AGROECOLOGY: AN ALTERNATIVE FOR FOOD SECURITY AND CONSERVATION OF BIODIVERSITY IN PUERTO RICO

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Received June 15, 2019; accepted October 15, 2019

Abstract - Increasing human population, geographic expansion and exploitation of natural resources have increased global biodiversity loss, putting food security at risk. In addition, extreme events such as hurricanes and droughts are environmental stressors that have put food security and often food quality at risk in Puerto Rico. Agroecology is a sustainable alternative that promotes the production of quality food and at the same time helps to reduce the impacts and environmental risks produced by traditional agricultural practices such as monoculture. This practice contributes to the economic, social, environmental and ecological value. This type of agriculture seeks to use ecological services and ecological interactions as tools for crop production.

Keywords: agroecology, food security, conservation, ecological systems biodiversity, ecological service

Resumen - El incremento de la población humana, la expansión geográfica y la explotación de los recursos naturales han aumentado la pérdida de biodiversidad global, poniendo en riesgo la seguridad alimentaria. En Puerto Rico, además, los eventos extremos como huracanes y sequías son estresores ambientales que han puesto en riesgo la seguridad alimentaria y muchas veces la calidad de los alimentos. La agroecología es una alternativa sustentable que impulsa la producción de alimentos de calidad, y a su vez, ayuda a disminuir los impactos y los riesgos ambientales producidos por la agricultura tradicional del monocultivo. Esta práctica aporta al valor económico, social, ambiental y ecológico. Este tipo de agricultura busca usar los servicios ecológicos y las interacciones ecológicas como herramientas de producción de cultivos.

Palabras clave: agroecología, seguridad alimentaria, sistemas ecológicos, biodiversidad, servicios ecológicos

Introduction

Globally the agriculture industry encounters many hurdles since the beginning of the global food revolution. Considering that, food security measures fall upon governments, farmers, and society as a whole, the joint effort of these groups could mitigate the exploitation of ecological services (Lang & Barling, 2012). All these impediments are in

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constant growth given the increase in human population, globalization and the environmental impact on biodiversity creating an array of consecutive and reoccurring hazards that affect our food security (Canchani, Espaillat, & Lopez-Colón, 2018). Nyantakyi-Frimpong et al. (2016) found a relation between food security, dietary diversity, agroecology and human health in particular how it affects patients with HIV.

The geographical expansion of human populations has caused more than 80% of land use to be devoted to agricultural practices that focus on monocultures, these monocultures, high land-use decrease biodiversity, and ecological spaces (Altieri, Nicholls, Henao & Lana, 2015). At the same time, this type of traditional agricultural practice, promotes the use of pesticides, herbicides and fertilizers.

Meanwhile the use of synthetic chemical agents in agriculture not only affects the land and becomes a pollutant, but also are precursors of respiratory diseases. Is important to consider the level of impact that these synthetic chemicals have on, such as neurotoxins in sensory, cognitive and behavioral development, which are neurodegenerative diseases that are apparent and expressed within our society. In the same way, different types of cancers like prostate, ovary, testicular, breast, cerebral, leukemia and Non Hodgkins (Kim, Kabir, & Jaham, 2017; Sarat, Sharma, Parween, & Patanjali, 2018) are exacerbated by traditional agricultural practices and risk factors to human health (Figure 1).

