Restoration of tree cover

Restoration of tree cover in pastures can achieve multiple goals.

Photo: World Agroforestry/Meine van Noordwijk

Suggested citation:

Miccolis A, Peneireiro FM, Marques HR. 2019. Restoration through agroforestry in Brazil: options for reconciling livelihoods with conservation. In: van Noordwijk M, ed. *Sustainable development through trees on farms: agroforestry in its fifth decade.* Bogor, Indonesia: World Agroforestry (ICRAF) Southeast Asia Regional Program. pp 209–231.

CHAPTER TWELVE

Restoration through agroforestry in Brazil: options for reconciling livelihoods with conservation

Andrew Miccolis, Fabiana M Peneireiro, Henrique R Marques

This is a shortened version of a published article[1] and is based on a manual on Portuguese[2]

Highlights

- The Brazilian Law for the Protection of Native Vegetation (2012) obliges farmers to restore degraded lands on all rural properties, which can be done through agroforestry systems as long as they maintain ecological functions in addition to social functions
- Among the different types of Agroforestry Systems (AFS), biodiverse and successional systems are most suited for restoration since they are capable of providing multiple environmental benefits and improving livelihoods while offsetting the high costs of restoration
- Ultimately, upscaling these requires co-designing solutions tailored to the socio-ecological contexts, particularly with regard to biophysical conditions, farmer objectives, input requirements, and the enabling environment (markets, policies)
- This chapter presents five examples of agroforestry options suited to commonly occurring contexts in the Brazilian Cerrado and Caatinga biomes, which vary in terms farmer objectives, labour and input requirements, farmer objectives, and key species and management practices

12.1 Introduction

The Brazilian Law for the Protection of Native Vegetation (known as the new Forest Code)[3] set a series of provisions regulating land use on all privately-owned rural areas, including obligations for restoring protected areas, known as Permanent Preservation Areas – PPAs and Legal Reserves – LRs (Box 12.1). While Brazilian law has required the conservation and restoration of these areas since 1965, compliance has historically been very low due mainly to low enforcement, lack of clear regulations, and the fact that PPAs, which include riparian zones (as well as springs and steep hillsides) are often the most humid and fertile areas and hence most useful to farmers. This conundrum is especially relevant for smallholders, or 'family farmers', in Brazil.

Figure 12.1 Illustration of an agroforestry system that can meet legal restoration requirements in Permanent Preservation Areas[2]

Box 12.1 Key definitions in the Brazilian legal framework[3]

Agroforestry Systems – AFS: Land use and occupation system in which woody perennials are managed in association with herbaceous, shrubs, trees, crops and forage plants managed in a single management unit, according to spatial and temporal arrangements, with a high diversity of species and interactions among these components.

Permanent Preservation Area – PPA: A protected area, covered or not by native vegetation, with the environmental function of preserving water resources, the landscape and geological stability and biodiversity, facilitating gene flows of fauna and flora, protecting the soil and ensuring the well-being of human populations.

Legal Reserve – LR: A percentage of all private rural properties, which varies according to biome, delimited according to the terms of Article 12, with the function of assuring sustainable economic use of natural resources on rural properties, aid in conserving and rehabilitating ecological processes and promoting biodiversity conservation, as well as shelter and protection for wildlife and native plants.

To address this issue, the new norms, passed in 2012, afford a series of special rights and conditions for using PPAs and LRs targeting family farmers, whose farm size can vary legally from 20 to 440 ha (depending on municipal economic indicators). First, it allows them to use agroforestry systems – including a maximum of 50% of the area with exotic species – for restoring PPAs, provided the agroforests maintain basic ecological functions and structure similar to the native vegetation. Second, it allows medium to large landholders to use LRs through agroforestry systems as long as annual and fruit crops – including alien tree species – are mixed with native tree species, while at the same time imposing stricter regulations for using PPAs for this category of farmers. Lastly, the new law establishes specific provisions stating that PPAs and LRs can be utilized to meet both environmental and social functions.

The new law does **not** specify, however, how – or what type of – agroforestry systems can be used in these different contexts, what alien species can be intercropped with native species and which management practices can or should be adopted at different stages of growth.

These knowledge and policy gaps have thus left a wide margin for interpretation, leading to many uncertainties that have discouraged technicians from making recommendations and farmers from adopting AFS in these areas. Meanwhile, environmental enforcement and rural extension agencies tend to take a conservative stance that also discourages farmers from playing a more active role in restoration processes. One of the main obstacles for restoring these 'protected areas' on private lands in Brazil, especially in the context of smallholders, is the lack of understanding of the economic costs and benefits of forest restoration and the lack of clear regulations on which alien species can be planted to generate additional income and improve the livelihoods of farmers on these areas.

To contribute to filling these knowledge gaps, this study analyses the most commonly occurring contexts in the Brazilian Cerrado and Caatinga biomes and proposes agroforestry options tailored to these contexts that can enable restoring degraded lands in Brazil while also complying with the provisions of the new forest law. To achieve this aim, we set out to address three main questions:

1. Are agroforestry systems suitable for restoring and conserving PPAs and LRs?
2. What are the most suitable types of agroforestry systems, management practices and species for reconciling ecological and social functions in these different contexts?
3. How to develop suitable options, design elements and species selection that can be applied to different contexts?

