avocado. Main sustainability dimensions found were economic and ecological, followed not so closely by social, cultural and political. Withstand economic indicators are revenue, new markets and production costs; also, prices, labor and technical training costs; study on clusters, credits by certification and break-even point determination.

In the ecological dimension, the more recurrent indicators were biofertilizers, conservation agriculture and climate change; the main focus is on the recovery of soils fertility and water conservation. As social indicators, education, health, equity and dwelling. Within political and cultural dimensions, the indicators were quality of life for producers, work quality, recognition of the empowerment of rural women, key participants identification and production networks.

Innovation is continuous; these results may significantly vary in the coming years. A subsequent and similar study is recommended to give continuity and monitor new innovations. Among those, for example, meteorological radars that seek to determine where it may rain and predict rainfall level of rainfall; or those related to genetic mutations and nanobiotechnology, which we found very few mentioned in this period of analysis.

ACKNOWLEDGEMENTS

To the UMSNH (Michoacan University of San Nicolás de Hidalgo) and to the Mexican Council of Humanities, Sciences and Technologies (CONAHCYT).

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