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Biodiversity-friendly Agricultural Practices in the Indigenous Agricultural Systems in the Biodiversity Corridor of the Alto Paraná Atlantic Forest (Paraguay)

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ABSTRACT

Agricultural systems result of the coevolution between social and natural systems, where biodiversity and natural resources play an important role, emerging interactions between crops and the natural environment that allow the development of ecological processes which interact with external inputs. This research aims to describe the agricultural practices developed by the Guarani Indigenous people in the agricultural systems located within the biodiversity corridor of the Upper Parana Atlantic Forest. This exploratory study is focused on multiple cases, with a qualitative approach and from data collected during 2017 and 2018 in eleven indigenous communities. The main practices developed for the management of biodiversity are polyculture, rotation, and embroideries; they also practice agroforestry and livestock-raising. The main difficulty they face is the reduction of the surrounding biodiversity, which affects the sustainability of the system. This study shows ways for nature-based solutions and ecosystem-based adaptation according to current needs for greening the economy.

1. Introduction

Through the processes of simplification of agricultural systems to improve their management, a high uniformity is promoted, altering biodiversity both at the scale of the landscape and the farm^[1,2] in systems in which some resources still depend on external factors such as pollination, water and biological controls. Peasant and indigenous agricultural systems are the result of cultural and biological co-evolution over time and through learning and, despite the diversity of existing systems, these have some points in common such as high

levels of biodiversity, conservation and management of soil and water resources, productive diversity, resilience, traditional knowledge, and forms of collective organization^[3]. Agrobiodiversity is a key element in these agroecosystems, and patterns of diversity, use and management are distinguished in relation to geographical-cultural regions of location of agroecosystems and plots^[4].

The Convention on Biological Diversity defines biodiversity as “the variability between living organisms of all types or origins including, but not limited to, terrestrial, marine and other aquatic ecosystems and

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the ecological complexes of which they are part of”^[2]. Biodiversity is the set of living organisms and resources, their genetic variability and how they are integrated into the landscape through ecosystems. The Alto Parana Atlantic Forest is one of the most endangered ecoregions shared among Argentina, Brazil and Paraguay; in Paraguay, around 10% remains with a representative forest cover. Original forest remnants gave the opportunity to design and create a Biodiversity Corridor within the general view for the conservation of the trinational Corridor which years ago pioneered a biological vision coupled recently by Chaco Biological Corridor^[5]. This trinational corridor with Argentina and Brazil is expressed in Paraguay by the Alto Parana Biodiversity Corridor (APBC)^[6] and its historical land use changes have been gathered in WWF/FVSA report^[7]. This national corridor recognized legally as the first corridor in Paraguay is composed of nuclear or core zones (protected area) with a productive landscape surrounding these ones which visually are patches of forests in the landscape. To maintain the connectivity among the remaining patches it is important to work with the agricultural practices and if areas are to be reconnected given the lost connectivity, these is to be done with local producers. The southernmost limit of this Corridor has been highlighted in terms of governance^[8].

Agrobiodiversity arises from traditional knowledge as a result of a co-evolution between the natural environment and humans, where small changes are introduced (considering the relationships of social ecosystems and the natural ecosystem) so that the environment adapts to the needs of human beings. At the same time, humans have adapted the productive system to the prevailing environmental conditions^[9].

The Guarani People is a linguistic family of Amazonian origin, who have occupied Paraguay about 1,000 years ago, characterized by the combination of agriculture with hunting and fishing, the gathering practiced in the forest; traditionally 80% of the diet depended on crops such as corn (*Zea mays* L.), bean (*Phaseolus vulgaris* L.), manioc *Manihot esculenta* Crantz, sweet potato (*Ipomoea batatas* L.) Lam. and *Cucurbita pumpkins moschata* (Duchesne) Poiret^[10,11].

For the Guarani, the importance of agriculture does not depend only on the quantity or quality of production, but also on what its own productive means. Its practice involves internal organization, reciprocity, exchange of species, experiments, rituals, renewal of life cycles, among others^[12].

Ecosystem based adaptation (EbA) and Nature-based solutions (NbS) have been indicated as ways of greening our planet and help adapt to climate-changes^[13] and in

many countries such as Paraguay, indigenous people have been living in different kinds of ecosystems such as high humid forest as the case of the Guarani people in Eastern Paraguay. The practices they may have evolved with may show pathways for these solutions. Exploring information on traditional knowledge and productive practices in native people may help identify ways of greening the economy, finding NbS and adapt according to the ecosystem (EbA) where these practices are held.

