Agricultural Sciences, 2026, 17(11), 1321-1339
https://www.scirp.org/journal/as
ISSN Online: 2156-8561
ISSN Print: 2156-8553

Agroecology: A Reality in Marginalized Areas of Mexico; Experiences from Six Years of Work

Pedro Cadena-Iñiguez[1], Rafael Ariza-Flores[2*], Lorena Jaqueline Gómez-Godínez[3], Karla Yuliana Cadena-Pérez[4], Eduardo José Cabrera-Torres[5], Jesús Uresti-Gil[6], Francisco Guevara-Hernández[7], René Pinto-Ruíz[7]

[1]The National Institute of Forestry, Agricultural and Livestock Research, Chiapas Central Experimental Field, Ocozocoautla de Espinosa, Mexico
[2]The National Institute of Forestry, Agricultural and Livestock Research, Iguala Experimental Field, Iguala de la Independencia, Mexico
[3]The National Institute of Forestry, Agricultural and Livestock Research, National Center for Genetic Resources, Tepatitlán de Morelos, Mexico
[4]Independent Research, Santa Cruz Xoxocotlán, Mexico
[5]The National Institute of Forestry, Agricultural and Livestock Research, Chetumal Experimental Field, Othón P. Blanco, Mexico
[6]The National Institute of Forestry, Agricultural and Livestock Research, Saltillo Experimental Field, Saltillo, Mexico
[7]Faculty of Agronomic Sciences, Autonomous University of Chiapas, Villaflores, Mexico
Email: cadena.pedro@inifap.gob.mx, *ariza.rafael@inifap.gob.mx, gomez.lorena@inifap.gob.mx, karla.cadena.01@gmail.com, cabrera.eduardo@inifap.gob.mx, uresti.jesus@inifap.gob.mx, francisco.guevara@unach.mx, rene.pinto@unach.mx

How to cite this paper: Cadena-Iñiguez, P., Ariza-Flores, R., Gómez-Godínez, L.J., Cadena-Pérez, K.Y., Cabrera-Torres, E.J., Uresti-Gil, J., Guevara-Hernández, F. and Pinto-Ruíz, R. (2026) Agroecology: A Reality in Marginalized Areas of Mexico; Experiences from Six Years of Work. *Agricultural Sciences*, **17**, 1321-1339.
https://doi.org/10.4236/as.2026.1711075

Received: July 8, 2026
Accepted: November 21, 2026
Published: November 24, 2026

Copyright © 2026 by author(s) and Scientific Research Publishing Inc.
This work is licensed under the Creative Commons Attribution International License (CC BY 4.0).
http://creativecommons.org/licenses/by/4.0/
Open Access

Abstract

For six years, a support program for producers in highly marginalized areas has been operationalized, covering 28 states of the Mexican Republic, addressing 14 production chains with three main components: direct support, technical assistance, and marketing actions, emphasizing the agroecological transition in order to increasingly replace industrialized inputs with bio-inputs produced at the production unit. The objective of this document is to show the most outstanding results of six years of work between the Ministry of Agriculture and Rural Development and the National Institute of Forestry, Agricultural and Livestock Research (INIFAP) as the implementing agency. The results shown indicate that participating producers have been enthusiastic and have participated in the installation of more than 5500 Farmer Field Schools throughout Mexico. In these schools, the technical support provided by the 1245 technicians has been effective. The data suggest that there is no significant difference between agroecological and conventional production, but there is a reduction in production costs across all the supply chains served. Therefore, the real challenge is how to feed Mexico's ever-growing population. While it is true that traditionally it is important to support the most vulnerable, as is the public policy of the current administration, it is also necessary to

consider the 76% of the population living in large cities who do not produce food and who must be fed. We must also consider the inputs required by the processing industry, not just food self-sufficiency for a significant portion of the rural population.

Keywords

Agroecology, Bioinputs, Marginalized Areas, Mexico

1. Introduction

It has always been believed that increased productivity requires large inputs, and this is true; feeding an ever-growing population requires government strategies that help supply basic or processed foods to meet the demand of all sectors of the population, as well as the processing industry, without depending on other sources beyond our borders.

Over the past six years, the Mexican government, under the so-called 4T public policy model, has allocated approximately 81 billion pesos [1] [2] to direct support for producers and technical assistance strategies provided by implementing agencies in the Mexican countryside across at least 11 production chains. The beneficiaries of this direct support, without intermediaries, are small and medium-scale producers with plots of up to 20 hectares of rainfed land and five hectares of irrigated land, and up to 100 beehives. They receive an annual quota for crops such as corn (*Zea mays* L.), beans (*Phaseolus vulgaris*), rice (*Oryza sativa*), wheat (*Triticum aestivum*), and other grains like sorghum (*Sorghum vulgare*), milpa, amaranth (*Amaranthus* spp.), and chia (*Salvia hispanica*). coffee, (*Coffea arabica*); cocoa, (*Theobroma cacao*); sugar cane, (*Saccharum officinarum* L.); honey, (*Apis mellifera* and *Apis beecheii*); and family dairy farming based on European cattle and *Bos taurus* and *Bos indicus* zebu cattle; all producers receiving support must be registered in the beneficiary registry of the Ministry of Agriculture of the Government of Mexico [3] (**Figure 1**).

Activities have been carried out in 28 states; however, until 2024, work was conducted by functional territories, encompassing 36 territories. Following the 2025-2026 agreement between the National Institute of Forestry, Agricultural and Livestock Research (INIFAP) and the Ministry of Agriculture, work began at the state level, serving 1018 of the 1345 municipalities prioritized by the Government of the Republic of Mexico. To this end, an average of 1245 technicians have provided technical support over the last six years. The professional workforce serving producers has operated in more than 5500 Farmer Field Schools (FFS), which are shown in **Figure 2**.

They also relied on support strategies and access to financing, activities that offer loans with accessible interest rates to producers who participate in the Technical Support, the target population has varied in the years of operation of the

program, starting with 24,000 producers and reaching about 196 thousand, of which 35% are women as shown in the following graph.

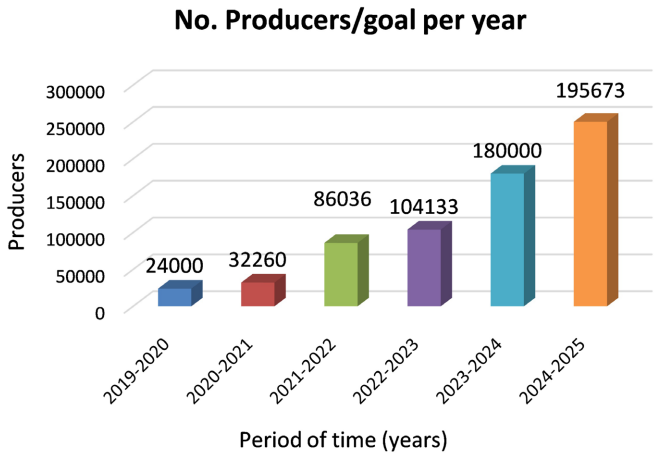


Figure 1. Beneficiary producers of the Production for Wellbeing/Harvesting sovereignty Program, 2019-2025. Source: [2].

