TECHNICAL GUIDEBOOK

AGROFORESTRY SYSTEMS for Ecological Restoration

HOW TO RECONCILE CONSERVATION AND PRODUCTION
Options for Brazil's Cerrado and Caatinga biomes

Andrew Miccolis
Fabiana Mongeli Peneireiro
Henrique Rodrigues Marques
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World Agroforestry

The degradation of ecosystems and loss of life forms throughout the planet is often associated with farming and grazing activities. Meanwhile, areas set aside for preservation are "protected" from humans by keeping them out altogether, or by only allowing entrance under strict controls. In this guidebook, we champion the notion that human action is not necessarily detrimental to the environment; rather, it can be beneficial, generating more life and resources to bring about positive impacts on the environment. Given the premise that the human species is part of nature, the main challenge lies in ensuring the quality and impact of human action on the environment. Striking this balance requires nurturing and improving our notions and attitudes about care for water, soil, and all life forms (including humans!). Some production-oriented land use practices deplete the area and degrade soils, while others make the soil and vegetation richer. What tips the balance one way or the other is the approach that farmers take to farming the land, to using and managing natural resources.

The main goal of this book is to guide the adoption of agroforestry systems (AFS) to restore and recover altered and degraded areas by using strategies that reconcile conservation with social and economic benefits. Based on a combination of technical, scientific and traditional local knowledge from innovative experiences, this book provides thorough guidance for technicians, farmers and policymakers about how Agroforestry Systems can and should be used to restore the various environmental functions that must be performed in certain portions of all private lands protected

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AGROFORESTRY SYSTEMS
for Ecological Restoration

How to reconcile conservation and production

OPTIONS FOR BRAZIL'S CERRADO AND CAATINGA BIOMES

ICRAF
BRASÍLIA
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World Agroforestry

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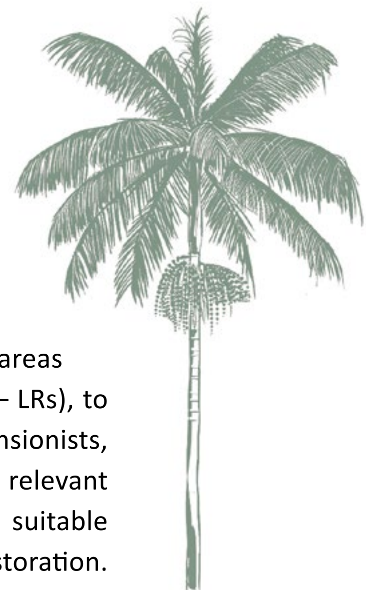
SUMMARY



The main objective of this book is to guide the adoption of agroforestry systems (AFS) to restore and recover altered and degraded areas, using strategies that reconcile conservation with social benefits. It came about through a participatory research process involving extensionists, farmers, researchers, policy makers and practitioners in the field of restoration and AFS. We began by analyzing norms governing the use of AFS in environmental protection areas (Permanent Preservation Areas – PPAs and Legal Reserves – LRs), to make their practical implications in the field clear to extensionists, farmers and policy makers. A broad-ranging survey of relevant literature investigated the feasibility of AFS and the most suitable systems to accomplish the ecological and social goals of restoration. In May 2015, during a participatory seminar on "Conservation with Agroforestry: pathways to restoration on family farms," 70 participants drafted principles and criteria to reconcile conservation with production. We then systematically analyzed 19 AFS experiences to draw lessons for best practices to be replicated, including visits to 16 farmers who shared their examples of promising management systems and practices, and consulted experts. With those inputs in hand, we propose recommendations to overcome challenges facing AFS and to draft enabling legislation for Brazil's new Forest Code. We developed an approach to social-environmental diagnoses in AFS planning attuned to the aspirations and conditions of families in their own environments. For some of the most common situations, like degraded pastures and areas with secondary plant growth, we present 11 agroforestry options to be adapted to each farm's specific characteristics. Recommendations include detailed descriptions of 19 key species for the recovery of degraded areas, and a total of 130 species deemed important for AFS-based restoration in a general table with functional attributes. Although this book focuses on Brazil's Cerrado and Caatinga biomes, the approach for socio-environmental diagnoses, the principles and criteria for selecting species and designing systems, as well as the implementation and management techniques, can be applied in other regions as well.