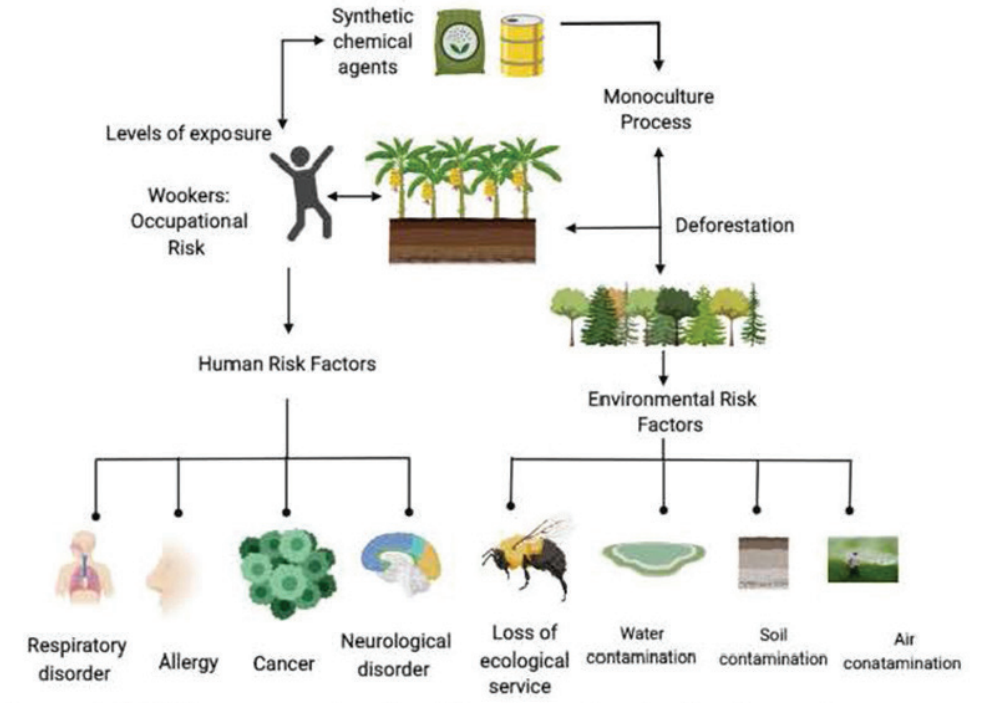

Figure 1. Risk factors associated with traditional agricultural practices

The impact that traditional agriculture has on the soil is strictly related to the change in the use of soil and its management. The substitution of forests and meadows transformed into agricultural lands, not only results in the fragmentation and loss of biodiversity in general, but also aids in the loss of naturally fertilized and biodiverse land. In regions of high agricultural development, where the management of terrain lacks a development plan taking into consideration the increase in percolation, erosion and nutrient loss which in turn amplifies exponentially the loss of organic matter and microbes (Ramankutty et al., 2018). Similarly, Tilman et al., (2018), suggested that species with medium and large sized bodies in the tropical region of Africa, Asia and South America, have a high risk of extinction due to the misuse of land and agricultural impact that affects their ecosystems. While biodiversity diminishes because of land use for agriculture, this practice may also stimulate an augmentation in rodent transmitted diseases, some examples of this are rabies and leptospirosis (Foley, Monfreda, Patz, & Ramankutty, 2012).

Agriculture contributes to 30% of the greenhouse gases produces globally, being this one of the main causes for climate change. According to World Resource Institute (2018), farms with agricultural value emit 6 gigatons (Gt) of greenhouse gases in 2011, and it is estimated that by 2050 the quantity emitted will increase to 9 Gt (1 Gt = 1000000000000 kg).

Biodiversity in species and all their interactions provide crucial functions indispensable for the enrichment of sustainable agriculture. Sustainable agriculture looks too become a self-sufficient community project, having the capacity of maintaining its productivity generating high quality products, reasonably priced, accessible to the buyer, promoting conservation of the adjacent ecosystems, supporting an effective sustainable management of soil and natural resources.

The ecological and economic value of biodiversity is provided by the interactions that occur inside the ecological networks correlating multiple species. An example of this are the benefits obtained by various pollinators like hymenopterans, birds, bats and in some cases biological controls for plagues that suppress the biomass of target species within agricultural land (Massol & Petit, 2013).

Agroecology focuses on applying ecology principles in agriculture accessing a socioeconomic dimensional analysis within the food system, as a sustainable alternative that takes into account the overall health of the farmland in terms of biodiversity, soil health, crop rotation and the mitigation or elimination of monocultures. These practices guarantee the conservation of natural resources, as well as food security. After extreme events in Puerto Rico occurred in 2017, our harvest was affected in terms of quality of products and supply. Starting from this concept of recovery after a natural disaster, we asked ourselves, if agroecology is a useful tool to guarantee the conservation of resources and food security for our island of Puerto Rico. Traditional agricultural practices represent a driving force to the loss of global biodiversity. Agriculture and biodiversity are factors that should be integrated and considered as viable alternative for food security and economic benefit. There exist many advantages that agroecology provides, such as conservation of species,

natural resources, and biodiversity being each one indispensable for the other creating all together a network of complex relations that are highly intertwined and interwoven.