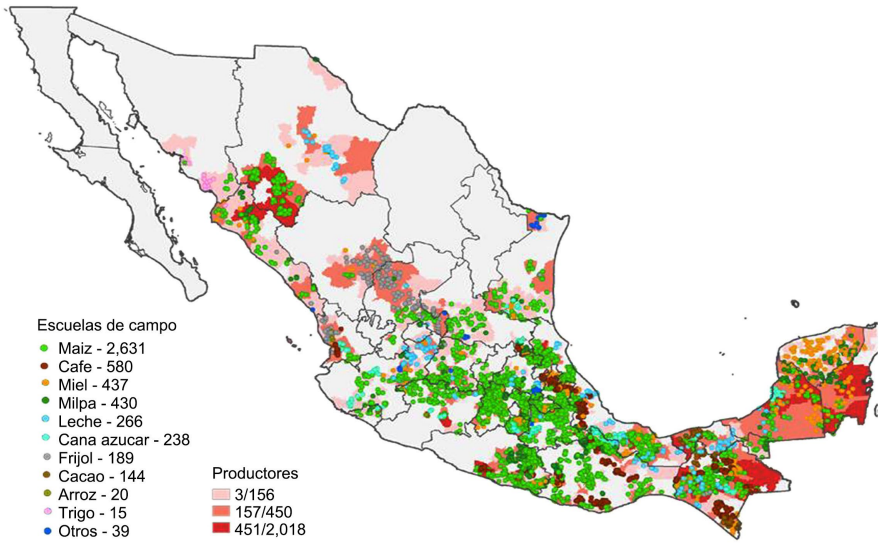


Figure 2. Number of Farmer Field Schools in Mexico, by production chain as of March 2026. of the Production for Well-being/Harvesting Sovereignty Program, 2019-2025. Source: [2].

In the selected municipalities, 54% have an indigenous presence to a greater or lesser degree. According to [1], 56% of the population directly served and supported is in the south-southeast, highlighting the states of Chiapas and Oaxaca with close to a third of the benefited producers.

The purpose of this article is to present the most outstanding results of six years of work between the Ministry of Agriculture and Rural Development and the National Institute of Forestry, Agricultural and Livestock Research (INIFAP), the implementing agency. INIFAP proposed the Farmer Field School model as its working method. This model originated in Southeast Asia and, since 2000, has

been adapted to Mexican conditions and context, initially in areas of high and very high marginalization. It is supported by andragogical methods of non-formal teaching for older producers, most of whom are over 53 years old. The Farmer Field School model is extensively documented in: [4]-[9].

2. Literature Review

Altieri and Nicholls [10] discuss the concept of agroecology as the design of practices carried out in accordance with the interactions between plants, animals, the environment, and humans, in order to conserve biodiversity and improve the components of the agroecosystem. A more advanced idea is declared as the agroecological transition, defined by [11], which they describe as the "process of change in agricultural practices and the biological readaptation of an agricultural system to achieve balanced results in terms of production, independence from external inputs, especially agrochemicals, and the restoration of all the ecological and social processes that allow it to achieve sustainability." After reviewing the evolutionary approach to the agroecological transition, [12] conclude that: "…the state of the agroecological transition is conceptually stagnant in a permanent process of substituting chemical inputs for organic inputs."

There has been much debate about the concept of agroecology which is identified as a holistic and integrated approach that simultaneously applies ecological and social concepts and principles to the design and management of sustainable agriculture and food systems. It is optimizing interactions between plants, animals, humans and the environment, while addressing the need for socially equitable and democratic food systems in which people can choose what they eat, and how and where it is produced. This concept has evolved to expand its scope, now representing a transdisciplinary field that includes the ecological, sociocultural, technological, economic and political dimensions of food systems, from production to consumption [13]. For its part, the opinion of one of the pioneer researchers in the study of Agroecology, [14], indicated that agroecology is a sustainable approach to agriculture, with implications that have to do with social aspects, interacting with the environment to achieve the sustainable approach. For its part, within the framework of the Technical Support project, the Government of Mexico, through the Ministry of Agriculture and Rural Development, from 2021 to date, conceives agroecology as the contribution and a solution to preserve our natural resources and the environment, an alternative way of producing healthy, nutritious, quality, accessible and sufficient food for Mexicans. Furthermore, this instance indicates that agroecological practices combine the available science and the cultural heritage of the people, which are mixed in an exchange of knowledge, which highlights the links between human work and sustainable livelihoods.

There is a current of thought among researchers known as the fifth wave of progress, which can be summarized as follows: the fifth wave of human progress can be understood as a new historical stage in which development is no longer measured solely by technological or economic advances, but by the capacity to

protect the environment, strengthen social cohesion, and ensure a sustainable economy. It is a vision that integrates three inseparable dimensions: nature, society, and economy. This concept is developed from the theoretical frameworks of [15]-[17], the UN 2030 Agenda [18] and [19] published in 2019, integrating the environmental, social, and economic dimensions of sustainable development, which together become sustainability, and agroecology is one component of this. [20] using data from 2721 farms in nine study areas across six African countries, demonstrated that agroecological transitions are highly diverse and influenced by farm structure. They found similarities to those reported in Mexico, which is the focus of this study. Three patterns emerged: smaller farms primarily combine self-sufficiency and income diversification, while larger farms tend to combine conventional intensification with crop and livestock integration. Other small and medium-scale farms are characterized by allocating more land to legume cultivation, which contributes to soil health.

3. Work Methodology

Based on the requirements of the Ministry of Agriculture to assist the most disadvantaged groups, who had been neglected for years, [21] indicated that, under the mandate of the Fourth Transformation emanating from the current government, support was and continues to be provided to groups, especially in the south-southeast region, which were previously considered poor, lacking productive capacity and potential. The work strategy was based on the following theoretical and conceptual model, which is duly documented in [22], whose antecedent was [23] [24], as shown in **Figure 3**:

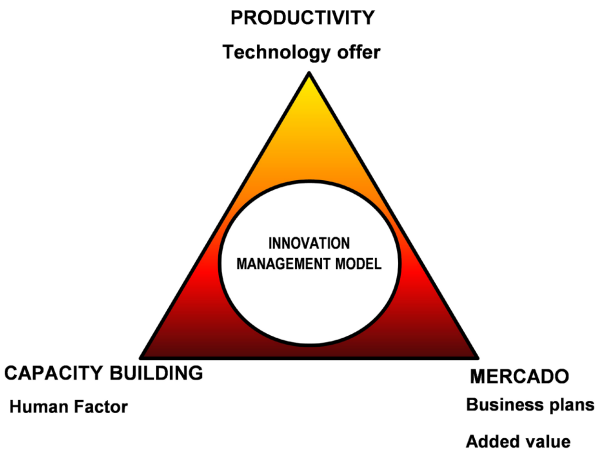


Figure 3. Innovation management model generated in the innovation project for the economic and social development of the rural productive sector in the south-southeast region of Mexico. 2010-2012. Source: [4].

According to the elements of the model, there is always a technological offer, which is called released and publicly available technology adapted or adopted to the conditions of each context, and of each production chain that is to be made

available to the producers, which serves as essential raw material to develop the capacities of the recipients, training is provided or capacities are developed so that technicians and producers acquire and appropriate the technologies or processes, however, this would not make sense if there is no impact on the economy of those who make the land produce, because if we stay only with the training course or the demonstration plot we would fall into the neoliberal model of traditional extensionism of training and visits, [25] and [26], and under this scheme it is about giving real support to the producers.