AGROFORESTRY SYSTEMS FOR ECOLOGICAL RESTORATION

HOW TO RECONCILE CONSERVATION AND PRODUCTION – **Options for Brazil's Cerrado and Caatinga biomes**

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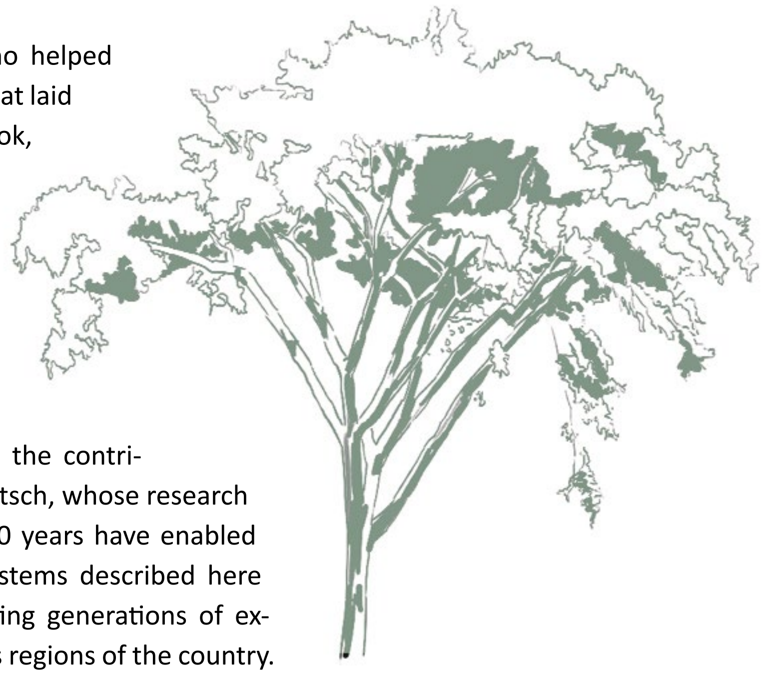

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CONTENTS

Diagnosis, design and implementation of AFS in different contexts

Photo: Fabiana Peneireiro

Photo: Daniel Vieira

INTRODUCTION

The world is undergoing an unprecedented environmental crisis. Over the last few centuries, soil use has depleted natural resources and aggravated social vulnerability in several regions throughout the world.

In rural areas, deforestation and predatory agriculture have driven plant and animal species into extinction, reduced the quantity and quality of available water, raised temperatures, altered rainfall regimes, diminished agricultural yields, eroded the soil and even desertified large swaths of land. Such degradation threatens the very presence of humans, pushing rural populations into cities to find work and generating a vicious cycle of social, economic, environmental and even cultural problems, leading to the loss of their identity as peasants.

Meanwhile, farmers, extensionists and scientists have developed and put into practice forms of production aimed at turning back these degradation processes. In many cases, nature itself is able to recover altered areas. Humans, however, can accelerate the restoration of such areas, caring for the soil and water, and introducing and managing plant and animal species that would find it hard to establish populations on their own in such situations. Rural communities, indigenous people and traditional communities can also benefit directly from well-managed vegetation, without necessarily causing degradation. Such strategies can be fundamental to the maintenance of ecosystem functions – the so-called environmental services – by regulating water cycles, adapting to climate change, controlling erosion and cycling nutrients. Areas undergoing restoration processes can also perform major socio-environmental functions including food and nutritional security and sovereignty, income generation, greater quality of life, conservation of water resources, balance in climate and biodiversity, among others. As they advance ecological restoration along with their own livelihoods, farmers shift from being problem makers to problem solvers.

Despite a growing awareness of how important it is to involve people in sustainable ecological restoration processes – i.e. conservation – many initiatives to "restore degraded areas" or to "recompose native plant cover" ignore the needs and potentials of the people and communities who live there. The high costs and lack of financial return to conventional restoration projects impel us to find more efficient forms of restoration that take into account those who live there and affect the landscape, to get them permanently involved in conserving and managing natural resources. Agroforestry systems (AFS) provide a range of opportunities to include people in processes to restore altered areas, as well as to include trees in agricultural landscapes.

For this publication to be useful, we recommend that it be distributed to farmers, to the agents and organizations responsible for technical assistance, rural extension, rural development, farm credit, capacity-building and environmental governance. We also encourage national and local policy makers to debate, adapt and internalize its suggestions with a view to developing and fostering systems and practices that can reconcile food production with environmental benefits and services through agroforestry systems.