12.1.1 The context of the Cerrado and Caatinga biomes

The Cerrado

The Cerrado, known as the Brazilian Savannas, spans across the vast plateaus of Central Brazil, forming a myriad of landscapes and amid mesas and valleys, rolling hills, and vast plains. The vegetation ranges from grasslands to woody savannahs and dense gallery forests. Often called the cradle of Brazil's waters, its springs feed eight of the country's twelve major river basins[4,5] over a vast expanse of some 200 million hectares, nearly a quarter of Brazil's land mass. The rainy season generally lasts six months (from October to April), followed by six months of very little or no rain, with annual rainfall ranging from 800mm in areas near the semiarid region to 2,000 mm in transition zones near the Amazon and Atlantic rainforests[6]. Today, the region has some 470,000 small farms, most of which belong to family farmers and traditional communities[7].

Figure 12.2 Characteristic landscape of "Vereda" vegetation typical of wetlands in the Cerrado. Photo credits: ISPN/Peter Caton

Brazil's Cerrado is the world's most biodiverse savannah, with 13,140 plant species, approximately 3,000 vertebrate animal species[8] and 67,000 species of invertebrates[9]. It is also the source of livelihoods for a wide variety of traditional peoples and communities, including extractivists, indigenous peoples, *quilombolas* (maroon communities), family farmers, among others[10], each with their own cultural diversity. Some of those communities have lived in the region for hundreds of years, often interacting with indigenous peoples, and learned over time to live with its diversity and extract its natural resources in a sustainable manner, while others still depend on traditional slash-and-burn practices to enable their production. There are still over 80 indigenous ethnic groups in the Cerrado, and another 70 in the Caatinga (described below).

The Cerrado is one of the world's most endangered biomes due to the expansion of industrial agriculture, including vast plantations of soybeans, maize and cotton, as well as cattle, eucalyptus for pulp and charcoal, and hydroelectric dams[6,5,11]. As a result, some 30,000 km^2 of the Cerrado are cleared every year[11] and only 55% of this biome's natural vegetation cover remains[12].

Figure 12.3 Caatinga and Cerrado as part of Brasil[2]

Figure 12.4 Characteristic landscape of the Caaatinga dry forest. Photo: Do-Design

The Caatinga biome occupies most of north-eastern Brazil (Figure 12.2), with several distinct vegetation types, from open fields to shrubby and tall forests, many thorny and succulent plants. This exclusively Brazilian biome is home to around 2,000 plant species, 300 of which are endemic to this environment. Its fauna is also very diverse, with 178 mammals, 591 birds, 177 reptiles, 79 amphibians, 241 fish and 221 bee species[13]. Average annual rainfall varies from as little as 300 mm in the driest areas to over 1,500 mm in zones that transition to other biomes[14,15].

Most of the Caatinga has shallow soils, an extremely hot climate and irregular rainfall, which makes the environment extremely sensitive and prone to desertification. With a population of over 27 million people, the land is occupied predominantly by smallholder family farmers and traditional communities whose livelihoods depend on local resources. The Caatinga's irregular rainfall pattern makes life extremely hard for these farmers and requires strategies for adapt to and co-existing with the semiarid[14].

Since early European colonization, the region's forests have been cleared for livestock, small-scale farming and charcoal production, still the mainstays of rural livelihoods and the main causes of degradation of the Caatinga's ecosystems[16,14]. Recently, parts of the Northeast in the region known as MATOPIBA, have become the new frontier of agricultural expansion. By 2009, 50% of its vegetation have been cleared and measures taken to restore and conserve the biome have been few and far between[15]. Of all of Brazil's biomes, the Caatinga has the fewest conservation units (protected areas), which cover only 7.5% of its territory.

12.2 Research methods

To tackle the basic question of whether AFS can indeed be a feasible approach to reconciling conservation goals with farmer aspirations and livelihoods needs, we examined evidence in the literature and experiences on the ground. After identifying the provisions in the legal and policy framework pertaining to the use of – and concepts surrounding – agroforestry, we conducted a literature review to shed light on the social, environmental and economic benefits and challenges of upscaling agroforestry systems for the purposes of conservation and restoration. We then engaged multiple stakeholders at three stages through:

1. semi-structured interviews with experts;
2. a national workshop, and
3. field visits on previously selected farmer experiences in the Cerrado and Caatinga biomes (Fig. 12.3).

The workshop, which was attended by 69 farmers, technicians, experts and policymakers from throughout the country produced a series of recommendations on principles and criteria for species selection and systems design in different contexts. Additionally, 19 farmers' experiences were analysed in-depth with the help of technicians, practitioners and/or scientists and later systematized by the authors to draw out key lessons about practical options for reconciling conservation with production. As a next step, 14 experiences led by innovative farmers (some of which were identified during the workshop) were visited by researchers to gain more in-depth knowledge on the factors underlying success and challenges. Based on these various inputs, we then developed an analytical framework (Fig. 12.5) and proposed systems, practices and species suitable to some of the most commonly occurring contexts in these two biomes.