After six years of collaborative work by a triad of Producers, Technicians, and Institutions from all three levels of government, several results have been achieved, among which the following stand out:

4. Results in Crop Production

The production of the main crops or production chains is presented in the following paragraphs and represents the work of the central team of the Ministry of Agriculture and Rural Development, in coordination with the agroecological technicians hired by each product system, in addition to the thematic specialists of INIFAP. It is important to mention that data is presented on the average baseline in the year 2019 and 2025, and the current state of the production chain after the intervention of the Technical Support.

Technical support for corn in 2019 reached 71,068 producers, compared to 106,931 in 2025. The number of Field Schools also changed from 2235 to 2980. Baseline yields were defined at 1.7 t·ha^{-1} compared to the 3.7 t·ha^{-1} achieved and reported in 2025. For producers who used at least one agroecological practice, production costs per hectare decreased by 2%, which seems insignificant but represents more than that percentage in the local and family economy. Another aspect to highlight is the reduction in the use of agrochemicals, since the baseline indicates that they were used at 24%, while in 2025, this decreased to 13.2%. There is a dilemma here as to whether the decrease in the use of agrochemicals was really due to the substitution of bio-inputs produced in the Production Unit or due to the increased cost of inputs from the petrochemical industry.

Technical support for bean cultivation: the average results are from priority bean-producing states, including Zacatecas, Durango, and Nayarit, as well as strategic states for this crop: San Luis Potosí, Puebla, Chiapas, Guanajuato, Tamaulipas, and Sinaloa. In these states, the main lines of work were: 1) Improvement and conservation of genetic material; 2) Conservation and efficient use of soil; 3) Conservation and efficient use of water; and 4) Innovation, processing, and value-added production. In the priority states, with the exception of Nayarit, the others face water scarcity issues, which compete for supply to other crops such as vegetables and for the population. These actions resulted in an increase in average production from 350 kg·ha^{-1} to 730 kg·ha^{-1}. Among the producers served in this production chain, a reduction in the use of agrochemicals was recorded from 12.6% to 9.21%, in addition to a reduction in production costs with the use of agroeco-

logical practices, which in current pesos went from $33,300 per hectare in 2019 to $15,608 pesos in 2025, and that is very significant. Another no less important aspect is the refreshing of improved and native germplasm in the producing states, since only using native or selected seed from other cycles can lead to a degeneration of the material.

Technical support for rice production was primarily provided in the states served by the program's agroecological technicians: Campeche, Morelos, Michoacán, and Colima. While other states such as Tamaulipas, Veracruz, and Sinaloa were also supported, the data presented mainly focuses on the first three states and, more recently, Nayarit. These states are considered priorities for rice production, given that Mexico has an 80% deficit in meeting its national requirements. [27], as shown in the following **Figure 4**.

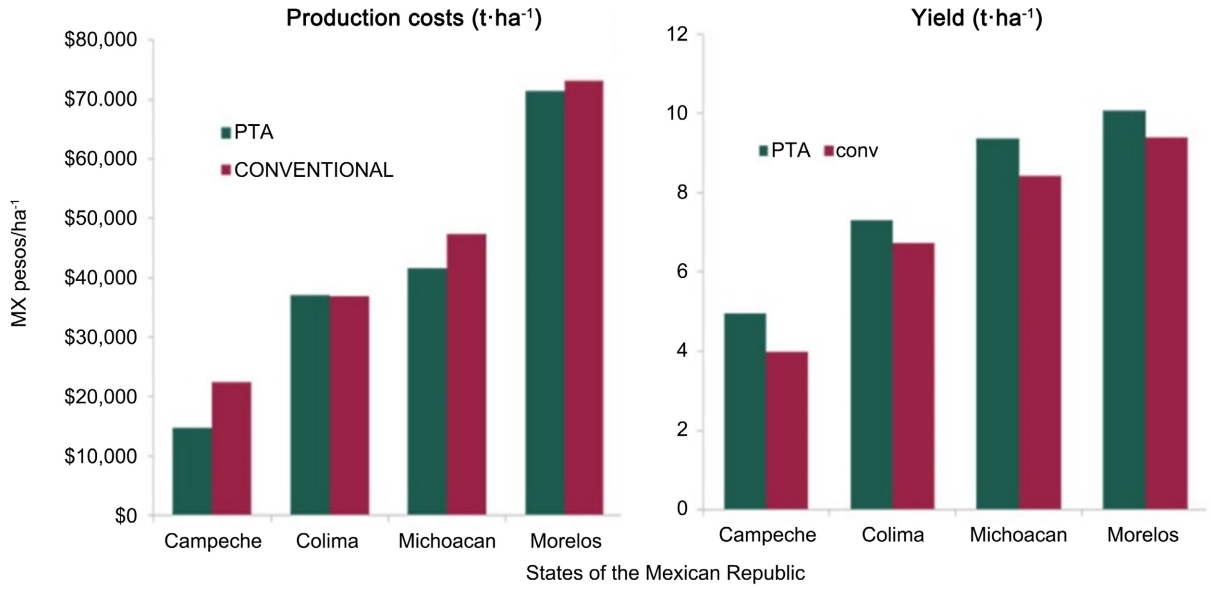


Figure 4. Production costs and yields in four rice-producing states. Source: [2].

The graph shows an average increase of 11% in production and an 8% decrease in production costs per hectare, with Agroecological Transition Practices (ATP) and conventional management.

Technical support for coffee production on both the Gulf of Mexico and Pacific slopes has resulted in average yield increases of 6% in quintals of coffee produced between 2019 and 2025. This increase is attributed to the expansion from three to seven agroecological practices adopted by the coffee producers participating in the technical support program. However, production costs are a stark contrast, rising by 18% by 2025 compared to 2019. This increase is primarily due to the labor required for producing the necessary bio-inputs. Nevertheless, crop management was comprehensive, encompassing plant and soil nutrition, microbiota restoration practices, management of the coffee plantation environment, and the production of secondary products.

Technical support for cocoa production, although primarily concentrated in two states, Tabasco and Chiapas, has recently garnered special attention in the Pacific coastal states of Oaxaca, Michoacán, and Guerrero. While promising, the results are still quite low compared to other production chains. For example, yields increased from 380 kg·ha^{-1} to 410 kg·ha^{-1} between 2021 and 2025, but a reduction in agrochemical use was only 0.08%, as baseline studies showed a usage rate of 0.10% among producers in Tabasco and Chiapas. Furthermore, the lowest production costs per hectare were recorded in 2025, at 38.53%.

Technical support for honey production: Mexico boasts diverse pollinator species. In the case of bees, the country is home to both the European honeybee (*Apis mellifera*) and various native bee species (*Meliponini*), and the sustainable management of their hives is fundamental to environmental balance. Beekeeping and meliponiculture activities directly benefit more than 43,000 producers and indirectly benefit the general population through the environmental services provided by bees. Among the benefits of beekeeping, the economic advantages stand out due to the production of hive products such as honey, propolis, pollen, beeswax, royal jelly, and venom. On a social level, the creation of jobs in rural areas is significant, primarily through the marketing and processing of these products, with the majority of these jobs going to women. Between 2019 and 2025, average results for bee colonies nationwide were presented. Honey yields increased by only one kilogram per colony per year; however, the average number of producing colonies increased by 32%, indicating that beekeepers are convinced of the benefits of this activity when using agroecological practices. Furthermore, the average amount of honey produced per producer per year increased by 33.3%.