The technical orientations presented here focus mainly on the context of family farmers. Nonetheless, the various techniques and options can also be applied by medium to larger farmers who wish to recover their Legal Reserves (LRs) and/or other altered areas outside the Permanent Preservation Areas (PPAs) with agroforestry systems. These principles, criteria and orientations indeed apply to any farmer who wishes to reconcile production and other social benefits with the conservation of natural resources. They are also useful for anyone who has been obliged to restore their land and still wants to obtain economic and/or social benefits in the process [141]. Although this publication focuses on Brazil's Cerrado and Caatinga regions, those who wish can adapt the options presented to other biomes as well, as long as they select species and modify some of the management practices suited to their context.

This Guidebook is divided into five main sections. Following an introduction and general context, we discuss the socio-environmental benefits and challenges of AFS based on a literature review (Section 1), as well as strategies to overcome these challenges (Section 2). Sections 3 and 4 focus on methods and techniques to implement restoration-oriented agroforests, beginning with an approach to socio-environmental diagnoses aimed at understanding the various limitations as well as the potentials of each context (Section 3). We then go over steps in financial planning and design of agroforestry arrangements, in addition to a variety of practical methods to implement and manage systems (Section 4). In Section 5, we describe eleven options for agroforestry systems that can be adopted in some of the most common contexts found in these two biomes, including key features of each context: farmer objectives, key species, and guidance on management practices. We then describe 19 key species for recovering degraded areas, their main characteristics and functional traits, as well as guidance on how to manage them, followed by a General Table of 130 species mentioned in this Guidebook and considered important for restoration with AFS in the Cerrado and Caatinga biomes.

The species descriptions contain both common and scientific names in the General Species Table, except when a species is only mentioned once in the text. In such cases, the common and scientific names are provided in the text. Throughout the book several boxes bring practical tips and quotes by farmers and extensionists who participated in the field visits and the seminar, as well as examples of successful experiences.

We hope this book will be a useful tool for meeting the challenges of restoring altered areas, including those specified by law. Its main goal is to help researchers, extensionists and family farmers develop and implement solutions that include the human component in restoring and conserving legally-protected areas (PPAs and LRs), while also supporting policy makers to enable the inclusion of trees in farming areas, generating socio-environmental benefits for farms and for society at large.

May you enjoy reading this and have success in your agroforestry harvests!

1. CONTEXT: THE CERRADO AND THE CAATINGA

CERRADO: THE CRADLE OF BRAZIL'S HEADWATERS

Brazil's Cerrado region contains a huge variety of landscapes including oases, hills, plateaus, high plains and valleys, with a myriad of vegetation types, ranging from grasslands and savannahs to dense forests. It is often called the cradle of Brazil's waters due to the number of headwaters of some of the country's most important rivers, which distribute water to eight of its twelve major basins: the Amazon, Tocantins-Araguaia, Parnaíba, North/Northeast Atlantic, São Francisco, East Atlantic, Paraná and Paraguay[73, 105]. In most of this biome, the rainy season lasts from October to April, with draught prevailing from May to September. Rainfall may vary from 800mm per year in areas near the semiarid region to 2,000 mm in transition areas near rainforests[53]. It occupies a vast expanse of some 200 million hectares, spanning across the entire Central-West and transitioning to three other biomes in the country's Southeast, North and Northeast regions, covering nearly a quarter of the national territory[127]. Today, the region has roughly 470,000 small farms, most of which belong to family farmers and traditional communities[128].

Brazil's Cerrado is the world's most biodiverse savannah, with 13,140 plant species, approximately 3,000 vertebrate species[1] and 67,000 invertebrates[127]. The Cerrado is also the source of livelihoods of a variety of traditional peoples and communities, including extractivists, indigenous peoples, *quilombolas*, family farmers and others[95], who also enjoy their own cultural diversity. Some of those communities have lived in the region for hundreds of years 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, Photo: Helena Maltez

Mirante das Janelas. Chapada dos Veadeiros. São Jorge – GO and another 70 in the Caatinga (described in the next section).

