Chapter 5

The Cacao Agrosystems in Tabasco, México

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Abstract

The cacao agrosystems are very suitable for reforesting completely cleared areas and can become biological corridors between segments of the forest, allowing the repopulation of birds, mammals, reptiles, and amphibians, among others. Cacao (*Theobroma cacao* L.) is one of the most important tropical crops both nationally and internationally. However, by appropriate management of cacao crops and the inclusion of aggregate values in forest, fruit, vegetables, and ornamental production, as organic cultivation, specific varieties of plants could generate significant income for small producers in the Southeast from Mexico. This cacao agrosystem is involved in erosion, soil fertility, plant nutrition, water quantity and quality, carbon sequestration, reduction of greenhouse gas emissions, and soil biodiversity.

Keywords: agroforestry, nutrient, organic, soil chemical properties

1. Introduction

Currently, global challenges such as deforestation, indefensible cultivation practices, loss of flora and fauna, greater risk of climate alteration, as well as the intensification of food shortages, poverty and malnutrition, can be observed and investigated [1]. Proper selection of trees and crop species helps meet wood demand, increase yield, soil fertility, promote sustainability and adequate efficiency of natural resources [2]. The cultivation of cocoa interspersed with tree species and high-density short rotation can be the best option to meet the growing requirements of raw materials for food and industry through the sustainability of natural resources [3].

The agroforestry systems of cacao in Tabasco (Mexico) is an ecological agricultural alternative, economically feasible, sustainable, and conservation of natural resources in the simultaneous preservation of forests and jungles. Given that *Theobroma cacao* is a shade-tolerant plant, this

Figure 1. The cacao agroforestry systems in Tabasco (México).

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production system manages genetic diversity of ecosystems in southern Mexico, Tabasco [4]. The objective of this review is to conduct a current investigation of the state of the art of cocoa agrosystems in the state of Tabasco, Mexico.

1.1. *Theobroma cacao* L

The *T. cacao* is a member of the Malvaceae family and is a neotropical species that originated in southern and central Mexico. It is widely grown in more than four countries in the humid tropical regions (Tabasco, Chiapas, Oaxaca, and Veracruz). Cocoa beans are used for chocolate, sweets, and drinks. The cacao pods (fruits) grow mainly on the tree trunk. Photo assimilates are translocated from source organs (leaves) to sink organs (pods) through a long-distance phloem pathway.

Based on the morphological characteristics and geographical origins, three main genetic groups have traditionally been defined within cocoa: Criollo, Forastero, and Trinitario. Trinitario has been recognized as a hybrid "Criollo × Forastero." Recently, molecular markers and chromosome analysis have been used to classify cocoa germplasm into 10 main groups: Amelonado, Contamana, Curaray, Guayana, Iquitos, Marañón, Nanay, Purús, Criollo, and Nacional [5]. The genomes of Criollo and Amelonado have been sequenced and cover 76 and 92% of the estimated genome size, respectively [5, 6].

These genomes are important for research in genetic characterization, phylogenetics, and viability. Tabasco is a state of the Mexican Republic located in the southeastern part of the country (Mexico), with 17 municipalities of which three are the largest producers of cocoa with the agroforestry system: Comalcalco, Cunduacán, and Cárdenas (**Figure 1**). It has a tropical humidity climate, with temperatures ranging from a minimum of 17°C to a maximum of 42°C, with a rainfall of 2000 mm per year and a relative humidity of 90%. The topography is generally flat and low and is covered to a large extent with lakes, lagoons, and wetlands [4]. These biotic and abiotic conditions have favored the agroforestry systems in the production of cocoa of the three groups Criollo, Forastero, and Trinitario, at the same time, an increase in the fertility of the soil, micro- and macroorganisms, conservation and together with the sustainability.

2. The cacao agrosystems

Diversification, efficiency in land use, climate change, sustainability, and permanent vegetation cover are important elements of agroforestry systems, which play an important role in adapting to climate change [7–10]. Agrosystem has been recognized as a process in agriculture as an innovative and promising way to reduce the concentration of atmospheric CO_2 by replacing fossil fuels in the Kyoto Protocol [11].

Tabasco is the first producer of cocoa under agroforestry systems, Mexico. It is mentioned as a green and economically viable alternative with the concurrent conservation of forest remains and economic services (**Table 1**). In this state, two typical systems of cocoa

State	Surfaces (Ha^{-1})		Production (T^{-1})	Performance (T/H^{-1})
	Seeded	Harvested		
Tabasco	40,887	40,668	6995	0.172
Chiapas	16,782	15,280	3947	0.259
Guerrero	250	79	24	0.307

Source: https://www.gob.mx/siap [12].