Today, according to data from the III National Indigenous Census conducted in 2012^[14], 61,902 people identify themselves as members of one of the five peoples of this language family in Paraguay. Within the APBC, there are three of these indigenous peoples, the Aché, the Mbya and the Ava Guarani^[10].

This Biological Corridor is a space defined under a protected area management category of the National System of Protected Areas of Paraguay (SINASIP), of just over one million hectares and located on the right bank of the Paraná River associated with the Itaipú Hydroelectric Dam discussed in the 2018 Forum of Green Business (<https://paraguaybiogreenforum.com/corredor/>).

The objective of this research was to describe the main agricultural practices developed to increase biodiversity by indigenous family farming in the biodiversity corridor of the Alto Paraná Atlantic Forest through the identification of the functional biodiversity used and production techniques to promote this biodiversity.

2. Methodology

The research was designed as an exploratory type to understand the relationship of the productive systems and nature, with multiple case studies with a qualitative approach. The variables studied correspond to the dimensions of biodiversity based on the proposal of Gliessman’s^[15] (Table 1) and the main agricultural practices that enhance these dimensions.

Table 1. Biodiversity dimensions after Gliessman^[2]

Dimension	Description
Genetics	Degree of genetic information variability in the system (Intra and interspecific): varieties, hybrids, clones, others.
Specific	Number of species present in the system
Vertical	Number of strata or levels in the system. Crop architecture.
Horizontal	Patterns of spatial distribution of organisms or crops
Structural	Number of habitats, niches, trophic roles determining the system’s organization
Temporal	Degree of heterogeneity in time: crop rotations and successions.
Functional	Complexity of interactions, energy flux and matter cycle among components of the system

The study population includes indigenous communities that are currently within the Biological Corridor identified by the Paraguay Biodiversity Project (<https://projects.bancomundial.org/es/projects-operations/project-detail/P094335>). Areas where indigenous communities are present and these communities reside in critical areas for the connectivity within the Corridor, either to maintain it or enhance the connectivity or areas of importance for the forest restoration. With these criteria, 20 priority areas were identified.

These areas comprise 11 indigenous communities (Table 2) in which random sampling was carried out according to the weighting of the population benefited by the project and the interview with key informants. Data were collected through interviews and surveys conducted with families and key informants living in the communities during 2018 and 2019. The project received the prior informed consent by the people participating and followed the Paraguayan Law in terms of consent and consult with indigenous people.

Table 2. A total of 46 family units (608 individuals) were visited and interviewed within 11 indigenous communities.

No	Community	People/Nation	Population	Percentage	Sampling units
1	Tapysavy	Mbya Guarani	44	7%	3
2	Ypeti	Mbya Guarani	42	7%	3
3	Mcal López	Ava Guarani	60	10%	5
4	Yvyty Miri	Mbya Guarani	25	4%	2
5	Itanarami	Ava Guarani	78	13%	6
6	Montania I y II	Ava Guarani	53	9%	4
7	Ara Pyahu	Ava Guarani	26	4%	2
8	Arroyo Mokoi	Ava Guarani	65	11%	5
9	Cerrito	Mbya Guarani	45	7%	3
10	Mytuy Araguayu	Ava Guarani	12	2%	1
11	Acaray mi centro	Ava Guarani	158	26%	12
	TOTAL		608		46

3. Results and Discussion

The 11 indigenous communities studied have communal ownership of the land, but the production systems and animals raised are family-owned; the leader of the community is the one who assigns the space or place where the family can settle their crops, which normally constitute small spaces of no more than 0.5 ha distributed in the forest; each family owns three to five of these spaces (1.6 – 7.5 ha); coinciding with what Glauser

^[10] said that the Paĩ Tavyterã (another of the peoples belonging to the Guarani language family that inhabits Paraguay) have on average about 2.5 ha of crops per family.

For them, the agroecosystem encompasses, in addition to the crops themselves, the surrounding space, fallow areas and the forest; therefore, the community as a whole could be considered as an agroecosystem. Productive systems or agroecosystems are in constant interaction with the forest as has been shown by Glauser ^[10], Ladeira ^[12] and Lehner ^[11]. This phenomenon occurs mainly in those communities that still have significant forest remnants, which constitute 8 of the 11 communities studied; in the other 3, the productive systems have almost no interaction with the environment.

The distribution of land use in the 11 communities studied (Figure 1) shows a potential relationship between the area of temporary crops and the availability of forest, coinciding with what Glauser ^[10] pointed out that as the forested area decreases, the areas destined for the production of other types of food increase in order to compensate for the decrease in harvesting within the native forests.