12.3 Results and Discussion

12.3.1 Benefits of agroforestry systems for restoration in Brazil

In Brazil, despite the scarcity of scientific literature with balanced assessments about the challenges faced in the wider adoption and dissemination of agroforestry, some authors have recommended AFS as an adequate solution for ecological restoration and recovering degraded lands[17,18]. Some studies have shown agroforests increase the occurrence of native tree species and promote forest succession[19,20] with characteristics like secondary forests. The role of AFS in maintaining and improving soil fertility, especially through the use of high biomass-producing species in nutrient deficient soils, has also been documented[18]. Similarly, complex and well-managed AFS increase the litter layer and thus create favourable environments for soil macrofauna[21].

Despite the scarcity of studies assessing the economic feasibility of agroforests in Brazilian protected areas such as PPAs, some authors point to the high economic potential of such systems in production-oriented areas throughout Brazil[22,23]. However, achieving economic success hinges on a series of enabling conditions, namely: adequate planning, administration and the adoption of appropriate management practices. An economic analysis of 77 agroforestry systems in different regions of Brazil shows that the systems with a broader range of species in different successional groups reap the best benefit–cost (B/C) ratio[24].

Some types of simple AFS do not manage to meet restoration criteria as established by Brazilian law due to low levels of biodiversity[25] and structural complexity needed to provide other ecosystem services, while others are clearly quite effective at providing such functions. In this regard, high biodiversity or 'successional' agroforests stand as the most advanced option in terms of structure and function. These systems were developed and widely disseminated by an agroforestry farmer and researcher, Ernst Götsch, who has spearheaded and inspired a series of innovative practices throughout different Brazilian biomes[20,26,27]. It is important to underscore that the high species diversity and functional heterogeneity of these successional systems requires intense management, selective weeding and successive pruning, which entails availability of labour as a main input and access to knowledge on management practices.

Despite these challenges, the 'complex', 'biodiverse' or 'successional' agroforests are the most suitable to meeting[28,29] environmental functions required for restoration of PPAs and LRs. Nonetheless, these systems cannot be seen as panaceas applicable to all contexts; rather, they must consider contextual variability, not only in biophysical conditions such as soil, topography and rainfall, but also in social conditions, such as aspirations and livelihoods strategies, access to labour, markets and policies such as credit and extension services.

12.3.2 Understanding the context: constraints for restoration in the Cerrado and Caatinga biomes

In the Cerrado, the main biophysical constraints are a long dry season (usually lasting around 6 months), which limits crop options in rain-fed systems; torrential downpours and flash flooding during the rainy season, leading to soil erosion and water logging in some soil conditions and potentially annual crop losses, low soil fertility and highly acidic soils with aluminium toxicity, which is aggravated by overgrazing, mechanized large-scale farming and the widespread use of fire; and low ecological resilience of degraded lands due to the combination of these factors.

In the Caatinga, where annual rainfall is typically below 800mm, averaging 300mm in some regions, with protracted droughts that sometimes last two or more years, the main biophysical constraints are: low water availability, high evapotranspiration rates and a very short planting window for annual crops. On the other hand, the low-lying Caatinga soils tend to be more fertile and less acidic than the oxisols of the central plateaus where most of the Cerrado is located.

There are, however, significant differences between family farmers in these two biomes. In the Caatinga, farm sizes are generally much smaller and tend to be more susceptible to extreme weather events, particularly droughts but also flooding, and face higher levels of extreme poverty. Nonetheless, the vast majority of farmers in both biomes face similar social and governance-related constraints, including: low access to knowledge and information about innovative and best agroecological practices; low access to inputs (especially chemical fertilizers and pesticides) due to their high costs and long distances to towns; low availability of labour; scant access to rural credit, especially for agroforestry and ecological agricultural systems; low access – due to high distances – to markets and poor infrastructure; cumbersome and onerous administrative and licensing procedures that make it difficult for farmers to organize themselves in cooperatives and obtain licenses for processing goods.

Agroforestry options must thus be tailored not only to the biophysical conditions but also to these other variables: farmer objectives, input and labour requirements, which can vary in space and over time, as well as access to knowledge, credit, and markets.

12.3.3 The options x context framework

The options x context[30] framework as developed in Brazil (Figure 12.3) begins by understanding how these constraints play out at the household/farm or local level to guide the design of systems, selection of management practices and key species that are manageable by – and suited to – each family or group of families. In addition to family (men, women, youth) objectives, key considerations in systems design and species selection across contexts should be agroecological suitability, labour requirements, marketing opportunities and biomass production, as well as resilience to extreme climate events, particularly droughts.

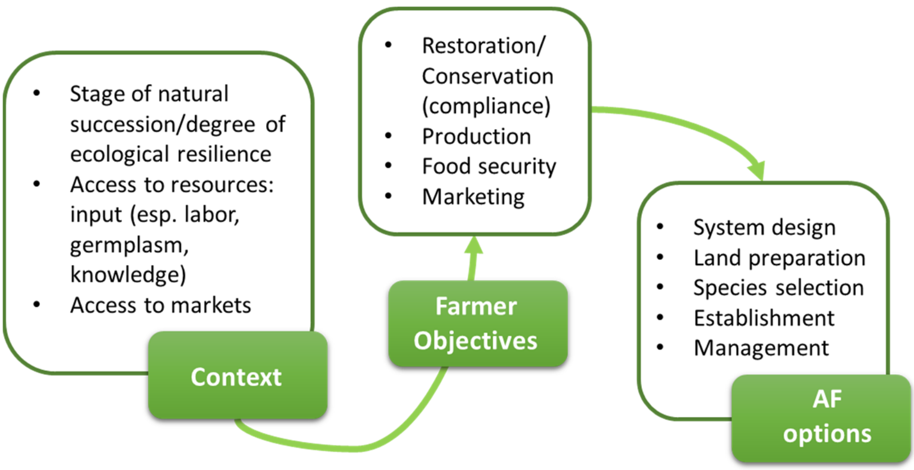

Figure 12.5 'Options x context' scheme used in the analysis

To balance the different social and environmental functions needed in these systems, priority should be given to species that:

- the farmer wants to cultivate, i.e., has experience with and likes;
- grow and produce well in that area, considering climate, soil, lighting, water and available inputs;
- are known to improve the soil and the conditions for the next plants in the succession;
- the farmer can manage with the locally available work force;
- have a potential for marketing; and
- are compatible with other species in the guild, in terms of the space they occupy over time.

In the Caatinga, for instance, species with a high capacity for storing water can be vital for coping with dry spells that can sometimes last for years. Succulent plants that swell to absorb water in their structures, such as cacti, can be important sources of water for animals, plants and even people. They keep the landscape green when all the rest has turned grey.

Other desirable features are high production of biomass and good response to pruning and ease of management. Examples of such species in the Cerrado include: eucalyptus, inga *(inga sp.)*, *mutamba* (*Guazuma ulmifolia*), Mexican sunflower (*Tithonia diversifolia*), yellow mombin (*Spondias mombin*). Some examples in the Caatinga are gliricidia (*Gliricidia sepium*), mesquite (*Prosopis juliflora* (SW) DC), *sabiá* (*Mimosa caesalpiniaefolia* Benth.), sisal (*Agave sisalana*), and pear cactus (Opuntia ficus-indica). In addition to choosing the right species, options must also adopt management practices and techniques suitable to that specific context.

Based on an analysis of the most commonly occurring contexts, particularly in the Cerrado and Caatinga, we propose a series of 11 options with a basic structure that can and should be adapted in terms of key species, design elements and management practices, 5 of which are summarized below.

12.3.4 OPTION 1: successional agroforestry for the cerrado with intensive management[a]

This option is very suitable for farmers whose primary objective is production for marketing, particularly in contexts where there is high access to inputs, labour, knowledge and markets. It can be adopted even on degraded soils with low ecological resilience, provided they are flat to enable easy management and mechanization. Such systems provide a high and quick return on investment and can accelerate restoration of tree cover and basic environmental functions, however, are extremely intensive in management, inputs and knowledge.

[a] This option is based on the AFS established by Juã Pereira, at the *Sítio Semente, Núcleo Rural Lago Oeste, Federal District,* inspired by the teaching and guidance of Ernst Götsch

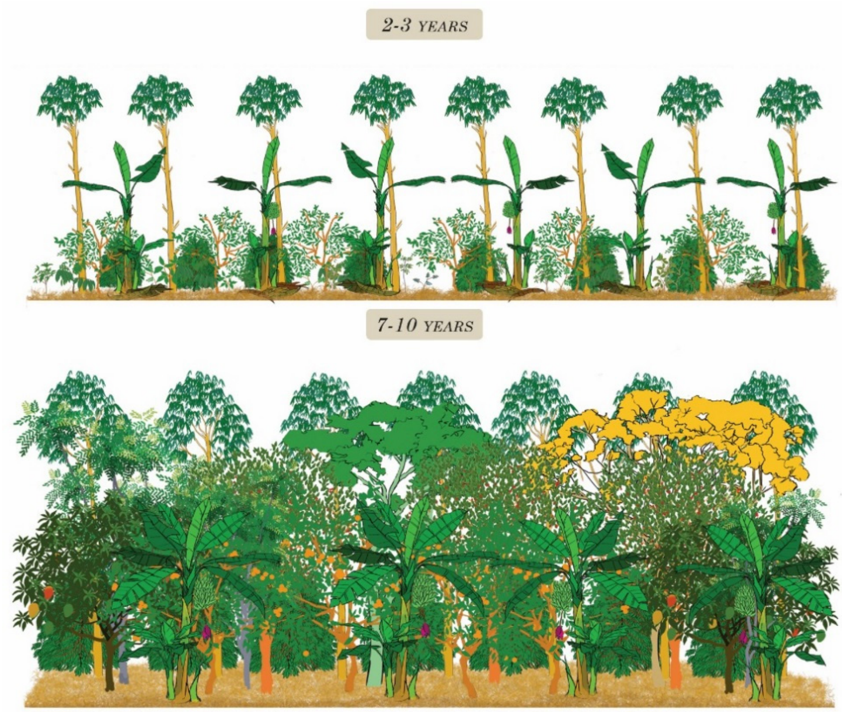

Figure 12.6 Successional agroforestry for the Cerrado with intensive management at two different moments (2-3 years, 7-10 years)[2]