Ecological systems: Resources for sustainable agriculture

Helms (2002) defined *forest* as an ecosystem characterized by the tree coverage with varying densities and extensive, that generally consists of stands that vary in characteristics for example; species, structure, composition, age classes and commonly including rivers, fish and nature. There exist different types of forests with different uses, industrial, public, protection, urban like parks and nature, mainly to manage unique products, diverse or specific values.

Tropical forests benefit agriculture; they are a source of an incalculable amount of endemic plants (Wadsworth, 2000). The traditional agriculture models find themselves united by the fact that they put at risk forest health and biodiversity. One of the many examples of the effects that traditional agriculture practices have in forests are; loss of tree coverage/canopy, loss of biodiversity, loss of genetic diversity, disturbances in ecological systems, and acceleration of species extinction (Saragón & Flores, 2014). In the beginning of the 20th century between the second and third decade (1920-1930), Puerto Rico suffered from mass deforestation because of traditional agricultural practices. Once Puerto Rico became industrialized, agriculture went on to becoming a secondary economic source, agriculture zones began once more to reforest themselves naturally, becoming what we consider today, secondary forest (Grau et al., 2003; López-Colón, 2017). Disregarding the importance that biodiversity had in correlation with agriculture, providing genetic resources and ecological services, traditional practices became the negative anthropogenic activity dwelling against biodiversity in the island.

The amount of productivity that agricultural land possess is directly and indirectly influenced by the interactions that agricultural practices, abiotic conditions and ecological services provided by the surrounding ecosystems. The two main ecological services that contribute to the food security and the production of crops are pollination and biological control of diseases. Classen et al. (2014) demonstrated that in *Coffea arabica* (Rubiaceae) crop cultivation zones are influenced by the ecological services integrated from the predators of disease and pollinators that increase productivity in the crop of great economic importance in the tropics. In high agriculture activity systems, there can be abrupt changes in the composition of pollinators, altering the ecological service provided. Within the coffee crops of Nicaragua, agroecology is a valuable tool used for conservation of biodiversity in zones where coffee is produced as a shade-crop. In these areas of crop production, it is essential to evaluate the existing forest biodiversity given that by providing shade to other species the trees multiply the complexity and levels of biodiversity of a farm. The forest biodiversity stimulates ecological processes for nutrient recycle, genetic flow, energy flow and population controlling mechanisms typical to tropical forests as shown in Table 1 (Méndez & Bacon, 2007). Philopott et al. (2008), in a comparative study, found that richness of species of ants, birds and trees is directly affected by intense traditional agriculture and management of coffee implemented as a sun-crop. Having concluded that rustic systems of agriculture are

not viable alternative for biodiversity conservation within the coffee habitats.

Table 1

Methodologies implemented in the management of an agroecological system

Biointensive beds	Cultivation beds with loose soil at an approximate depth of 60cm where the roots of the plants grow in a balanced way, provide a constant amount of nutrients and the water can move freely.
Sowing to the contour	Used for planting on slopes and mountainous areas. An "A" instrument is used to search and trace the level of the slope, marking the distance between tree and tree. Controls soil erosion on slopes, making better use of water, allowing it to not fall into strong runoff and nutrients are not lost.
Organic fertilization	Provides supply of nutrients (macronutrients and micronutrients) for the development of plants from decomposition processes of organic residues of animal origin (poultry manure, cow dung, and horse) and vegetable (compost). It serves as an energy source for soil microbiota, increases moisture retention, and improves soil bio-structure and root growth.
Crops Association	It is a low cost and highly effective technique to increase the production of the planting. Reduces the use of machinery, prevents soil compaction, infiltration of water into the soil is slow allowing moisture to be retained, incorporates organic matter continuously, produces exchange of nutrients and helps reduce the evapotranspiration of the agricultural system.
Crops rotation	Consists of planting different crops to maintain soil fertility. They should be rotated by integrating the plant architecture and root differentiation with nutritional needs. This technique supports keeping the soil open by promoting biological balance, decreasing the cycles of pests and diseases, allowing a better use of the area of the crop and generating a minimum cost of production.
Leaf litter	Coverage of dry leaves which when falling to the ground are incorporated as organic waste depositing nutrients to the soil. Maintains humidity, and temperature.
Stubble	Residues and post-harvest organic waste (stems, branches, firewood, leaves) these are cut deposited on the ground. This type of decomposing organic matter provides and retains moisture in the soil and deposits nutrients in its decomposition process.