4.1. Results in Food Analysis and Quality

In laboratory analysis, crops produced with agroecological practices had higher nutritional values compared to traditional or conventional management, and their values in Sugars, Proteins, antioxidant activity, flavonoids and anthocyanins were mostly higher, especially in corn, beans and cocoa. Of 2095 samples of corn grown with agroecological transition vs. conventional or traditional management, the nutraceutical results were superior with agroecological management in four of six parameters (sugars, protein, Flavonoids, and anthocyanins) [28].

Table 1 presents the maximum, minimum, and range values for each variable, revealing significant variability due to endogenous characteristics among genotypes, diverse agronomic management practices, and climatic conditions. However, each maize variety is acceptable and important for its specific location, as producers cultivate them for various reasons, including adaptability, yield, traditional uses and customs, and local consumption. Therefore, each maize variety from every site where it is grown is valuable as long as it meets the tastes and preferences of producers and consumers, and should be conserved as a unique genetic resource in each community, town, municipality, state, and nation.

Table 1. Maximum, minimum and range values of the quality, nutraceutical, proximate and nixtamalization variables of native maize varieties from Mexico with analysis in 2024 and 2025 [2].

Variable	Unit of measurement	Maximum grain value	Minimum grain value	Range	Maximum value tortilla	Minimum value tortilla	Range
Sugar	g 100 g^{-1}	6.35	1.29	5.06	4.75	0.19	4.56
Protein	g 100 g^{-1}	16.99	5.5	11.49	24.57	1.65	22.92
Phenols	mg EAG 100 g^{-1}	0.25	0.07	0.18	0.28	0.05	0.23
Flavonoids	mg EQ 100 g^{-1}	18.12	0.0	18.12	7.89	0.0	7.89
Antioxidant Activity	mg EAA 100 g^{-1}	2496	279	2217	1173	213	960
Anthocyanins	mg ECY3G 100 g^{-1}	90.36	2.47	87.89	67	0.6	66.4
Calcium	Ca^{+2} mg·kg^{-1}	1388	21	1367	3801	86.17	3714.8
Zinc	Zn^{+2} mg·kg^{-1}	127	11	116	928.5	4.25	924.3
Magnesium	Mg^{+2} mg·kg^{-1}	2501	573	1928	1972	589	1383
Iron	Fe^{+2+3} mg·kg^{-1}	599	2.1	596.9	259	8	251
Fiber	%	48	10	38	130	3.85	126.15
Lipids	%	15.23	8.9	6.33	2487	1.16	2486.8
Ash	%	3.7	0.89	2.81	1.38	0.08	1.3
kg of nixtamal/kg of corn	kg	3.01	1.54	1.47	---	---	---
kg of masa/kg of corn	kg	2.98	1.47	1.51	---	---	---
kg of tortilla/kg of corn	kg	1.97	1.26	0.71	---	---	---

Source: [2].

Table 2, presents the dynamics of the variables under study from their physical condition from grain to tortilla, where it is observed that the sugars decrease from grain to tortilla by 75.6% and 78% for agroecological and conventional management, respectively.

Soluble protein from grain to tortilla increased by 20.5% in agroecological management and 29% in conventional management; Phenolic compounds increased in agroecological management by 12% and decreased by 34% in conventional management; Flavonoids decreased in both types of agronomic management between 24.4% and 26.9%; antioxidant activity increased from grain to tortilla by 24.4% in agroecological management and 26.9% in conventional management; anthocyanins decreased in both types of agronomic management between 72% and 79%.

Regarding mineral content, when the tortilla was made, calcium increased by 741% in agroecological management and by 577% in conventional management; zinc decreased by 16% in agroecological management and by 29% in conventional management; magnesium decreased by 7.6% in agroecological management and by 11.4% in conventional management; and iron decreased by 25% in both agroecological and conventional management.

Table 2. Average values by agronomic management of the quality, nutraceutical, proximate and nixtamalization variables of native maize varieties of Mexico and their respective tortillas with analysis in 2024 and 2025 [2].

Variable	UNIT OF MEASUREMENT	Grain AG	Tortilla AG	Diference	%	Grain CV	tortilla CV	Diference	%
SUGARS	g 100 g^{-1}	3.24	0.79	−2.45	−75.6	3.32	0.73	−2.59	−78
PROTEIN	g 100 g^{-1}	10.53	12.69	2.16	20.5	10.56	13.62	3.06	29
PHENOLS	mg EAG 100 g^{-1}	0.125	0.14	0.015	12	0.12	0.079	−0.041	−34
FLAVONOIDS	mg EQ 100 g^{-1}	1.65	0.67	−0.98	−59.4	1.32	0.44	−0.88	−66.7
ACTIVATED ACIDS	mg EAA 100 g^{-1}	604	751.5	147.5	24.4	586	743.5	157.5	26.9
ANTHOCYANINS	mg ECY3G 100 g^{-1}	24.27	6.78	−17.49	−72.2	26.38	5.55	−20.83	−79
CALCIUM	Ca^{+2} mg·kg^{-1}	212	1783	1571	741	259	1753	1494	577
MAGNESIUM	Zn^{+2} mg·kg^{-1}	1204	1112	−92	−7.6	1270	1125	−145	−11.4
ZINC	Mg^{+2} mg·kg^{-1}	46.14	38.77	−7.37	−16	47.69	34	−13.69	−29
IRON	Fe^{+2+3} mg·kg^{-1}	93.53	69.74	−23.79	−25.4	91.46	68.5	−22.96	−25.1
FIBER	%	24.73	60	35.27	143	25.47	59.5	34.03	134
LIPIDS	%	10.84	4.14	−6.7	−62	10.72	4.27	−6.45	−60
ASH	%	2.56	1.40	−1.16	−45	2.51	1.32	−1.19	−47
CORN/NIXTAMAL	kg of nixtamal/kg de maíz	1.8				1.78			
CORN/MASA	Kg of mass/kg corn	2.09				2.08			
CORN/TORTILLA	Kg of tortilla/kg corn	1.60				1.61			

Source: [2].

In the proximate variables, an increase in fiber of 143% was observed in the agroecological management and of 134% in the conventional management; lipids decreased by 61% and ash by 46% on average for both types of agronomic management.

The yield of nixtamal, masa and tortillas was very similar in both agronomic managements since in nixtamal it had a yield of 1.8 kg per kg of grain, the dough yield was 2.09 and 2.08 per kg of grain and the tortilla yield was 1.60 and 1.61 kg per-kg of corn grain. The grain color of the 231 corn in the tortilla making study was white (49%), black or blue corn (30%), red (12%) and yellow (9%). The luminosity or brightness of the color, once the tortilla was made, the brightness in the yellow corn maintained the highest values between 47.9% and 60.72%, followed by the white corn between 56.36% - 56.83% and the red and blue or black corn with lower brightness.

Regarding chromaticity, which indicates the vividness or purity of the color when making the tortilla, the vividness of the color decreased in whites, yellows, and reds, but to a lesser extent in blacks, which remained at values similar to the grain. As for the hue that defines the color of the corn kernels, it was observed that the minimum values increased in the tortillas, while the maximum values remained the same as in the finished tortilla.