Every 5-6m, rows of eucalyptus and bananas, which are intensely pruned, also concentrate citrus, coffee, and assorted fruit, such as mango (*Mangifera indica*), jackfruit (*Artocarpus altilis*), with 3 rows of garden beds in between, including a rotation of vegetables and annual crops (e.g. maize, beans) followed by tubers (cassava, taro or sweet potatoes) and later occupied by more citrus or coffee or other fruit trees such as *jaboticaba (Plinia cauliflora)* and Surinam cherry (*Eugenia uniflora*)), depending on market conditions and farmer interests. After three or four years, vegetables and herbs dependent on sunlight are withdrawn, while the emerging trees and shrubs remain, and the eucalyptus is gradually replaced by other biomass-producing trees and native trees (e.g. West Indian Locust (*Hymenaea courbaril*), copaiba (*Copaifera langsdorffii*), and cedar (*Cedrela fissilis*)). This system is systematically pruned and mulched to maintain sunlight in the understory and soil fertility.   The management relies on the concentration of biomass, particularly from pruning the trees and bananas, whose material is cut up or shredded and used to mulch both the beds and the strips in between them. Depending on the situation, fertilizer trees may continue to be pruned for a few years to maintain the production of the rows of fruit trees. Slower-growing native trees are left alone until crowns begin to overlap, when they can either be allowed to close the canopy or be pruned to let light in for commercial species in the middle and lower strata.

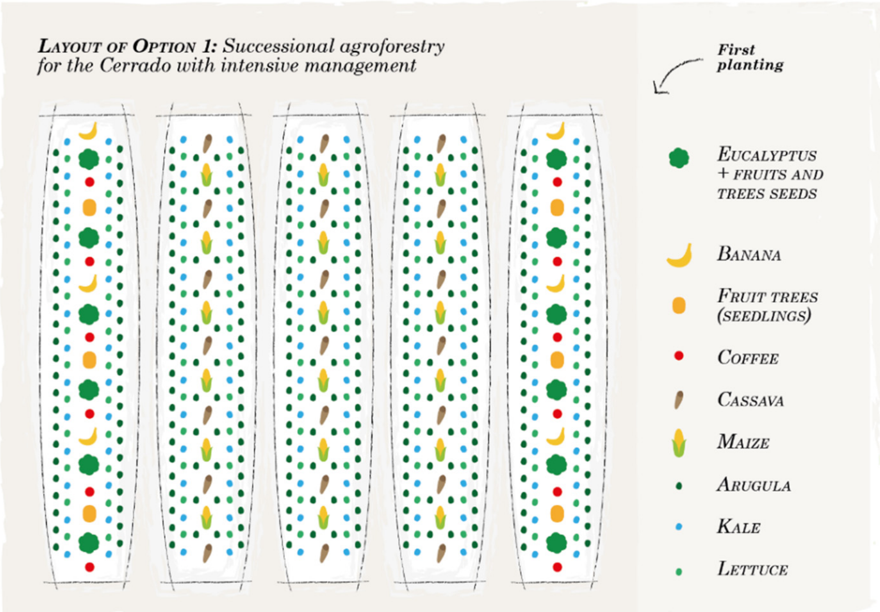

Figure 12.7 Layout of Option 1 Successional agroforestry for the Cerrado with intensive management[2]

12.3.5 OPTION 2: biodiverse successional agroforestry for restoration of riparian zones[b]

This option is ideal for contexts where the goal is to restore riparian zones that have been cleared and taken over by grasses, farmers have low labour availability but enough market access for some of the key products (tropical flowers and fruits, coffee). Annual food crops including maize, cassava, squash and hearty greens (bur cucumber (*Cucumis anguria*), mustard, okra, and parsley), along with bananas, create the basic conditions for establishing intercropped trees, followed by tropical flowers and medicinal plants in the understory.

No agrochemicals (pesticides or chemical fertilizers) or heavy machinery are used in these environmentally more sensitive areas. Rows of fruit, timber and biomass trees with bananas are intercropped with food crops and shade-loving medicinal herbs, shrubs and tubers (e.g. taro, turmeric, ginger and cardamom) and ornamental plants in single-species rows, including torch flowers (*Etlingera elatior*), and heliconias (*Heliconia rostrata*), and/or elephant ears (*Xanthosoma sagittifolium*), which occupy most of the understory, maintain a microclimate and replace the grasses, thus contributing to prevent the spread of forest fires and providing supplementary income. Fruit trees and shrubs (e.g *jaboticaba*, mango, jackfruit, coffee) can also be introduced in the lower and middle stories. Some examples of species that can meet biomass-production objectives in this context are ice-cream bean (*Inga edulis*) and other riparian *ingás*, achiote (*Bixa orellana*), *pau pombo (Tapirira obtusa)* and *pimenta de macaco (Xylopia aromatica).* These pioneer species will create the conditions needed by timber species such as ipe (*Handroanthus spp.*) and West Indian Locust to prosper. While this option can be

[b] A successful example of this option was established by Marcelino Barberato, at the *Sítio Geranium* in Taguatinga, Brasília, based on the teaching and guidance of Ernst Götsch

economically appealing to farmers, it is much less intensive in terms of inputs and labour - and generally less profitable - than Option 1 as it focuses more on commercially valuable shade-loving perennial species, but also provides key environmental functions needed in riparian zones.