Guarani agriculture is a migratory or slash, tomb and burn agriculture; based on a lunar and seasonal calendar governed by a large number of religious rites; characteristic that can still be observed in the 11 indigenous communities. The crop cycle begins with the selection of a new site in the forest (currently three of the communities studied no longer practice this cycle, keeping their crops in the same places, due to the lack of forests), proceeded for a time of cultivation and a period of rest for the soil.

Within the agricultural systems, permanent and temporary crops are observed; among the main permanent crops, there is a great variety of fruit crops among which banana stands out for its frequency (*Musa X paradisiaca* L.), the yerba mate (*Ilex paraguariensis* A.St-Hil.), the orange tree (*Citrus sinensis* (L.) Osbeck) and the papaya (*Carica papaya* L.); according to interviews, these crops are an important source of food, mainly for children, and partly replace the fruits of the forest; on the other hand, yerba mate today has become an important source of income through the sale of its leaves.

Temporary crops are represented by corn, bean and cassava, complemented by crops of sweet potatoes, two varieties of pumpkins (*Cucurbita mixta* Duchesne), in addition to other recently introduced species such as sesame (*Sesamum indicum* L.) or rainfed rice (*Oryza sativa* L.).

As for the specific diversity of agricultural crops sown, each family on average sows between 7 to 15 species, among annual crops, fruit trees and vegetables. Among

