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Genetic resources and product diversification in a transitioning coffee agroecosystem in Mecayapan, Veracruz, Mexico

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ABSTRACT

Objective: To analyze a coffee agroecosystem undergoing an agroecological transition —considered as an alternative for the efficient use and the conservation of resources— through an agroecological association design with three legumes and one cucurbit in coffee cultivation.

Design/Methodology/Approach: Collection and identification of genetic resources found in the agroecosystem; agroecological association design with three legumes and one cucurbit in a coffee crop; zig-zag soil sampling for physical, chemical, and biological analyses; data analysis using JASP software version 0.16.2.

Results: We identified 42 weed species with various uses within the coffee agroecosystem, as well as the criteria for the association of species according to use. The soil analysis showed a significant correlation between micronutrients and nitrogen-fixing bacteria. The boron variable also influences the growth of such bacteria.

Study Limitations/Implications: The results apply to the agroecological model in transition presented.

Findings/Conclusions: Agroecological transition in coffee agroecosystems is slow but contributes to improving soil conditions. It also allows for the reappearance of usable weed species. There is a significant correlation between boron and the development of nitrogen-fixing bacteria. Likewise, the physical properties of soil have a direct impact on the growth of such bacteria.

Keywords: agroecology, transition, agroecosystem.

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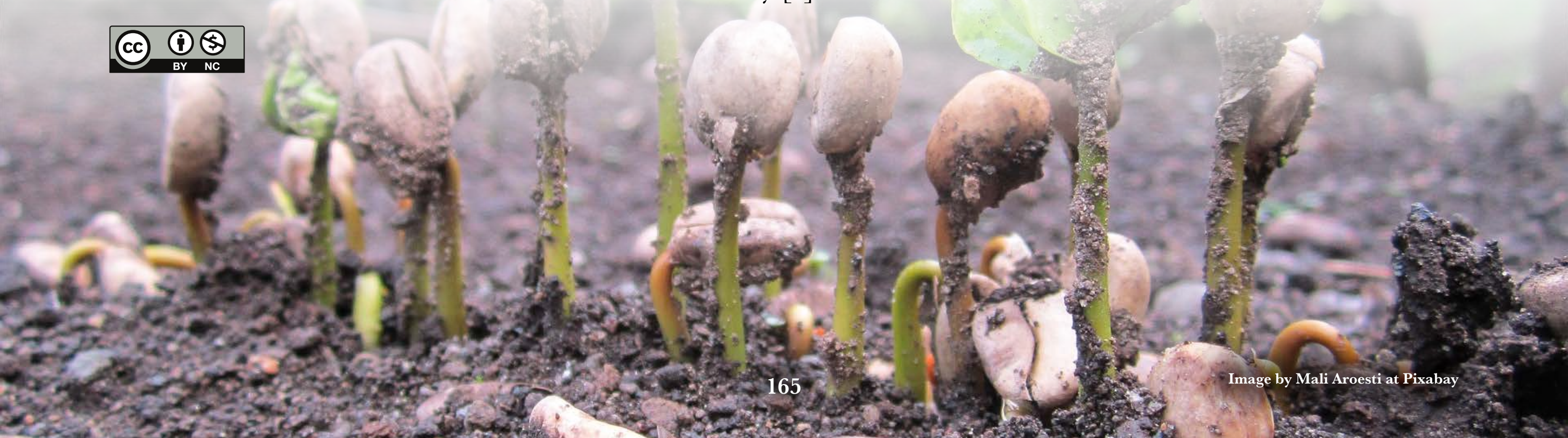
INTRODUCTION

Over the last decades, coffee agroecosystems have endured a bleak outlook as a consequence of the crisis caused by the drop in the price of grain in international markets. This situation led to the abandonment of farms and the appearance of diseases such as rust [1]. It also resulted in a change in land use to grow new crops, a process that, in its turn, caused the loss of biodiversity [2].



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Coffee-growing is a major activity in several indigenous regions of Mexico. Coffee has great economic, environmental, and cultural relevance in shaded agroecosystems. However, despite its wide biocultural and genetic diversity, the use of crop association is currently limited in the coffee-growing agroecosystems of Mecayapan, Veracruz. In this context, we must also take into account the drop in prices and the appearance of diseases, as well as the high production costs and the promotion of monoculture.

Agroecosystems can be defined as ecosystems "modified by human beings to a certain degree in order to use natural resources in production processes," satisfying food, fibers, medicine, and timber needs [3]. Agroecosystems aim to conduct agricultural activity in such a way that an efficient and sustainable production is achieved, adequately and fairly exploiting resources without exceeding their load capacity [4].