Figure 12.8 Biodiverse successional agroforestry for restoration of riparian zones at three different moments (2-3 years, 7-10 years. 20 years)[2]

12.3.6 OPTION 3: agroforestry to reconcile enrichment of natural regeneration with food production[c]

This option is ideal for farmers who need to reconcile low-input food production with restoration, particularly in the context of fallows (secondary growth) that have been degraded over time by logging, slash-and-burn farming and forest fires. The secondary growth is

[c] This option is a combination of options 3 and 4 in the Guidebook Restoration through Agroforestry: reconciling conservation with production. Options for the Cerrado and Caatinga biomes[2]

managed selectively by pruning trees and shrubs and weeding or cutting grasses to enable the introduction of multi-functional species, either in rows or “islands of fertility” (Figure 12.9).

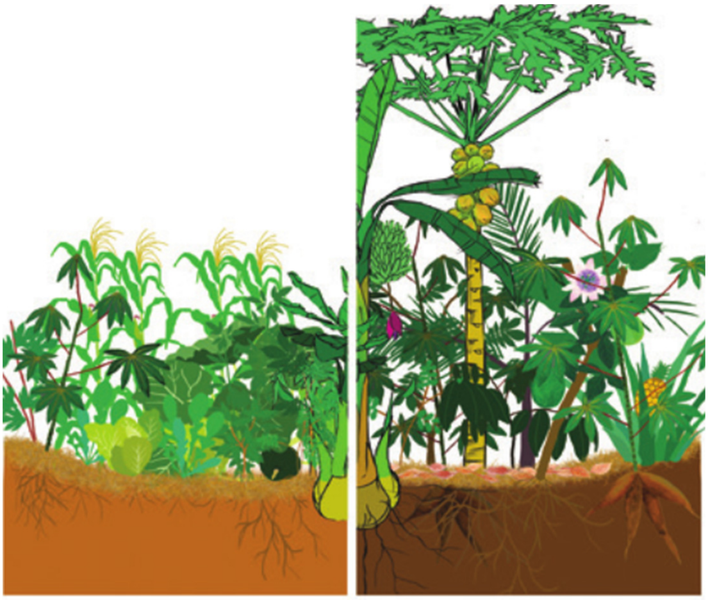

Figure 12.9 Islands of fertility comprised of short-cycle crops and fertilizer species in the beginning to establish fruit and timber trees[2]

Fast-growing species such as bananas, cassava, mulberries or tithonia are planted in the same island (or strip) along with short-cycle crops such as corn, beans, and squash, to optimize fertilizer and labour, along with fruit and native trees planted either by sowing seeds directly or by planting seedlings. As the islands or strips grow, the fruit and timber trees become part of the overstory, increasing biological diversity and ecosystem function while also providing food and supplementary income for farmers. Beekeeping is also a very promising alternative in this context. This option is meant to require low inputs and labour so that whatever fertilizer is available can be concentrated in the islands or strips along with valuable seedlings.

Figure 12.10 Enrichment of fallows and food production with agroforests at two different moments (3-4 months, 2-3 years)[2]

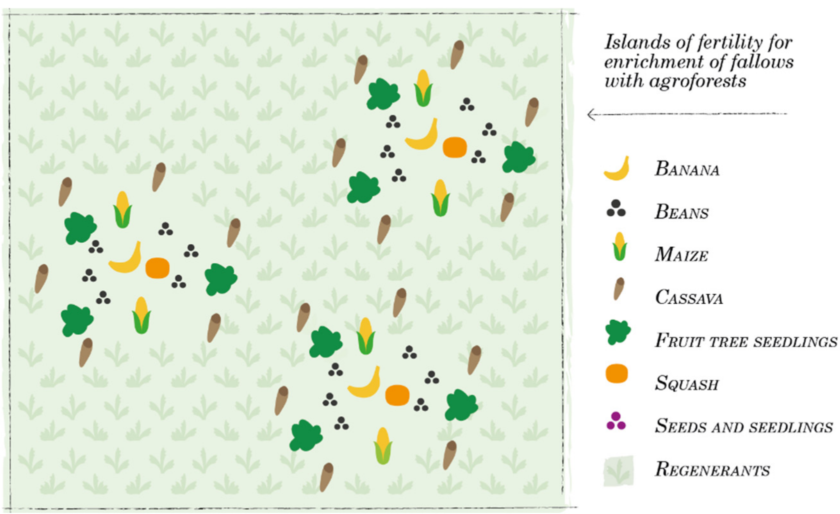

Figure 12.11 Islands of fertility for enrichment of fallows with agroforests[2]

12.3.7 OPTION 4: agroforestry to restore degraded areas with fertilizer and food species[d]

This option is ideal for farmers who wish – or are required by law – to restore pastures back into forests but aren't able or willing to spend too many resources (labour, fertilizer and germplasm). This system requires low-intensity management as compared to other biodiverse systems and can produce enough to at least offset the restoration costs, albeit without requiring markets close by. While some hearty greens, vegetables and grain (maize, millet or sorghum) can be grown in the first year or two, depending on soil fertility and/or availability of fertilizer, the focus is more on perennial species such as bananas, fruit and timber trees intercropped with hearty fertilizer species.