The Cerrado is one of the world's most endangered ecosystems due to the expansion of mechanized agriculture and the annual monocropping of soybeans, maize and cotton, the opening of new areas to graze livestock, forests planted to produce pulp and charcoal and dams built for hydroelectric projects [53, 105, 106]. Those mostly predatory activities are clearing some 30,000 square kilometers per year of the Cerrado – 1.5% of its plant cover [108]. Today, only 55% of this biome's natural plant cover remains[74].

Those threats highlight the importance of stimulating and appreciating the traditional sustainable practices of rural communities and promoting innovative approaches to landscape management that ally production with the restoration and conservation of natural resources. To that end, it is essential to foster public policies that uplift the Cerrado's products, its cultural wealth and the sustainable management of its landscapes. Agroforestry systems are excellent alternatives in this context, because they respect the potential of local resources as well as the region's ecological and productive possibilities.

Geraizeiro community crossing a spring in the Cerrado of Northern Minas Gerais State

Photo: Peter Caton/ISPN

Photo: Do Design

Landscape with the dry Caatinga forest

THE CAATINGA, NORTHEASTERN BRAZIL'S "WHITE FOREST"

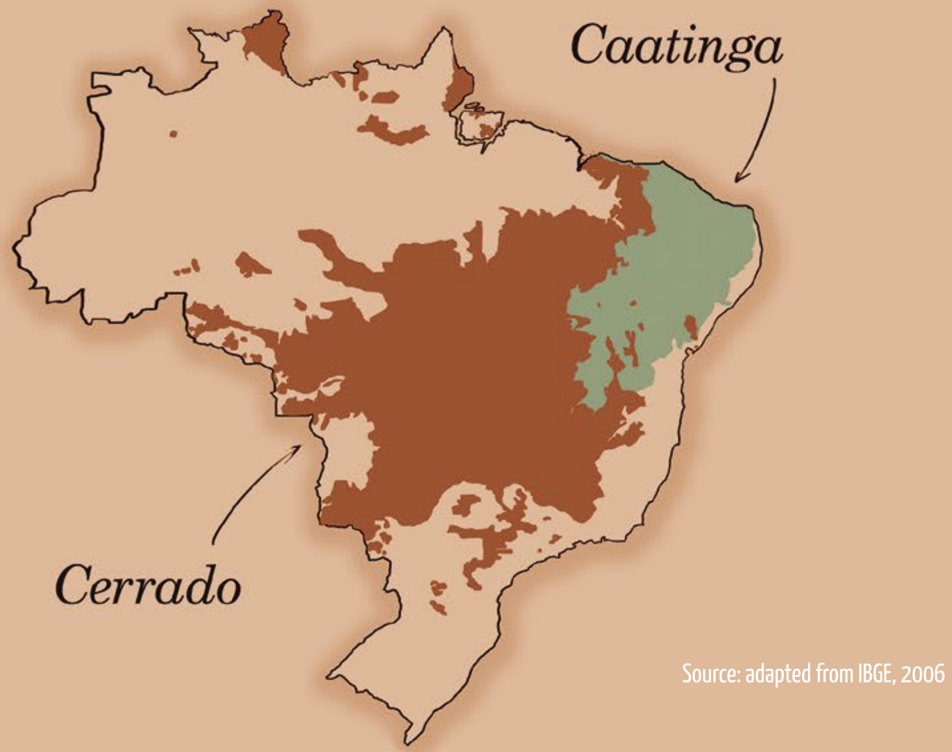
The Caatinga is northeastern Brazil's largest biome, with several types of vegetation in fields, shrubby and tall forests, an ephemeral herbaceous stratum and many thorny and succulent plants. The trees and brush drop their leaves during the dry season when their white trunks and branches give the vegetation a whitened physiognomy, which is behind its name in the indigenous Tupi language: (Caa) Forest (Tinga) White [70, 88]. The biome occupies about 85 million hectares in Brazil, in almost all the states of the northeast – Ceará, Bahia, Sergipe, Pernambuco, Alagoas, Paraíba, Rio Grande do Norte and Piauí – as well as small segments in Maranhão and Minas Gerais [52].

This exclusively Brazilian biome is home to some 2,000 plant species, 300 of which are endemic to this environment. Its fauna is also very diverse, with 178 species of mammals, 591 of birds, 177 of reptiles, 79 of amphibians, 241 of fish and 221 of bees[70]. Average annual rainfall varies from a little under 300 mm, in Paraíba state's Cariris Velhos region, to over 1,500 mm, in zones that transit into other biomes. In the other direction, there tends to be much more evapotranspiration than rain, some 1,500 mm to 2,000 mm per year[52, 72].