Agroecosystem design is based on local knowledge about the use, function, importance, and characteristics of species. This subject has been barely studied from an ethnobiological approach. Ethnobiology is based on peasants knowledge about the use, interactions, and reciprocal relations between nature and human beings. The dependence on technological packages, the pollution of aquifers, erosion, eutrophication, and loss of native germplasm of cultivated species have modified the operation and structure of agroecosystems [5]. For example, the loss of microorganisms affects ecosystems, because several processes depend on them, such as the cycle of C, N, and other nutrients, animal and plant health, and agriculture.

Agroecology seeks to "restore flows of energy and nutrients within ecosystems and agroecosystems to maintain a dynamic balance between their constituting elements" [6]. This approach goes beyond organic production. It is a transdisciplinary scientific effort that strives to bring together traditional and scientific knowledge to solve problems affecting specific environments. Therefore, it must consider any phenomenon relating to the management and use of natural resources [7]. According to Zambrano [8], as an interdisciplinary science, agroecology requires participatory processes that involve all parties; likewise, it needs to develop proposals that impact the social, economic, and productive spheres.

Therefore, agroecology proposes an analysis that allows us to conceive agroecosystem design as a response to rural problems, focusing on the production of healthy food through the implementation of peasant knowledge and organization structures [9]. Agroecology also entails reclaiming a vast lore guarded by communities about the use and management of local species [10].

Safeguarding biodiversity is essential to maintain the dynamic balance of agroecosystems. Their conservation requires the design of strategies that enable the study, protection, and adequate use of species, without exceeding their load capacity —for example, creating seed repositories. One of the multiple benefits of conservation is the upkeeping of whole sets of species, populations, communities, and ecological services within the agroecosystem [11]. Consequently, proposals that respond to productive, economic, and social needs should be developed. These proposals should be based on agricultural lore and its application to the diversification of coffee agroecosystems with local species.

MATERIALS AND METHODS

This work was conducted in a 2.5-ha plot transitioning towards agroecology, located in Mecayapan, Veracruz, Mexico. This region is inhabited by indigenous Nahuas and Popolucas, who typically practice agricultural activities in maize fields, coffee-growing, and, on a smaller scale, husbandry. Mecayapan is located in the Santa Marta Sierra, at 18° 13' 10.71" N and 94° 50' 14.36" W. It is adjacent to the municipality of Tatahuicapan de Juárez to the east and the municipality of Soteapan to the west. It has an altitude of 360 m.a.s.l. [12].

To conduct our research, we used two methods to identify the number of genetic resources that can be found in coffee agroecosystems undergoing ecological transition. We put in place a diversified design and carried out soil analyses to determine the correlations between physical, chemical, and biological parameters present in associations.

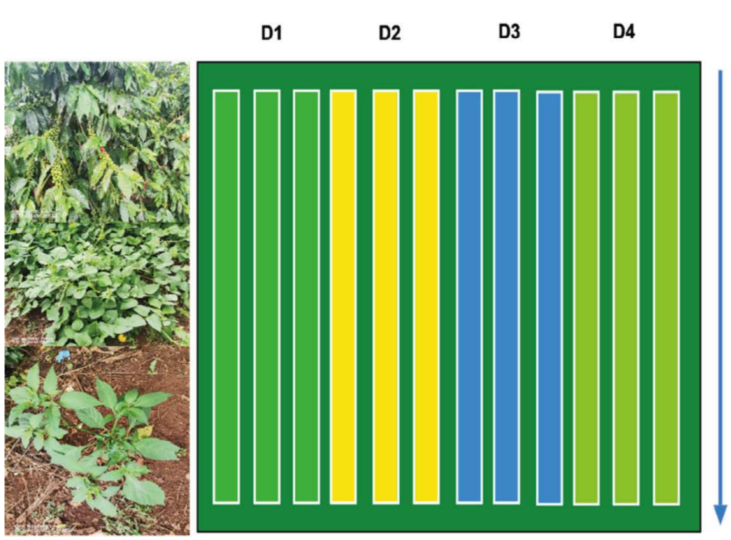
Collection of weeds. We collected plants to obtain a record of species diversity. We collected plants with flowers and subsequently spread them out on paper, in order to maintain their quality. Once each species was placed on a sheet of paper, we pressed and stored them [13]. Afterwards, the specimens were identified and grouped according to their environmental, social, and cultural use [14].

Agroecological design. We developed an agroecological design based on the interaction of three legumes (*Vigna unguiculata*, *Pachyrhizus erosus*, *Arachis hypogaea*), one cucurbit (*Cucurbita argyrosperma*), and native black and guajolotero maize (*Zea mays*) (Figure 1). Soil sampling surveys were conducted in 30 m × 10.20 m (length × width) growing blocks.