Table 1. The producing states of *Theobroma cacao* in Mexico under agroforestry system [12].

production are managed: (1) traditional farming system, where cocoa plantations are implanted under forests or natural forests, and herbaceous, shrubby, and upper canopy individuals are eliminated to provide greater light input [13–15]; and (2) cocoa plantations are established in areas where the entire forest or native has been removed and replaced by a single forest species and the cocoa plants are shaded with banana and other crops such as cassava and corn as a provisional shade until forest species provide sufficient shade [13, 16, 17].

Environmental performance in cocoa production as monoculture and agroforestry through life cycle assessment based on ISO 14040 and 14044, with adaptation for local impact indicators. The analysis considered cocoa production at the farm level, from field establishment to the limit of the cocoa crop. The results showed that agroforestry has the smallest contribution to the categories of global impact of global warming, acidification, and eutrophication, which represent carbon dioxide (3.67E+01 kg CO_2^-), sulfur dioxide (4.31E−02 kg SO_2^-), and phosphate (2.25E−05 kg PO_4^-), respectively [18].

Agroforestry with cacao and monoculture of cocoa also had the highest amount of organic carbon and organic matter in the soil, conditions that favor the growth and activity of beneficial microorganisms for the soil rhizosphere (*Pseudomonas* sp. and *Trichoderma* sp.) [19]. In addition, this cocoa agroforestry system had the highest value at 1.36 tons per hectare, as compared to the monoculture of cocoa that was below 1 ton per hectare. Therefore, this agroforestry system is a wise option to promote the environmental sustainability of cocoa crops associated with plant diversity [19].

Agroforestry is increasingly considered as an important adaptation and mitigation strategy against climate change. In particular, the use of fruit trees, trees, and shrubs has been promoted as a practice that contributes to improving soil fertility through nitrogen fixation and the use of macro- and beneficial microorganisms, by increasing the supply of nutrients for the production of crops. While much of the evidence on the impact of tree diversity is based on ranch experiments and correlation analysis, there is a paucity of rigorous evidence under the real conditions of small farmers. Research on the impacts of the adoption and the change of arboreal vegetation such as *Gliricidia sepium* and *Faidherbia albida* [19].

The producers in Malawi adopted the agroforestry system with cocoa and the changes of trees or shrubs of the legume type showed the increase in value to the different crops by 35%. It also had an impact on the disaggregation through stratification by land ownership revealing that farmers with smaller farms of up to 2 acres obtain the greatest benefits. In addition, the use of legume-type shrubs along with corn also significantly increased the value of food crops. This study offers preliminary ideas that contribute to an emerging field of research on the quantitative assessment of agricultural interventions, such as agroforestry practices using new analytical approaches. We provide some policy ideas and recommend the need to design future research on development initiatives that consider small-scale variation in the social, economic, and ecological context of farmers to improve their absorption and adaptation in order to take advantage of the full potential of the agroforestry to improve soil fertility and family food security [20].

2.1. The cocoa beans

Chocolate has been attributed to attainment of optimal human health and development due to its high content of flavonoids that are crucial in reducing the risk or delaying the development of cardiovascular disease, cancer, and other age-related diseases [21].

The production of chocolate had a great impact with the appearance of the diseases of "*Phytophthora,*" "*Ceratocystis fimbriata,*" "*Crinipellis perniciosa,*" and "*Moniliophthora roreri*" in the cocoa plants (**Figure 2**). To recover the production of cocoa, many hybrid plants resistant to diseases have been developed (**Figure 3**). However, some different cocoa hybrids produce

Figure 2. The healthy and diseased "*Moniliophthora roreri*" cocoa pod present in agroforestry systems.