Figure 12.12 Layout of Option 4 Agroforestry to restore degraded areas with fertilizer and food species[2]

In cases where enough labour and fertilizer are available, biomass can be concentrated in rows 5-6m apart, whereas more resource-constrained farmers can opt for investing the little they have in islands or nuclei. These guilds enable establishing a wide diversity of crops in a small space and are highly efficient strategies for establishing fruit and timber trees in the middle of pastures. Their circular, concave shape concentrates fertility and increases water available in the system during the dry season while also providing tiny ecological niches both for plants that require more humidity (e.g. bananas, taro) and for tubers (e.g. cassava) that don't tolerate waterlogging during the rainy season. The basic principle is systematic concentration of biomass in the row of trees or around nuclei with bananas and/or papaya/ + maize + squash + cassava + pineapples, intercropped with fertilizer species such as tithonia, gamba grass (*Andropogon gayanus*), guinea grass (*Panicum maximum*), gliricidia, stylosanthes, pigeon peas (*Cajanus cajan*), and crotalaria. Overall, species should be well adapted to poor soils and the fertilizer species should be fast-growing, highly efficient in producing biomass and relatively easy to manage.

[d] This option is based on the AFS established by Fabiana Peneireiro at the *Ecovila Aldeia do Altiplano*, in Altiplano Leste, Federal District and was inspired by the teaching and guidance of Ernst Götsch

Figure 12.13 Agroforestry to restore degraded areas with fertilizer and food species at three different moments (3 months, 2-3 years, 7-10 years)[2]

12.3.8 Option 5: restoring degraded areas in the caatinga drylands with biodiverse agroforests[e]

This option is suitable for farmers wishing to restore degraded lands in the drylands characterized by low to medium fertility soils, low regeneration and potentially undergoing desertification, while also producing food, storing water in the vegetation and feeding livestock. These systems are highly efficient at restoring areas in advanced stages of degradation, including those in the process of desertification. Soil properties are recovered, and economic species are established initially through "engineer" species that are extremely hearty and drought-resistant, have a high capacity to store water, and can also be used for forage, such as pear cactus (*Opuntia ficus-indica*), sisal (*Agave sisalana*), gliricidia (*Gliricidia sepium*), and leucaena (*Leucaena leucocephala*).

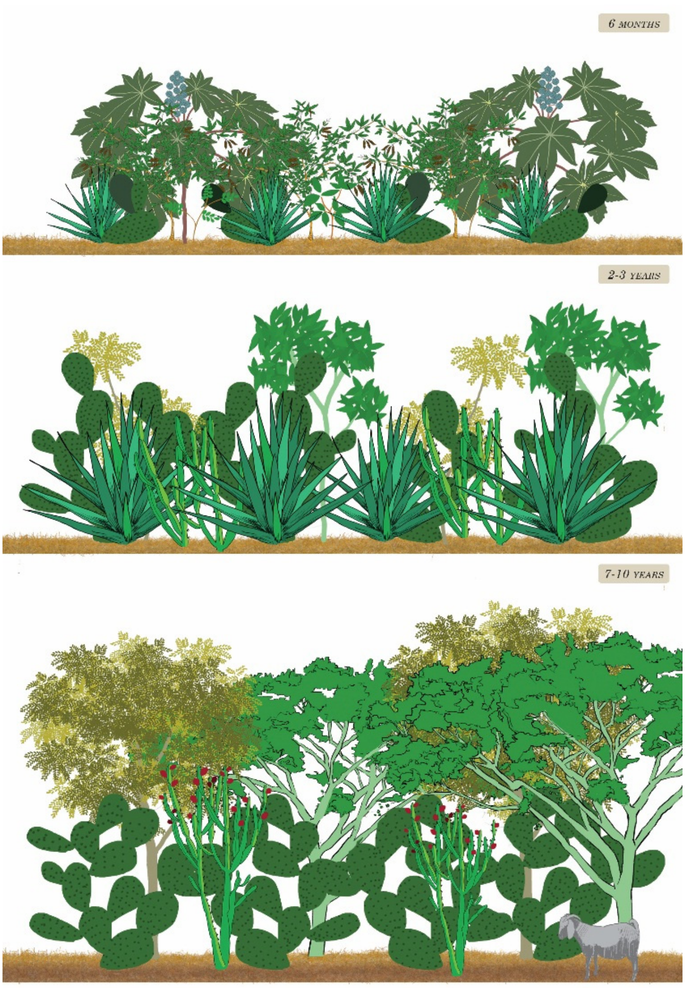

Figure 12.14 Agroforestry to restore degraded areas in the Caatinga drylands at three different moments (3 months, 2-3 years, 7-10 years)[2]

[e] This option is based on the experience of Henrique Sousa, with guidance by Ernst Götsch, in Cafarnaum, Bahia