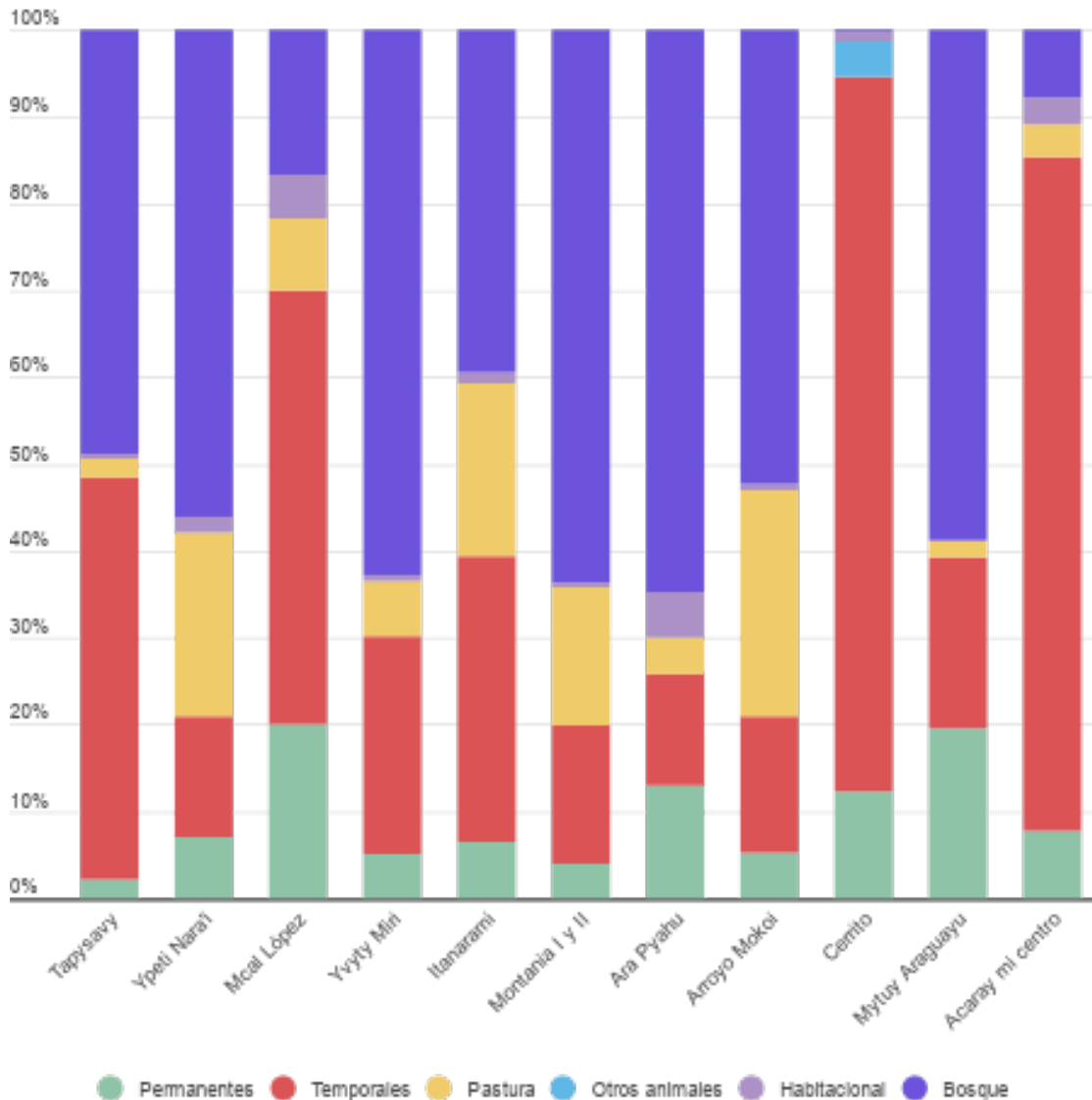


Figure 1. Distribution of land use in the indigenous communities studied

communities, 7 have a number of between 14 and 15, and four are below the 9 species sown. Though the number of species has decreased with respect to the traditional agriculture of the Guarani, based on the comments collected, there is still interaction between these crops and the natural environment which may suggest the importance of the associated biodiversity for them. This situation coincides with that expressed by Glauser^[10] who found a diversity of cultivated species of between five to 11 species among the Paĩ Tavyterã communities.

In conjunction with this variety of species, there is also a genetic variety in terms of cultivated items, with 20 varieties of corn, 12 varieties of sweet potatoes, 7 of beans as well as the bean (*Vigna unguiculata* (L.) Walp.) and sugar cane (*Saccharum officinarum* L.) and 5 varieties of cassava.

The agricultural practices developed by the Guarani to enhance agricultural biodiversity within their systems are grouped into four main practices and are in line with what Gliessman^[15] reported: cover crops, polycultures, rotations and embroidery.

In Paraguay, traditional Guarani agriculture did not possess exclusive plant species for the cover and used different species and varieties of beans and peanuts, combined with pumpkins^[16]. Eleven communities visited cultivated beans and pumpkins; while in four sweet potatoes were grown, and in two, bean is cultivated in association with watermelon *Citrullus lanatus* (Thunb.) Thell.) and melon (*Cucumis melo* L.).

Guarani agriculture has a very specific rotation system that consists of the alternation of crop cycles with soil rest cycles (fallow or *kokuere* as it stands in guarani language).

This complete cycle (Figure 2) could last approximately 30 years, where 5 corresponded to crops and 25 to soil recovery through the ecological process known as natural succession; the right time to let a soil rest is identified by the presence of natural indicators such as the *yvy'a* (*Jacaratia corumbensis* Kuntze), the *kapi'i atĩ* (*Cenchrus echinatus* L.), the *kapi'i una* (*Bidens pilosa* L.), *kapi'i pororó* (*Digitaria insularis* L.), the *ñuatĩ pytã* (*Solanum sisymbriifolium* Lam.) and the *kauguetĩ* (unidentified species). This rotation system is still partially applied in 8 of the communities, where the habilitation of new places (slash-and-burn) is subject to approval by the community assembly; on the other hand, in 3 communities it is no longer practiced because they almost no longer have forest cover.

For the effective practice of this traditional cycle, biodiversity is considered of vital importance, since the recovery of the soil depends on it; in traditional management, once the soil shows signs of exhaustion, they leave it at rest and the succession process becomes evident. The appearance of these indicator species needs to be furthered researched.

For polyculture or crop association, maize is usually combined with cassava and peanuts; corn with cassava and beans; corn with cassava and beans and cassava with watermelon; in addition, different kinds of pumpkins are planted by dispersing seeds on the ground. These combinations are observed in all indigenous communities, mainly the planting of cassava and corn, associated with

beans pumpkins. These crop combinations combine with those found by Glauser^[10] which mentions that the Paĩ Tavyterã usually grow corn with pumpkin; corn with cassava and bean; cassava, bean and sweet potatoes in an associated way; among other combinations.

Embroidery techniques were one of the key traditional Guarani agriculture practices, since agroecosystems were completely surrounded by forest and fallow areas^[10,16].

Currently, in the study area, this can only be seen in those communities that still have forest cover (8 communities); in the others they have incorporated as embroideries the crops of species such as sugar cane (2 communities) or pastures such as Cameroon Grass (*Pennisetum purpureum*) (1 community). In addition, they maintain natural regeneration spaces in depleted plots, called *kokuere* or fallow land.

This interaction of cultivated spaces with natural spaces could demonstrate the importance of the associated biodiversity, since, according to the interviews conducted, through this, pest control was achieved, reducing the effects of droughts, winds and frosts, improving the sustainability of the system. It is important to note that pollination is also a service of the surrounding nature, not always visualized.

In addition to the existing techniques mentioned, there are others that also have an impact on the biodiversity of the system, such as agroforestry systems, and the integration of crops and animals^[3].