The results described above were found to be very similar regardless of agronomic management. It is important to highlight that the nixtamalization and tortilla-making process was beneficial in increasing the protein, calcium, antioxidant

activity, and fiber content compared to the corn kernels. Even with the reduction in nutraceuticals, minerals, lipids, and ash, the contribution of beneficial molecules is significant in the tortilla, attributed in part to the proportion of pigments that provide attractive colors for the consumer. Furthermore, it should be considered that tortillas made with native Mexican corn varieties have sustained countless generations since ancient times, making them a staple food for the human population. They remain a vital part of Mexican cuisine today and will continue to be so in the future [28]. Hasan *et al.*, [29] found something similar: farmers producing high-value crops for export, such as peppers and tomatoes, are more likely to use agroecological methods because they are more integrated into the market and more focused on quality. Conversely, farmers producing exclusively for domestic consumption or those heavily reliant on inputs are less likely to use these methods.

In addition to the above, [30], conducting experiments with bioinoculants in soil, found that the combination of conservation agriculture and bioinoculation appears to promote a more diverse and balanced soil microbial community. They conclude that management practices can play a key role in shaping microbial communities, which could improve soil ecosystem functionality and resilience. These results highlight the potential of integrating bioinoculants with sustainable agricultural practices to promote soil health.

In the Republic of Cuba, [31], in a case study found that the combined application of agroecological practices and renewable technologies significantly improves energy efficiency (40% - 90% reduction in fossil fuel consumption depending on the technology), increases the resilience of agroecosystems (25% improvement in water retention, 52% in soil organic matter) and reduces dependence on external inputs in tropical contexts.

4.2. Results of Soil Analysis

Between 2024 and 2025, soil sampling was carried out in the Field Schools (ECA's) and they were analyzed in different laboratories specialized in the matter. From this, specific fertilization recommendations were defined for each soil sample. Likewise, in order to extend these recommendations to sites surrounding the ECAs, they were interpolated and presented in cartographic form, in such a way that, at any point in the area served by the EAT, it is possible to know a fertilization recommendation. In this sense, the objectives of this study were: 1) Define the SPECIFIC fertilization recommendations for corn, bean, rice and sugar cane crops for each soil sample collected in the Field Schools and 2) Prepare national maps of fertilization recommendations for corn, bean, rice and sugar cane crops. The analyzes were based on 4395 soil samples taken in the 28 states served by the EAT.

To establish the specific fertilization recommendations, the rational method was used, while to interpolate these recommendations and prepare the national maps, the ArcGis Weighted Inverse Distance method was used between recommendation points. The interpolation area was defined as square polygons of 100 ha. The centroid of each of these polygons was assigned a fertilization recommen-

dation. As a result, from the analysis of soil samples, the supply of Nitrogen (N), Phosphorus (P) and Potassium (K) through the soil was quantified; Likewise, the requirements of these three nutrients for corn, beans, rice and sugar cane were quantified. Subsequently, 4395 fertilization recommendations were defined, that is, one recommendation for each soil sample or ECA for corn, beans, rice and sugar cane. Each recommendation is integrated as follows: 1) Three thematic maps with the supply of NPK by the soil, 2) Three thematic maps with the NPK needs of corn, beans, rice and sugar cane, 3) Three fertilization maps using the simple fertilizers Urea (UR), Super Triple Calcium Phosphate (SPCT) and Potassium Chloride (KCL), 4) Two fertilization maps using the compound fertilizer Diammonium Phosphate (DAP), supplemented with UR, 5) Three fertilization maps with Bocashi organic fertilizer (BOK) complemented with DAP and KCL, 6) Three fertilization maps with Lombricompost organic fertilizer (LMC) complemented with DAP and KCL, 7) Three fertilization maps with LMC complemented with UR and KCL and 8) Three fertilization maps with LMC and complemented with UR, DAP and KCL.

In total, 23 maps were created: 6 thematic maps and 17 maps with individual fertilization recommendations (recommendations by nutrient), grouped into six fertilization alternatives. Based on these, ninety-three national maps were developed as follows: 1) Thirteen thematic maps and 2) Twenty maps with individual fertilization recommendations for each of the following crops: maize, beans, rice, and sugarcane, for a total of eighty maps. At this stage, the objectives of the work were achieved, and through the informed, reasoned, and responsible application of the developed fertilization recommendation scheme, the planning and operation of fertilization programs can be significantly improved at the plot (or field school) level, as well as at the municipal, state, regional, and national levels. (Ariza and Cadena, 2025) [32]. An example of these maps is shown in the following **Figure 5** and **Figure 6**.

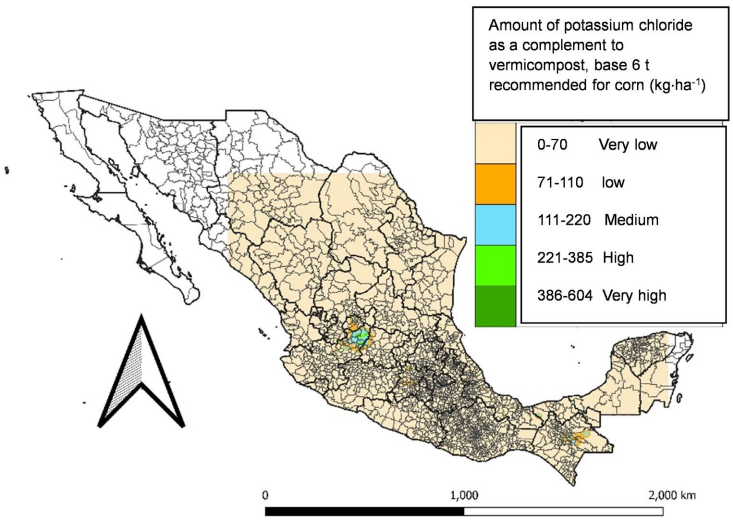


Figure 5. National map of industrial fertilizer requirements, supplemented with vermicompost in maize. Source: Prepared by the author based on fieldwork, 2025.

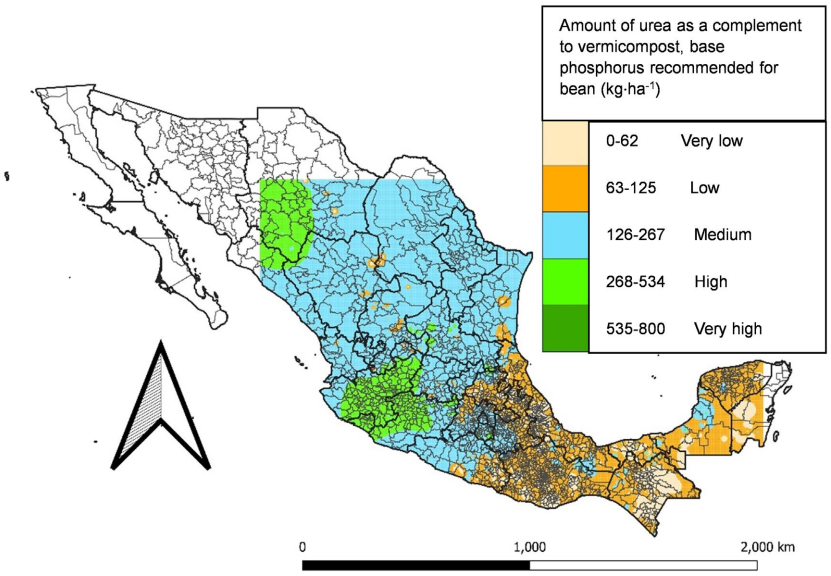


Figure 6. National map of industrial fertilizer requirements, supplemented with vermicompost in beans. Source: Prepared by the author based on fieldwork, 2025.