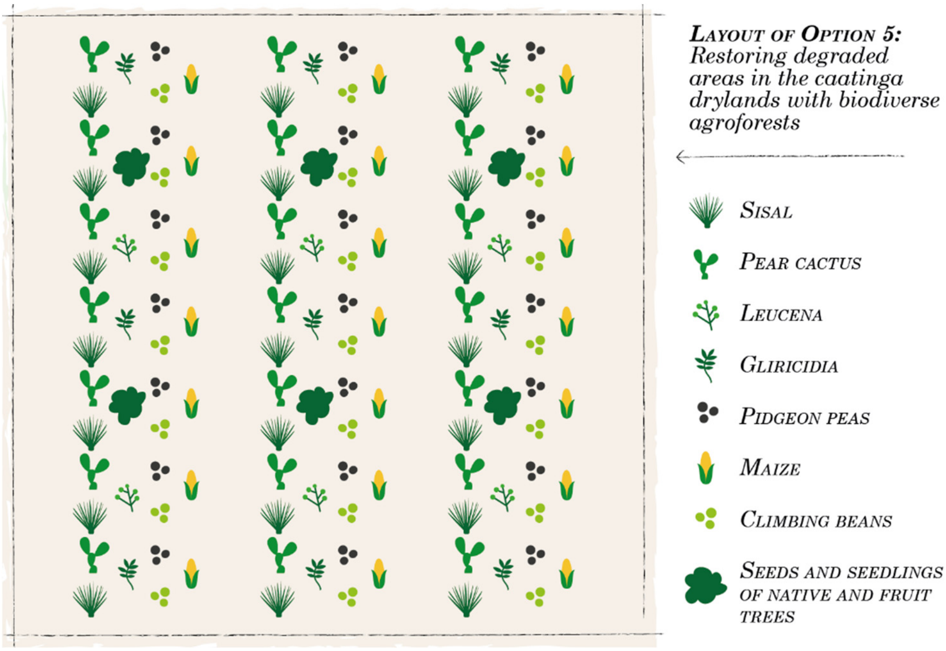

Figure 12.15 Layout of Option 5: Restoring degraded areas in the caatinga drylands with biodiverse agroforests[2]

These engineer species are planted very densely in rows and regularly pruned for mulch and/or feeding livestock, in varying proportions depending on the farmer's objectives over time. Fruit and native trees such as *umbu (Spondias tuberosa)*, yellow mombin (*Spondias mombin*), cashew (*Anacardium occidentale*), *emburana (Amburana cearensis), juazeiro (Zizyphus joazeiro), catingueira (Caesalpinia pyramidalis), and sabiá (Mimosa caesalpiniaefolia),* among others, are then sown directly by seed (or planted by seedling in the second year) alongside the rows of engineer species or in a mixture with leguminous shrubs such as pigeon peas (*Cajanus cajan*) or climbing beans (*Phaseolus vulgaris*), in addition to maize or sorghum and castor beans (*Ricinus communis*).

12.4 Conclusions

This study confirms that agroforestry systems can indeed provide practical solutions for turning the onus of restoration into a bonus for farmers. Among the wide variety of agroforests adopted by farmers in Brazil, biodiverse successional systems are most suited to reconciling the various environmental goals of Legal Reserves and Permanent Protection Areas (e.g. erosion control, nutrient cycling, ecological corridors, buffers for riparian zones, increasing and regulating water flowing) with their social function (e.g. food, fodder, income). How they are planned and managed, however, will determine the extent to which their impact swings one way or the other, or towards a middle ground solution. As seen in the five agroforestry options presented here, some systems are more production-oriented and others more geared towards conservation goals though all of them perform both functions to varying extents and enable shifting objectives.

The challenge to striking the right balance between these goals at the plot/farm level lies in adopting management practices and selecting key species that accelerate ecological processes and increase resilience along with species and practices that meet farmer aspirations and take their capacities and vulnerabilities into account. Since access to labour and knowledge are common constraints across most contexts, systems need to be simple enough – and appropriately sized – to be manageable yet complex enough to ensure key ecosystem functions desired are maintained over time. Oftentimes complex systems can be implemented using simple techniques that optimize scarce resources (e.g. labour and fertilizer), such as direct sowing of tree seeds, planting of cuttings, slash and mulch (as opposed to slash and burn) and use of highly efficient pioneer species to help raise others that come later in the succession.

Achieving impacts beyond the plot/farm to the landscape scale entails organizing stakeholders around common objectives and strategies and drawing connections between farms, but adopting the right combination of systems, practices and species for the reality of each farm. This entails co-designing a set of solutions aimed at mini-contexts and functions within the landscape by drawing together technical expertise and traditional agroecological knowledge, promoting farmer-to-farmer learning and participatory innovation. In some contexts, supplying basic training and initial inputs such as seeds and seedlings can be enough for farmers to get started on developing their own systems.

Meeting ambitious restoration goals at the national, subnational or biome level will require recognizing and regulating these best practices for reconciling conservation with livelihoods. In addition to establishing basic ecological indicators and protocols for monitoring restoration, state governments will also need to tackle the thorny but crucial issues of the composition between exotic and native species, how – and how much – trees can be cut or pruned, and what sorts of inputs can be used at different stages of restoration, among other factors. Moreover, mainstreaming these practices into rural credit, extension and environmental regularization policies will be instrumental to overcoming some of the key vulnerabilities faced at the farm level.

Ultimately, restoring millions of hectares of pastures and degraded lands in Brazil with scarce resources will require combining biodiverse agroforestry practices with more passive and inexpensive methods such as natural regeneration, simpler agroforests aimed at environmental functions, or mixed solutions mingling passive and active methods on the same plot or within the same landscape. Whatever the combination of methods, the key to restoring all this land lies in including people in the restoration process, in ensuring that they reap direct benefits in addition to the collective benefits they provide to others in the landscape and to the planet.

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