Count of free-living nitrogen-fixing bacteria (BFNVL). We used the viable count method by serial dilution ($1/10^4$), with 10 g of soil in a combined carbon culture medium [15].

Soil analysis. Composite samples were obtained for each agroecological design using a zig-zag sampling method. Initial and final soil samples were collected (1 kg per design).

Data analysis. The following parameters were taken into consideration: field capacity, permanent wilting point (PMP), hydraulic conductivity, apparent density, pH,



Design	Species in association
1	Coffee, corn and peanuts
2	Coffee, corn and beans
3	Coffee, corn and pumpkin
4	Coffee, corn and jícama

Figure 1. Coffee agroecosystem design with native species.

total carbonates, organic matter (OM), P-Bray, K, Ca, Mg, Na, Fe, Zn, Mn, Cu, B, and N-NO_{3-}. They were analyzed before and at the end of cultivation, estimating the percentage variation of each property by association. Statistical data were analyzed with JASP software version 0.16.2, using a Pearson linear correlation.

RESULTS AND DISCUSSION

Agroecological transition models have been promoted as an alternative to face high production costs. Model diversification has also been presented as a biodiversity conservation strategy. Their goal is to seek efficient exploitation and use of local resources by changing some production paradigms and giving priority to the potential relations between individuals within the agroecosystem.

Genetic resources in the transitioning agroecosystem

A total of 42 plant species, grouped into 25 families, were identified at the Mecayapan coffee plantation undergoing an agroecological transition. Fabaceae, Asteraceae, Euphorbiaceae, and Poaceae are some of the most abundant families in the region (Table 1).

The use value of all species in the study area were classified as follows: twelve can be used as green matter (incorporating them into the soil); nine species have various uses; eight are edible; six are used as cover crops to protect the soil and control other weeds; and four have medicinal use, mainly as antiseptics, diuretics, and treatment for intestinal and urinary infections (Table 2).

Use level is distributed into four main categories:

Environmental: Species used as cover crops for soil protection and species pruned and mixed as organic matter into the soil.

Environmental-economic: Species used for shade that also have other uses (*e.g.*, firewood, fodder, medicine, and food).

Social: Edible species.

Cultural: Species used for medicinal, artisanal, and culinary purposes.

Identified species are sorted into three main groups according to their usable parts: leaves, the whole plant, and fruits (Table 3).

In agroecological transition models, a natural process of biotic regulation takes place, contributing to the appearance of various species that had been disturbed by the use of synthetic products or by some other activity [16]. Associated crops within these models allow for more interaction between species. The number of weeds in the agroecosystem plays an important environmental role, since weeds tend to grow in disturbed soils and are considered indicators of soil health [17].

Traditional association in coffee agroecosystems responds to the need to improve production and allows producers to obtain other valuable products. Coffee systems may include timber, fruit-bearing, edible, medicinal, ornamental, and construction species. There are also double-purpose species that provide a product and fix atmospheric nitrogen, thus contributing to the improvement of soil [18]. A relevant criterion for

Table 1. Frequencies per amount of species/family.

Species/families	Frequency	Percentage	Valid percentage	Accumulated percentage
Asteraceae	3	7.143	7.143	7.143
Boraginaceae	1	2.381	2.381	9.524
Amaranthaceae	1	2.381	2.381	11.905
Brassicaceae	1	2.381	2.381	14.286
Chochlospermaceae	1	2.381	2.381	16.667
Convolvulaceae	1	2.381	2.381	19.048
Cucurbitaceae	1	2.381	2.381	21.429
Cyperaceae	1	2.381	2.381	23.810
Dennstaedtiaceae	1	2.381	2.381	26.190
Euphorbiaceae	3	7.143	7.143	33.333
Fabaceae	8	19.048	19.048	52.381
Fagaceae	1	2.381	2.381	54.762
Iridaceae	1	2.381	2.381	57.143
Leguminosae	1	2.381	2.381	59.524
Lygodiaceae	1	2.381	2.381	61.905
Malpighiaceae	1	2.381	2.381	64.286
Malvaceae	2	4.762	4.762	69.048
Marantaceae	1	2.381	2.381	71.429
Oxalidaceae	2	4.762	4.762	76.190
Passifloraceae	1	2.381	2.381	78.571
Plantaginaceae	1	2.381	2.381	80.952
Poaceae	3	7.143	7.143	88.095
Rubiaceae	2	4.762	4.762	92.857
Solanaceae	2	4.762	4.762	97.619
Vitaceae	1	2.381	2.381	100.000
Total	42	100.000		

Table 2. Use frequency of genetic resources found in the agroecosystem.