In traditional Guarani agriculture it is normal to

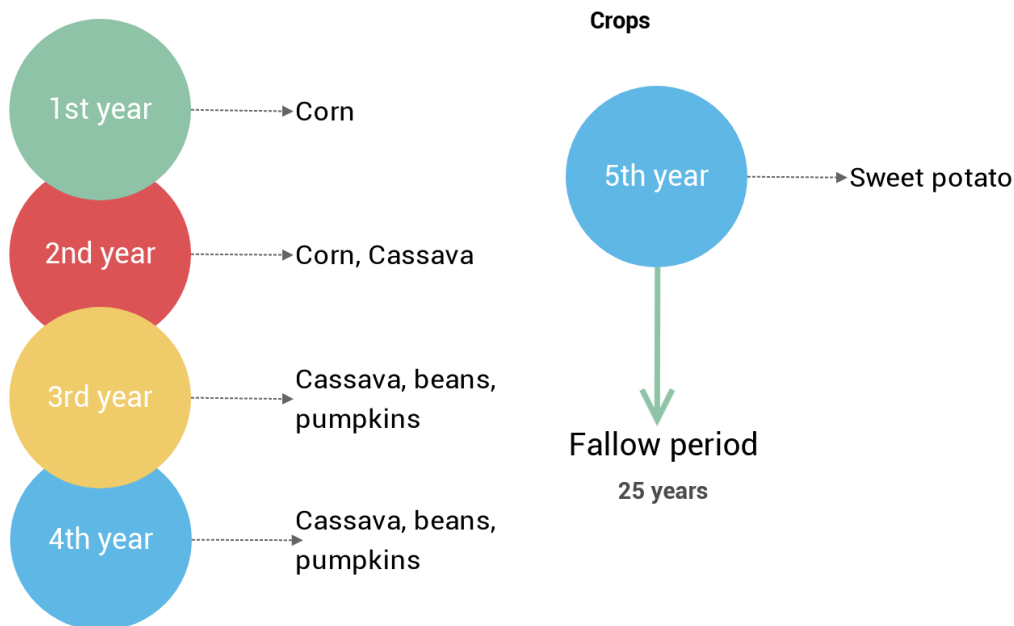


Figure 2. Crop cycle in the Guarani communities studied

observe the existence of trees in crop spaces, as this helps a faster recovery of forest cover, once the soil begins to experience symptoms of exhaustion, with which natural cycles could be accelerated. Currently, they have also incorporated the cultivation of different species of fruit trees such as the citrus and the papaya, in addition to the yerba mate (*Ilex paraguariensis* A.St-Hil.) coinciding with what was observed with Glauser^[10] who mentions that the Paĩ Tavyterã cultivate different species of fruit trees around houses for human and animal consumption.

Currently, in all communities raising of minor animals, and in 6 cases, cattle is integrated into the farming systems. Smaller animals normally have a lot of freedom of movement and interact with crops naturally; on the other hand, cattle are usually fenced in natural or cultivated pastures. These domestic animals play an important role in maintaining the diversity of plants by helping with seed dispersal.

4. Conclusions

Biodiversity continues to play a preponderant role in Guaraní agriculture and its management occurs both according to the number of species cultivated and the structure, both cultivated and associated with the interior of the farm and in the surrounding landscape. The native areas of forests are needed for the restoration of lands used for crops. These practices may be seen as solutions for sustainability for restoration of habitats, and could be considered as Nature-based Solutions (NBS) which increasingly are being debated to guide the design of resilient landscapes^[17] including sustainability, resilience, ecosystem services, coupled with human and environmental needs. Ecosystem-based adaptation is considered needed to fight against climate change and advance with adaptation^[18], this study shows a way of productive systems associated with a particular ecosystem, the Atlantic Forest where native people have evolved practices in association with these ecosystems, and though human induced, these agrosystems increase resilience to climate change.

The associated biodiversity is fundamental for the sustainability of agriculture considering that it depends on the existence of different ecological processes that provide fundamental ecosystem services such as nutrient recycling, pest control, resilience capacity, and ecosystem services provided by forest also benefit food security to the Indigenous People.

Currently, the main difficulties faced by Guaraní communities are linked to the extreme reduction of surrounding nature which generates some imbalances in the system and causes them to incorporate inputs

and practices outside their culture, mainly related to the control of pests and fertilizers. The conservation and restoration of biological corridors such as the Alto Parana Biological Corridor in Paraguay and its connection with natural habitat in the neighboring countries rely on nuclear areas and sustainable practices which are associated with the native biodiversity, native people such as the Guaraní shows a way of doing this locally and help the connectivity of the entire biological corridor.

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