4.3. Results of Microbiological Analysis

Microbiological analysis conducted within the framework of the Farmer Field Schools (FFS) allowed for the evaluation of both the microbial composition of soils under agroecological management and the microbiological and functional quality of bio-inputs produced locally by farmers. A total of 2547 soil samples from different regions of the country were analyzed. The results showed a predominance of beneficial microorganisms, representing 83% of the isolates obtained, followed by fungi (9%), actinomycetes (7%), and oomycetes (1%) [33] [34]. The high proportion of beneficial microorganisms is a positive indicator of soil biological quality, as these organisms actively participate in essential processes such as organic matter mineralization, nutrient recycling, biological pathogen suppression, and the promotion of plant growth. Likewise, the presence of actinomycetes and saprophytic fungi suggests a favorable microbiological dynamic for the decomposition of organic waste and the maintenance of soil fertility, [35].

Additionally, 1369 samples of solid and liquid bio-inputs produced by farmers in the Agricultural Extension Centers (ECAs) were evaluated. Microbiological safety analysis indicated that 96% of the samples were free of total and fecal coliforms, demonstrating that the production and handling processes implemented by the farmers were adequate from a sanitary standpoint [34]. Besides safety, the functional potential of the microorganisms present in the bio-inputs was determined. Three isolates with phosphorus-solubilizing capacity, 149 siderophore producers, 30 indoleacetic acid (IAA) producers, 11 potassium-solubilizing microorganisms, and 101 biological nitrogen fixers were identified [34] [36]. These characteristics are widely recognized as mechanisms for promoting plant growth, because they increase the availability of nutrients, favor root development and

contribute to improving the efficiency in the absorption of essential elements by plants. Furthermore [37], analyzing 64 soil samples from citrus orchards in the Gulf of Mexico region, observed significant differences in microbial composition associated with the management system. Soils under organic management showed a greater diversity of beneficial microorganisms, as well as a lower incidence and relative abundance of phytopathogenic microorganisms, compared to those managed under conventional systems. These findings suggest that organic management practices favor the establishment of more diverse and balanced microbial communities, capable of contributing to the natural suppression of pathogens and the maintenance of soil health. Consequently, the results support the importance of promoting strategies aimed at conserving and strengthening the soil microbiota as a fundamental component for integrated disease management and the sustainability of agricultural systems [37].

Taken together, the results obtained indicate that the agroecological transition has favored the conservation and strengthening of functional microbial communities, both in agricultural soils and in locally produced bioinputs. Although the direct effect of these microorganisms on the observed yield increases requires complementary long-term studies, there is evidence that they contribute to improving soil health, nutrient availability and the resilience of agroecosystems. Additionally, one of the most significant advances associated with the adoption of agroecological practices has been the gradual reduction in the use of synthetic herbicides, particularly those based on glyphosate, as well as the strengthening of sustainable agricultural biodiversity management strategies. The conservation of native maize varieties, the protection of pollinator species, the recovery of local varieties, and the establishment of community seed banks are actions that strengthen food sovereignty and contribute to the preservation of genetic resources important to Mexican agriculture.

4.4. Results of the Milk Strategy

Milk production in Mexico takes place under highly heterogeneous technological, agroecological, and socioeconomic conditions, resulting in four distinct production systems: specialized or intensive, semi-specialized, dual-purpose, and family or backyard. Technical support is provided to two of these systems: family and dual-purpose. Four dairy regions have been identified in the country: the north (Chihuahua, Durango, and Coahuila), the west (Jalisco, Aguascalientes, and Michoacán), and the central region (Guanajuato, Querétaro, Hidalgo, Mexico State, Puebla, and Tlaxcala), which operate with the family production system; and the south-southeast (Veracruz, Oaxaca, Tabasco, Chiapas, and Campeche), where dual-purpose production is prevalent, accounting for 30.9%, 26.7%, 21.8%, and 12.5%, respectively, of national production. The cattle breed used is Bos taurus. The Holstein breed, and to a lesser extent American Swiss and their crosses, are of lower genetic quality than the specialized system. The technological level is considered low; producers employ deficient practices in reproduction, preventative

medicine, and genetic improvement; production records are lacking; facilities are rudimentary; and milking is generally done manually.

A total of 98 technicians attended to 16,149 producers who were incorporated into the Register of Welfare producers, with an average of 164.79 producers/technician. The attention in general considered training and participation in experience exchange events and technological tours. However, 25 producers who constituted the core of the group were followed up on time, with whom we worked through follow-up visits and evaluation of results, from which the indicators were obtained. The average milk production/cow/day at the beginning was 16.6 and at the end 17.3 for the family system and 4.7 and at the end 6.2 for dual purpose. Regarding milk quality in the somatic cell count (SCC), the results for the family system were 452,000 in the 2021-2022 cycle, decreasing to 395,000 in the 2023-2024 cycle. In the case of dual purpose, it has not been possible to evaluate the results since the producers do not implement this management in the long term. In family dairy farming, the practice of using bioinputs for the fertilization of pastures or crops to produce the ingredients to prepare the concentrate for animal feed, as well as the use of bioinsecticides, is not a common practice in the family dairy production system. Regarding the implemented technologies, the following stand out: Good management practices in milking in 99.8% of the UPP, the California test and the black cloth test for mastitis were implemented in 49.78% in the family production system. In the reproductive area, the Diagnosis of pregnancy by rectal palpation, the Use of sexed semen and the synchronization protocols for insemination at a predetermined time were implemented. The use of records was promoted in 100% of the producers, its practice implemented in 57%, likewise this was only for the family production system.

5. Conclusion

While it is true that the participating producers have been enthusiastic and have contributed to the establishment of more than 5500 Farmer Field Schools throughout Mexico, and that the technicians responsible for providing technical support for this program have done their job well, the data suggests that there is no significant difference between agroecological and conventional production. Therefore, the real challenge is how to feed Mexico's ever-growing population. It is true that traditionally it is important to support the most vulnerable, as is the public policy of the current administration, but it is also necessary to consider the 76% of the population living in large cities who do not produce food and who must be fed. We must also consider the inputs required by the processing industry, not just food self-sufficiency for a significant portion of the rural population. Agroecology is considered a good step, given that it is more resilient, more sustainable, and more environmentally friendly. However, it is also true that it does not guarantee sufficient production to feed 130 millions of inhabitants that we will soon be in Mexico, but the reduction in costs and the care for the environment is remarkable.

Author Contributions

PhD, Pedro Cadena Iñiguez, Researcher of the National Institute of Forestry, Agricultural and Livestock Research, Chiapas Central Experimental Field, technical lead for the project in question that gives rise to this document.

PhD, Rafael Ariza Flores Researcher of the National Institute of Forestry, Agricultural and Livestock Research, Iguala Experimental Field, co-lead of the project in question at the national level.