Use	Frequency	Percentage	Valid percentage	Accumulated percentage
Edible	8	19.048	19.048	19.048
Medicinal	4	9.524	9.524	28.571
Handicraft	3	7.143	7.143	35.714
Cover	6	14.286	14.286	50.000
Firewood, forage, medicinal, edible	9	21.429	21.429	71.429
Organic matter	12	28.571	28.571	100.000
Total	42	100.000		

Table 3. Usable parts frequency.

Usable part	Frequency	Percentage	Valid percentage	Accumulated percentage
Leaves	15	35.714	35.714	35.714
Fruit	6	14.286	14.286	50.000
Root	1	2.381	2.381	52.381
Bole height	3	7.143	7.143	59.524
Leaves and seeds	2	4.762	4.762	64.286
Whole plant	15	35.714	35.714	100.000
Total	42	100.000		

crop association is avoiding direct competition for light and nutrients among the species. When they first establish the associations, coffee producers at Mecayapan take into account this criterion.

Analysis of physical, chemical, and biological parameters in soils with crop association

Twenty-one variables were studied using the JASP software. The soil analyses provided results for five physical parameters and 16 chemical parameters that enabled the identification of important variables for the further development of BFNVL. There is a strong correlation between the saturation point (Figure 2a) and PWP regarding the growth of BFNVL (Figure 2b). Regarding peanut, corn, and coffee association, the following decrease percentages were recorded: saturation (5.71%), field capacity (5.59%), and PWP (5.38%). These decreases could affect the biological activity of the soil.

The P-Bray results show a significant positive correlation with BFNVL —*i.e.*, the higher the amount of P-Bray, the greater the development of BFNVL (Figure 2c). In the peanut, corn, and coffee association, a 558% decrease was observed. Growing peanuts requires high P and K contents. This crop exhausts the said elements, resulting in a decrease [19].

B has a strong correlation with the development of biological activity, in this case, BFNVL (Figure 2d). In this study, the rest of the parameters did not have a significant correlation ($p \geq 0.05$) with the development of BFNVL.

Most macronutrients had a significant positive correlation (Figure 3a) —*i.e.*, the greater the number of macronutrients, the greater the biological activity [20]. However, the peanut, corn, and coffee association in this analysis recorded the highest decrease in macronutrients (234.9%), as a consequence of the nutritional requirements of the crop [21].

Micronutrients showed a moderate, but not significant, correlation with BFNVL (Figure 3b). These variables play a key role in the increase of the number of bacteria in the soil. The various associations in which the initial and final amounts of micronutrients showed a decrease include squash, corn, and coffee (71.2%) and peanut, corn, and coffee (51.8%). The highest percentage of macronutrient extraction occurred in the peanut, corn, and jicama association (234.9%).