Therefore, it is of great importance to; know about the ecological services that species provide associated with these areas of agricultural production, and to establish strategies of management that will become key for their conservation and to create a balance between biodiversity of species that provide these ecological services and agricultural processes. Studies conducted in Argentina revealed that the management of agricultural land could cause the quality of pollination services to diminish therefore affecting mainly the native plants. With the driving for the need for pollinators comes the introduction of exotic species, increasing in abundance the inflorescence of plants and their interactions with exotic pollinators like *Apis mellifera* (Marrero, Medan, Zarlavsky, & Torreta, 2016).

Agroecology: Biodiversity within an agroecosystem

Within a natural ecological system, the soil embodies an important role. On the other hand, soil fertility is maintained stable through biogeochemical cycles, nutrient recycling and reestablishment of organic material (Jeavon & Cox, 1999).

Agroecology creates the base for the development of sustainable agriculture (Gliessman, 1997); it is one alternative to ensure a food system with the global changes (Weel et al., 2009).

Figure 2. Comparative between agroecological crop vs monoculture crop

It is a system of production in which it is possible to imitate natural interactions found in natural environments for example, forests (Hecht, 1995). The relationship that exists between agriculture and nature looks to find a way to sustain and maintain the other. Agroecological systems are a tool that replace synthetic and organic introductions. Agroecological systems focus their efforts in the adoption of management practices capable of starting ecological processes (Figure 2) that are favorable for productive execution, environmental integrity and economic efficiency in agricultural work (Gianella-Estrems, Maza, & Pinzas, 2007).

Agricultural exploitation and use of terrains throughout decades have supported economic development and food security globally; yet it has been a factor in environmental risk for biodiversity, species richness and interactions by exploiting their natural habitats. The tropical agricultural lands are distinguished for great mosaics formed by medium farms, small farms, forest fragments all intertwined. Given that, these characteristics developed are practices implemented for conservation based on solid ecological theory in which the idea is the inclusion of different social sectors (Perfecto & Vandermeer, 2008). In this way, we could guarantee food security and conservation of biodiversity (Hanspach et al., 2017).

Diversity in ecological services within agricultural systems are essential because it is a way to satisfy basic needs of humanity, such as food security and the use of sustainable resources. In addition, agroecology involves many diverse sectors. This practice looks to form alliances so that farmers can have better access to agroecological knowledge, good soil management, sustainable agriculture practices, governmental services, and markets where they can sell their products. A market in which the farmers can display their products and in this way help to untangle the complex industrialized food production and establish agroecological alternatives that satisfy the needs of the consumer, while also conserving ecosystems (Altieri &Toledo, 2011).

Indisputably, the agroecosystem has an important role in the conservation of biodiversity with better management and practices the impact on species richness and interspecies interactions can be mitigated. Ecological intensification within an agricultural system is undoubtedly establishes as the midway point to make intensive and intelligent use of the characteristics and functionalities natural to the ecosystem to produce food, energy and ecological services in a sustainable way

Table 2
Advantages of agroecology for the conservation of natural resources and food

Protection	Shade trees protect plants for agricultural use (example: coffee) from strong winds, excessive light and soil erosion
Controller	Homogenize the temperature and humidity of the farm. Reduces use of chemical compounds, such as herbicides and insecticides by reducing the contamination of soil and bodies of water adjacent to the growing area
Services	Benefits before the quality of the food (example shade coffee). Ensure and guarantee the production of food, fiber, fuel, fodder. Contribution of wood, firewood, medicinal properties, fruit trees. Improve the recycling of nutrients through deep roots. They deposit leaf litter on the soil and surfaces. Increases native and endemic biodiversity. Reduces weed growth. Refuge for species such as birds, insects and bats Food resource for frugivorous species and seed dispersers. Allows adaptation to changing conditions, including climate change

(Tittonell, 2013). Theoretically, traditional agriculture involves many risks that impact ecosystem services including threatening the presence of many species, modifying interactions that are necessary in natural ecosystems as well as in agricultural processes. The concepts of agriculture and biodiversity should be integrated as one holistic vision that considers the use of land for a variety of ecological services (Noris, 2008). Diversity can increase profit according to the methods implemented in agricultural processes (Table 2). The biodiversification in areas destined for agricultural processes tend to be results from plague regulations from a natural restauration of insects, diseases, nematodes and the production of nutrient recycling and the conservation of the land through the dynamic microbes and their environmental implications that lead to conservation of energy and minimized dependency to outside intrusions (Altieri, 1999).