PhD, Lorena Jaqueline Gómez Godínez, Researcher, of the National Institute of Forestry, Agricultural and Livestock Research, National Center for Genetic Resources, B Researcher responsible for the microbiological studies presented in this article.

MSc. Karla Yuliana Cadena Pérez in Environment, Culture and Society. Independent research, social researcher responsible for the project's adoption and communication studies.

MC Eduardo José Cabrera Torres, Researcher of the National Institute of Forestry, Agricultural and Livestock Research, Chetumal Experimental Field, Quintana Roo, Researher Responsible for the Milk Program and the results of milk-related support initiatives across the Mexican Republic.

PhD, Jesús Uresti Gil, Researcher of the National Institute of Forestry, Agricultural and Livestock Research, Saltillo Experimental Field. Researcher esponsible for soil analysis results in the Mexican Republic.

PhD, Francisco Guevara Hernández Professor and Researcher, Autonomous University of Chiapas, Faculty of Agronomic Sciences, Campus V; Researcher collaborator on agroecology and soil microorganisms focused on maize and bean production.

PhD, René Pinto Ruíz Professor and Researcher, Autonomous University of Chiapas, Faculty of Agronomic Sciences, Campus V; Researcher collaborator on topics related to environmental livestock farming, forage, and soil microorganisms.

Conflicts of Interest

The authors declare no conflicts of interest regarding the publication of this paper.

References

[1] Enciso-Sánchez, C. (2023) Programa Producción para el Bienestar. Evolución y logros de los apoyos productivos directos. En: La Agroecología como eje trans-formador en el Campo mexicano. Coordinador: Instituto de Estudios para el Desarrollo Rural Maya, A.C., 42-44.

[2] Secretaría de Agricultura y Desarrollo Rural (2025) La agroecología es el presente para el campo. Secretaría de Agricultura y Desarrollo Rural. https://www.gob.mx/agricultura/articulos/la-agroecologia-es-el-presente-para-el-campo?idiom=es

[3] Instituto de Estudios para el Desarrollo Rural 'Maya', A.C., Secretaría de Agricultura y Desarrollo Rural, Subsecretaría de Autosuficiencia Alimentaria and Instituto

Nacional de Investigaciones Forestales, Agrícolas y Pecuarias (2023) La agroecología como eje transformador en el campo mexicano (Primera edición). 381 p.

[4] Cadena-Iñiguez, P., Rodríguez-Hernández, R.F., Zambada-Martínez, A., Berdugo-Rejón, J.G., Góngora-González, S., Salinas-Cruz, E., Morales-Guerra, M. and Ayala-Sánchez, A. (2013) Modelo de gestión de la innovación para el desarrollo económico y social en áreas marginadas del sur sureste de México (Libro técnico N° 10). Secretaría de Agricultura, Ganadería, Desarrollo Rural, Pesca y Alimentación; Instituto Nacional de Investigaciones Forestales, Agrícolas y Pecuarias; Centro de Investigación Regional Pacífico Sur; Campo Experimental Centro de Chiapas. 156 p.

[5] Cadena-Iñiguez, P. (2015) Las Escuelas de Campo (ECA): Una estrategia de trabajo para zonas de alta marginación en México. In: Aguilar Ávila, J. and Santoyo Cortés, V.H., Eds., *Modelos Alternativos de Capacitación y Extensión Comunitaria*, Editorial Clave/CIESTAAM, 141-160.

[6] Morales-Guerra, M., Hernández-Galeno, C. de Á. and Vásquez-Ortiz, R. (2015) Escuelas de campo: Un modelo de capacitación y acompañamiento técnico para productores agropecuarios (Folleto técnico No. 48). Instituto Nacional de Investigaciones Forestales, Agrícolas y Pecuarias, Centro de Investigación Regional Pacífico Sur, Campo Experimental Valles Centrales de Oaxaca, 37 p.

[7] Pérez, K.Y.C., Iñiguez, P.C., Flores, R.A. and García, M.Á.C. (2022) Agroecological Farming, Climate Change and Migration in Marginalized Areas of Mexico. *Brazilian Journal of Animal and Environmental Research*, **5**, 2061-2074. https://doi.org/10.34188/bjaerv5n2-048

[8] Guerra, M.M., Iñiguez, P.C. and Rejón, J.G.B. (2022) The Field Schools in the National Institute of Forestry, Agricultural and Livestock Research. *Brazilian Journal of Development*, **8**, 77025-77035. https://doi.org/10.34117/bjdv8n12-018

[9] Iñiguez, P.C., Guerra, M.M., Hernández, R.R., Rejón, J.G.B. and Flores, R.A. (2024) Contribution of Field Schools to Extensionism in Mexico. *Brazilian Journal of Development*, **10**, e70875. https://doi.org/10.34117/bjdv10n6-078

[10] Altieri, M. and Nicholls, C. (2010) Diseños Agroecológicos para incrementar la biodiversidad de entomofauna benéfica en agroecosistemas. Sociedad Científica Latinoamericana de Agroecología (SOCLA). https://tierrasagroecologicas.es/items/disenos-agroecologicos-para-incrementar-la-biodiversidad-de-entomofauna-benefica-en-agroecosistemas/

[11] Venegas-Carlos, V., Bárbara Gómez, M., Agustín Infante, L. and Raúl Venegas, V. (2018) Manual de transición agroecológica para la agricultura familiar campesina. Instituto de Desarrollo Agropecuario de Chile. Organización de las Naciones Unidas para la Alimentación y la Agricultura (FAO). 29.

[12] Guadarrama-Zugasti, C. and Trujillo-Ortega, L. (2019) Revisando el enfoque evolutivo de la transición agroecológica. In: Lopes do Carmo, D., Silva Pereira, D., da Silva Miguel, E., Oliveira Lopes, S. and Eloiza Priore, S. Eds., *Pesquisa em Agroecologia*: *Conquistas e Perspectivas*, Editora UFV/Funarbe, 29-43.

[13] FAO (2023) Qué es la agroecología? Centro de conocimientos sobre agroecología. Organización de las Naciones Unidas para la Alimentación y la Agricultura.

[14] Gliessman, S.R., Guadarrama-Zugasti, C., Mendez, V.E., Trujillo, L., Bacon, C. and Cohen, R. (1998) La Agroecología; un enfoque sus-tentable de la agricultura ecológica. Lectura Nº 2-1 del módulo de trabajo personal: Programa interuniversitario oficial de posgrado: 5. Agroecología. Un enfoque sustentable de la agricultura ecológica (Stephen Gliessman *et al.*).pdf https://www.ucm.es/data/cont/media/www/%20pag-104576/5.%20Agroe-

colog%C3%ADa.%20Un%20enfoque%20sustentable%20de%20la%20%20agricultura%20ecol%C3%B3gica%20(%20Stephen%20Gliessman%20et%20al.).pdf

[15] Toffler, A. (1980) La tercera ola. Plaza & Janés. 339 p.

[16] Schwab, K. (2016) La cuarta revolución industrial. Debate, 303 p.

[17] Comisión Mundial sobre el Medio Ambiente y el Desarrollo (1987) Nuestro futuro común. Naciones Unidas. Informe Brundtland, 427 p.

[18] Organización de las Naciones Unidas (2015) Transformar nuestro mundo: la Agenda 2030 para el Desarrollo Sostenible. Naciones Unidas, 40 p.