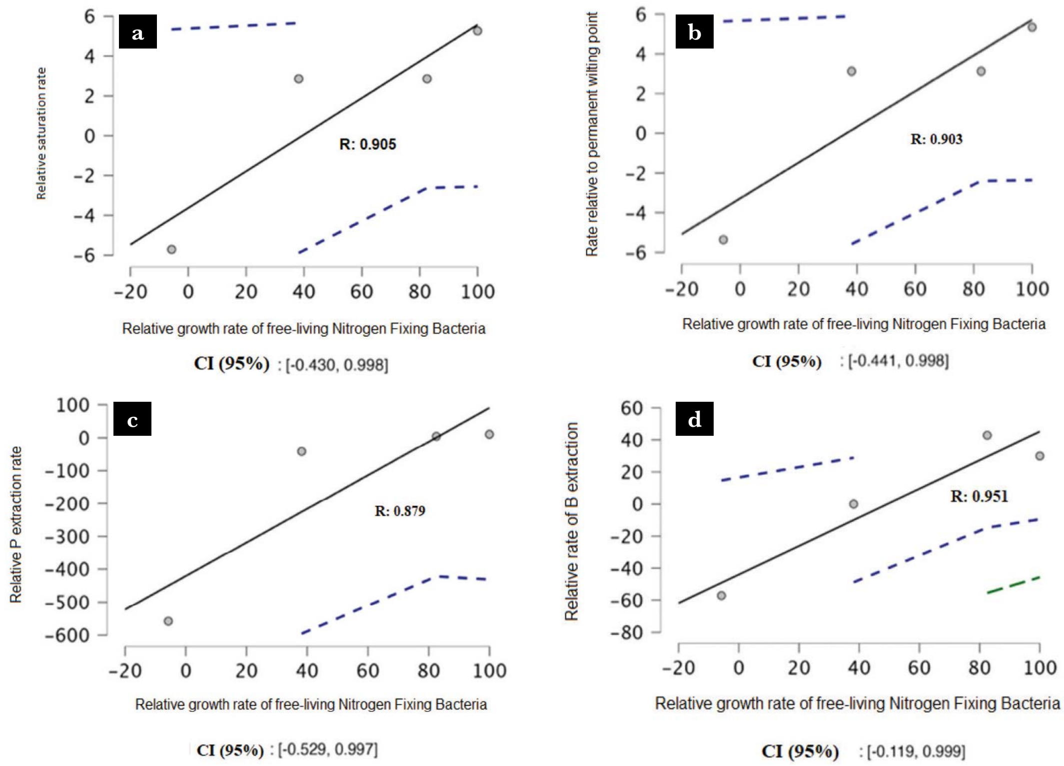


Figure 2. Diagram of the correlation between free-living nitrogen-fixing bacteria (BFNVL) and the degree of variation of the saturation point (a) and permanent wilting point (PWP) (b), Bray phosphorus (P-Bray) (c), and boron (d), at the beginning and end of cultivation.

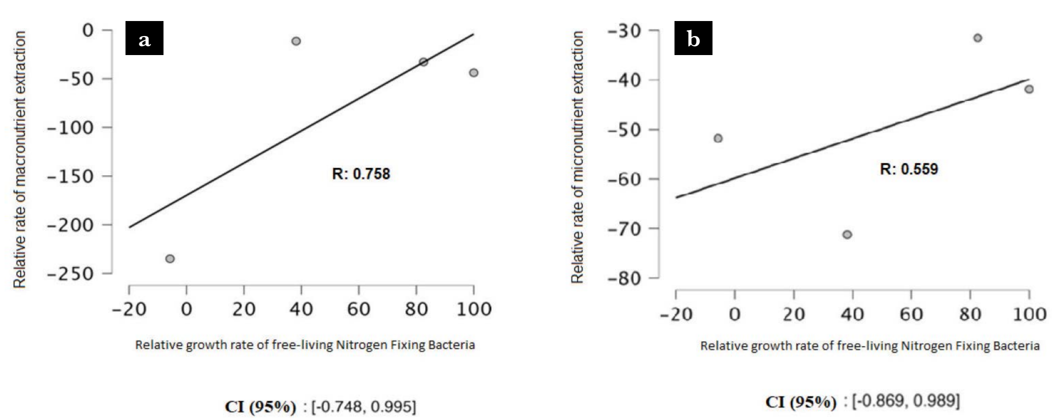


Figure 3. Diagram of the correlation between free-living nitrogen-fixing bacteria (BFNVL) and the degree of variation of macronutrients (a) and micronutrients (b), at the beginning and end of cultivation.

The association that caused the greatest modification to physical properties was jicama, corn, and coffee (37.3 %). Meanwhile, the same association extracted the highest amount of pH, carbonates, and CE (1,614.7 %).

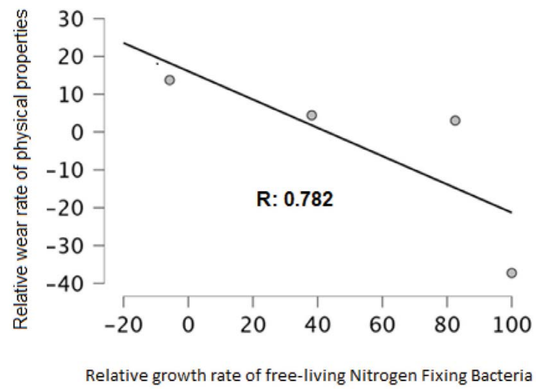


Figure 4. Diagram of the correlation between free-living nitrogen-fixing bacteria (BFNVL) and the degree of decrease of physical properties, at the beginning and end of cultivation.

CONCLUSIONS

The use of agrochemicals in this coffee agroecosystem was suspended three years ago. This situation has contributed to the reappearance of edible, medicinal, and artisanal use species, thereby increasing the diversity of local flora and fauna.

To establish a diversified association model for agroecological transition, the nutritional requirements of the species involved must be taken into consideration, since many of them extract macro and micronutrients from the soil, which in turn leads to degradation by absorption.

The beans, corn, and coffee association absorbed the lowest percentage of micro and macronutrients.

B is a micronutrient that has a strong correlation with BFNVL and directly impacts their development.

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