Ecological networks and their benefits towards agroecology

Mutual and antagonistic interactions have shaped biological diversity on the planet. Ecological interactions are of paramount importance for maintaining biodiversity and species richness in tropical ecosystems. Ecological networks are characterized by freedom scales; a node defines the species and the degree of nodes within the network describes the interaction that is occurring between species (Bascompte & Jordano, 2007). Mutual and antagonistic interactions in ecological networks trigger patterns that develop coevolutionary processes linked to two pressing combinations that are involved in these natural processes, coevolutionary complementarity and evolutionary convergence (Thompson, 1999), many aspects of plant and mutual agent and antagonist coevolution have major implications for biological controls, agriculture and conservation. Likewise, the mutual interactions between pollinators and plants contribute to the diversity of the silks (Tremblay, Ackerman, & Pérez, 2010). In fact, wild bees play an important role in many of the agricultural crops; in agroecological farms, the services of pollinators tend to increase the yield and the quality of the crop (Morandin & Winstson, 2006).

Plant species construct complex networks of interactions with their mutualists; for example, pollinators can be effective agents not only improving seed production but also improving pollen dissemination at population levels. Animals are also key players in

ecological networks, the reduction of animals within agricultural guilds and the size of the ecological network have a direct effect on seed dispersal and consequently on seedling recruitment (Donoso, Schleuning, & Fründ, 2017). Plant populations visited by effective pollinators tend to produce more fruit and seeds than populations visited by ineffective pollinators (Gómez, Perfectti, & Jordano, 2011). Similarly, seed dispersers are key pieces in ecosystems; seed dispersal interacts with all the factors influencing current changes in biodiversity: climate change, invasive species, fragmented habitats, and over-exploitation of natural resources, thus greatly influencing conservation practices (McConkey et al., 2012).

Antagonistic interactions are partnerships between organisms where one benefits at the expense of the other. (Soper & Adler, 2013) These associations involve interactions between herbivores and plants, parasites and hosts, frugivorous and fungi, and carnivores and animals, these organisms being able to obtain energy or nutrients from the surrounding environment. Futuyma & Agrawal (2009) stipulated that the interactions between parasites and their hosts and between herbivores and the plants serving as food sources are effective and specific to their hosts, these associations being phylogenetically conserve. Similarly, the diversity of herbivores, host plants and their respective adaptations involve diverse defense strategies, which can develop chemical and physical components that have arisen through coevolutionary processes.

Multiple abiotic factors can have great effects on a network of mutualistic and antagonistic interactions. Nutrients in the soil can infer and strongly influence individual interactions, increasing the proportion of antagonistic agents in floral visitors and leaves. (Soper & Adler, 2013). The strong interactions between plants with specific combinations of mutualist and antagonist agents tends to increase the diversity of species in a large network of ecological interactions supporting their spatial distribution (Melian, Bascompte, Jorno & Krivan, 2009).

Transition of the agriculture in Puerto Rico

The regulation of land use during centuries of agricultural development in Puerto Rico was very similar to that of other Caribbean and tropical countries. The lowlands were intensively used for sugar cane cultivation and, coffee cultivation was already exploited in higher lands in low quality soils that were used for short production periods (DRNA, 2015). In the late 1800s and early 1900s, forest cover in Puerto Rico was reduced to 6% due to the high intensity of agricultural production (Birdesey & Weaver, 1987). Between 1899 and 1934, agriculture in Puerto Rico represented 45% of the national gross product, while manufacturing represented only 7%. At the end of the Second World War and the beginning of the 1950s, the political structure changed, and the Commonwealth of Puerto Rico was founded. This change boosted industrialization by displacing agriculture. This economic change caused the population to migrate to urban areas and outside Puerto Rico, abandoning the agricultural lands in use, which allowed a large part of the island's vegetation cover to be restored (Grau et al., 2003).