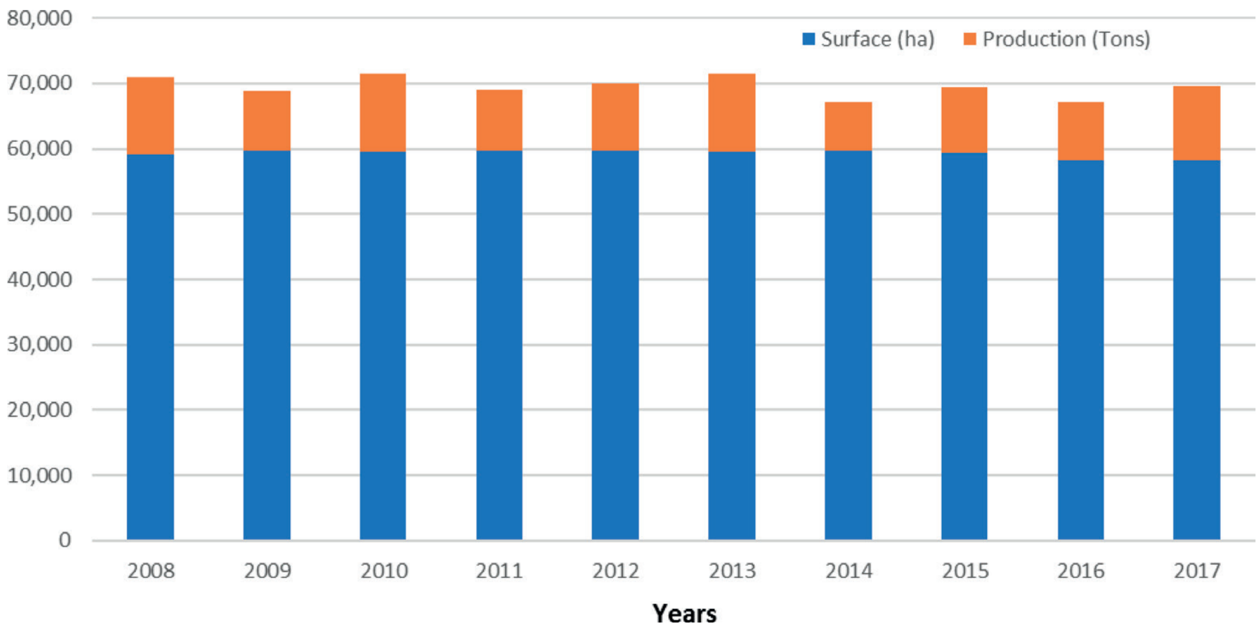

Figure 3. The surface area and production of cocoa in the state of Tabasco [21].

cocoa beans that generate chocolate with variable quality. The fermentation of cocoa beans is a microbiological process that can be applied to the production of chocolate flavor precursors, which leads to overcome the problem of the variable quality of chocolate [22]. The beneficial microorganisms in the use of cocoa production have influence on the microbial communities present in the fermentation process of the compounds involved during the fermentation and the sensory characterization of chocolate. In the bitter or semibitter taste, the use of microorganisms such as: *Saccharomyces cerevisiae*, *Lactobacillus plantarum*, and *Acetobacter pasteurianus* is proposed as starter cultures for the fermentation of cocoa.

Climate change can create serious problems for farmers by increasing the variability of rainfall, droughts, and floods. Understanding how to build the resilience of livelihoods for these purposes is a hallucinatory necessity. Agroforestry can be considered as a potential solution, although many people intuitively link agrosystems with livelihoods against floods and drought, there is little comprehensive empirical evidence. Agrosystems for small farmers can develop livelihood capacities for floods and drought: it is possible to adapt various strategies to climate change, but is crucial for small farmers, and agroecosystem can be a promising option to balance the main production of cocoa, which is mainly chocolate grains [23].

3. Soil chemical properties and nutrient

The soil of the agroforestry systems is enriched with the addition of litter in large quantities by the different plant species, which ultimately improves fertility in terms of organic carbon available from the soil to the plant and the participation of macro- and microorganisms in the soil. The processes of crushing, degrading, and transforming the available nutrients (N, P, and K) provide alternative sources of income and employment to the population of the rural areas that help in the economic systems [13, 24].

The fall of litter is an important input for the replacement of microbial substances in the soil and is one of the most essential ways to maintain soil fertility and quality of vegetable production with free of agrochemicals. The agroforestry system is a proven system of land use to vertically improve the health, quality, and microbial stability against unsuitable climatic conditions. This system contributes to increase the nutritional balance in the soil compared to the open system, that is, pH (7.9), EC (0.43 dSm^{-1}), available nitrogen (253.48 kg/ha), potassium (219.63 kg/ha), organic carbon (1.07%), and available soil phosphorus (22.72 kg/ha) [13, 24].

The spatial integration of land use for the management of soil fertility, soil health, economic services, crop quality, and the key factors that influence the integration of land conservation based on multipurpose agrosystems such as outputs and inputs in the process of agroforestry-cocoa integration and the use of agroforestry space lands have been discussed [13, 25–28].

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