[19] Ross, F. (2019) Kate Raworth-Doughnut Economics: Seven Ways to Think Like a 21st Century Economist (2017). *Regional and Business Studies*, **11**, 81-86. https://doi.org/10.33568/rbs.2409

[20] Girard, P., Mercandalli, S., Berre, D., Andrieu, N., Bezner Kerr, R., Coe, R., *et al.* (2026) Starting Points of Agroecological Transitions in Africa: Why and How Farm Structure Matter. *Ecological Economics*, **249**, Article 109117. https://doi.org/10.1016/j.ecolecon.2026.109117

[21] Suárez Carrera, V. (2023) Autosuficiencia alimentaria con transición agroecológica en el México de la Cuarta Transformación. In: Instituto de Estudios para el Desarrollo Rural 'Maya', A.C., Ed., *La Agroecología Como eje Transformador en el Campo Mexicano*, Secretaría de Agricultura y Desarrollo Rural, Subsecretaría de Autosuficiencia Alimentaria and Instituto Nacional de Investigaciones Forestales, Agrícolas y Pecuarias, 24-34.

[22] Cadena-Iñiguez, P., Rodríguez-Hernández, R., Morales-Guerra, M., Rendón-Medel, R., Aguilar-Ávila, J. and Berdugo-Rejón, J.G. (2018) Management of Innovation for the Economic and Social Development of the Rural Production Sector in the Southeast Region of Mexico. *American Journal of Agricultural Science*, **5**, 35-43. http://article.aascit.org/file/pdf/8920875.pdf

[23] Cadena-Iñiguez, P., Morales-Guerra, M., Berdugo-Rejón, J.G., Zambada-Martínez, A., Rodríguez-Hernández, R.F., Ayala-Sánchez, A., Salinas-Cruz, E., Fernández-González, I. and Rangel-Quintos, J. (2012) Los pequeños agricultores también pueden… Modelo de innovación con competitividad en áreas marginadas. *Agroproductividad*, **5**, 3-9.

[24] Cadena-Iñiguez, P., Rodríguez-Hernández, R., Morales-Guerra, M., Berdugo-Rejón, J.G., Salinas-Cruz, E., Camas-Gómez, R., Guevara-Hernández, F. and Pinto-Ruíz, R. (2019) Model of Management for Innovation in Small Farmers of Latin America: A Successful Proposal. *International Journal of Agricultural Sciences and Natural Resources*, **6**, 1-7. http://www.aascit.org/journal/ijasnr

[25] Swanson, B.E., Bentz, R.P. and Sofranko, A.J. (1997) Improving Agricultural Extension: A Reference Manual. 3rd Edition, Food and Agriculture Organization of the United Nations, 220 p.

[26] Swanson, B.E. and Rajalahti, R. (2010) Strengthening Agricultural Extension and Advisory Systems: Procedures for Assessing, Transforming, and Evaluating Extension Systems (Agriculture and Rural Development Discussion Paper No. 44). World Bank.

[27] Secretaría de Economía (2024) Arroz: Intercambio comercial, importaciones y exportaciones, mercado y especialización. Data México and Gobierno de México.

[28] Alía-Tejacal, I. and Ambriz-Cervantes, R. (2025) Características de calidad, nutracéuticos, minerales y proximales de maíces nativos de México y sus tortil-las. Instituto Nacional de Investigaciones Forestales, Agrícolas y Pecuari-as-Secretaría de Agricul-

tura y Desarrollo Rural, publicación especial, 397 p. (en prensa) https://doi.org/10.34117/bjdv12n10-019

[29] Yılmaz, H., Doğan, H.G., Kan, M., Dağ, M.M. and Diallo, T. (2026) Adoption Dynamics of Agroecological Practices in Greenhouse Agriculture: Behavioral, Socio-Economic, Technological and Policy Perspectives. *New Medit*, **25**, 121-138. https://doi.org/10.30682/nm2602g

[30] Reyes-Sosa, M., Delgado-Ruiz, F., Guevara-Hernández, F., Velázquez-Ríos, I.O., Pinto-Ruíz, R. and Cadena-Iñiguez, P. (2025) Effects of Conservation Agriculture and Bioinoculation on the Microbiota of a Soil Cultivated with Maize. *Agro Productividad*, **11**, 129-135. https://doi.org/10.32854/g468cn69

[31] Chile-Bocourt, A., Alfaro-Ortega, O., Milanés-Soroa, J.E., Álvarez-Valdés, R. and Vázquez-Fonseca, D. (2026) Integración de agroecología y energías renovables para la eficiencia energética en agroecosistemas tropicales: Un estudio de caso en Artemisa, Cuba. *Revista INCAING*, No. 56, 18-29.

[32] Ariza-Flores, R. and Cadena-Iñiguez, P. (2025) Informe de Resultados Interpretación de Análisis de Suelos y Definición de Recomendaciones de Fertilización, Abonos Orgánicos y Fertilizantes Sintéticos. Informe interno. Secretaria de Agricultura y Desarrollo Rural, Instituto Nacional de Investigaciones Forestales, Agrícolas y Pecuarias, 33 p.

[33] Estrada Aguilar, J.A. (2023) La transición agroecológica avanza: Evaluación de microbiología de suelos, bioinsumos elaborados localmente y calidad nutracéutica del maíz producido con prácticas agroecológicas en las Escuelas de Campo. In: Instituto de Estudios para el Desarrollo Rural 'Maya', A.C., Ed., *La Agroecología Como eje Transformador en el Campo Mexicano*, Secretaría de Agricultura y Desarrollo Rural, Subsecretaría de Autosuficiencia Alimentaria and Instituto Nacional de Investigaciones Forestales, Agrícolas y Pecuarias, 48-50.

[34] Gómez Godínez, L.J., Arteaga-Garibay, R.I., Ruvalcaba-Gómez, J.M., Cadena Iñiguez, P. and Ariza-Flores, R. (2023) Evaluation of Microbiological Safety in Bioinputs Produced in Mexico. *Agro Productividad*, **10**, 259-270. https://doi.org/10.32854/agrop.v16i9.2681

[35] Sharma, I.P., Chandra, S., Kumar, N. and Chandra, D. (2017) PGPR: Heart of Soil and Their Role in Soil Fertility. In: Meena, V., Mishra, P., Bisht, J. and Pattanayak, A. Eds., *Agriculturally Important Microbes for Sustainable Agriculture*, Springer, 51-67. https://doi.org/10.1007/978-981-10-5589-8_3

[36] Hernández-Cruz, E., Gómez-Godínez, L.J., Cadena-Iñiguez, P. and Ariza-Flores, R. (2023) Comparación de medios de cultivo para la evaluación de desarrollo de raíces por Trichoderma spp sobre germinados de Phaseolus vulgaris. *XIII Reunión Nacional de Investigación Agrícola. Memoria*, Chihua-hua, 8-11 de noviembre de 2023, 153-155.

[37] Gómez-Godínez, L.J., Cortés, M.G.Q., Avendaño-Arrazate, C.H., Flores, R.A. and Iñiguez, P.C. (2025) Survey of Citrus Microbiome: Their Diseases and Management Aspects. In: Kumar, A., de los Santos Villalobos, S. and Solanki, M.K., Eds., *Fruit Microbiome*, Elsevier, 287-307. https://doi.org/10.1016/b978-0-443-33963-9.00001-6