In Puerto Rico, the focus on economic development at the state and international levels drives an integrated public policy that incorporates economic and social needs. Several laws and regulations protect, regulate and encourage agricultural activity in Puerto Rico. Article 60 of the Land Law of Puerto Rico considers a farmer to be a legal entity that directly or indirectly sows, cultivates or harvests agricultural products on land belonging to him or under his position or control dedicated to agricultural processes (ATPR, 1941). On

Figure 3. Traditional farm with soil erosion after Hurricane María in Adjuntas Puerto Rico

the other hand, Puerto Rico's Agricultural Contributive Incentives Act seeks to balance agricultural development with various economic sectors in order to generate sources of income and provide infrastructure services for agricultural sustenance. Seeking that the Puerto Rican population be oriented toward the consumption of local agricultural product to promote an economic-agricultural development. Furthermore, this law defines a "bona fide" farmer as any natural or juridical person who during the tax year for which he claims deductions, credits and other benefits, is certified by the Puerto Rico Department of Agriculture and is dedicated to the exploitation of agricultural activity (DAPR, 1995). This includes the use of herbicides, insecticides, and artificial fertilizers, which, by implementing this type of practice, put at risk the quality of the surrounding natural resources, the health of those who consume the harvested product, and become an occupational risk due to their exposure (Figure 3).

Currently in Puerto Rico, there are farms with agroecological uses; however, are minimal compared to traditional farms of bona fide farmers, and because the agricultural

processes are different, compared to a farm based on monoculture. For example, a traditional farm uses fertilizers, herbicides and pesticides; in an ecological farm, the soil is inoculated, the interactions of ecological networks are used to control plagues, and the crops are rotated to enrich the soil, and so on. It is a fact, that many consumers during the last decade has changed their food lifestyle preferring the use of ecologically friendly products, which are harvested under a system of sustainable agriculture, free of chemical and synthetic agents (colorants, preservatives, pesticides, herbicides and fertilizers). In order to meet the needs of these consumers and offer such products, the Puerto Rico Department of Agriculture created the Organic Products Law of Puerto Rico in 2003 (DAPR, 2003).

Conclusion and recommendations

Agroecology is a useful tool for food security, the consumption of healthy foods and guarantees in one way or another that supplies may exist after some extreme event such as hurricanes or fires on the island. The resilience of future farms depends on the measures taken for sustainable farming; the use of agroecology not only feeds current generations but also if implemented correctly can ensure a healthy sustainable environment that will feed generations to come by evolving and adapting to the environment and not the other way around Secretariat of the Convention on Biological Diversity (2008). One of the focuses of agroecology is on the elimination of poverty and food scarcity by incorporating local farms to provide sustainable food supplies and diverse food supplies. Human population growth, climate variability, consumer demands, agricultural subsidies, as well as social pressures, represent the challenges faced by current agricultural movements (Altieri, Funes-Monzote, & Petersen, 2011). Agroecology allows the conservation of natural resources, mitigating and reducing the loss of biodiversity to meet the challenges mentioned above within a globalized and constantly changing world. These benefits can only be achieved with good policy and the right backing and adequate tools from lawmakers and politicians alike.

Farmers who practice sustainable methods and utilize the free training and education that must be provided to them should have greater access to land; they should also have access to natural resources such as water, energy, and tools if necessary, for the maintenance of their farms. The owners of agroecological farms should have greater access to government incentives that support these practices and needs as a tool to provide food security in Puerto Rico. Training for traditional farmers on sustainable agroecological methods should be mandatory, in order to receive such benefits, as well as maintained a minimum amount of training/education hours a year. Training and education should allow not only for general knowledge backed by scientific findings but also allow farmers to find cost-effective ways to practice sustainable agriculture while benefiting biodiversity and making a profit.

Acknowledgments

I am grateful to Mr. Damian Olmo-López, Rebeca Rivera-Rivera, Kidany Sallés, Evelyn Baez, Leily Feliz-Carrasco, and two anonymous reviewers for supporting this manuscript and for the feedback received on agroecological crops.

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