Most of the Caatinga has shallow soils, a warm climate and irregular rainfall. Those three factors combined make the environment extremely sensitive and vulnerable to desertification. The region's human population is around 27 million, many of whom are family farmers whose livelihoods depend on local resources. The Caatinga's irregular rainfall pattern makes life extremely hard for locals, known as *sertanejos*, and demands alternatives to adapt to and co-exist with drought in the semiarid[52, 105].

Ever since Brazil was occupied and colonized by Europeans, the region has suffered from the clearing of its forests for cattle grazing and charcoal production, which are still its main economic activities and the main causes of degradation of the Caatinga's ecosystems[7, 52]. Its plant cover had declined by nearly 50% by 2009, and measures taken since then to restore and conserve the biome have been few and insufficient[72]. Of all of Brazil's biomes, the Caatinga has the fewest conservation units (CUs), covering only 7.5% of its territory.

Farmers harvesting *umbu*, a typical fruit tree in the Caatinga. Photo: Do Design



The region's residents face major challenges related to the protection of its natural resources, living with and adapting to droughts, appropriate restoration and management approaches and the reduction of socioeconomic inequalities. Those challenges demand effective action to counter the degradation of the region's soils and natural resources, including better ways to raise livestock and make use of the native vegetation.

In the Caatinga, agroforestry systems to produce animal feed, short-cycle crops and fruit-bearing trees are alternatives that can combine conservation with quality of life for farm families. Some specific strategies for the Caatinga context, including livestock, are discussed in this book. We also share suggestions based on farmers' and extensionists' local experiences, for people to help avoid and even reverse desertification in the Caatinga.

The Cerrado and Caatinga need production techniques that enable native vegetation to be managed in consortia with cultivated species, to balance ecological and social functions on a landscape scale and spread mosaics interlinked with corridors between production and preservation areas. As we shall see in the next section, agroforestry systems provide countless practical opportunities to strike a balance among different objectives.

2. AGROFORESTRY SYSTEMS: SOCIO-ENVIRONMENTAL BENEFITS AND CHALLENGES

Agroforestry systems (AFS) can generate income and provide multiple environmental services. They have been evolving worldwide for thousands of years, mainly among traditional peoples, and now sustain at least 1.2 billion people (about a sixth of humankind)[82]. Only in the past 50 years, however, has science begun to study these systems, their costs and benefits and the complex interactions among their plant, animal and human components.

2.1 WHAT ARE AGROFORESTRY SYSTEMS (AFS)?

There are several ways to define Agroforestry Systems. One of the first, published in 1977, defined "agroforestry" as: *"a sustainable management system for land that increases overall production, combines agricultural crops, tree crops, and forest plants and/or animals simultaneously or sequentially, and applies management practices that are compatible with the cultural patterns of the local population."* [14]

The World Agroforestry Center (ICRAF) has suggested another definition: "Agroforestry is a collective name for land-use systems and technologies where woody perennials are deliberately used on the same land-management units as agricultural crops and/or animals, in either a spatial arrangement or a temporal sequence." [80,81] ICRAF has also proposed that AFS are "dynamic, ecologically based, natural resource management systems which, through the integration of trees on farms and the agricultural landscape, diversify and sustain production in order to increase social, economic and environmental benefits for land users at all scales." [56]

There are several distinct types of agroforestry systems and practices, ranging from simplified combinations of a few species and low-intensity management to extremely complex systems with high biodiversity and high-intensity management, as well as several types in between. The terms that describe them usually vary according to the main components.

Silvopastoral systems focus on livestock associated with pastures and trees. In some contexts, particularly in the context of restoration, the presence of domesticated animals such as cattle, goats, horses, sheep, buffaloes, swine and poultry is controversial, since these animals may potentially have negative impacts on the vegetation and soil. Besides leaving the soil compacted, if not managed properly, they can also leave it bare or upturned, eliminating plants through uncontrolled foraging, especially of new buds or stripping tree bark (very common for sheep and goats). Even so, the animal component can also be a mainstay of livelihood strategies that also enable family farmers to adapt to climate change, especially in semi-arid regions. Thus, in such contexts, solutions need to find ways of reconciling livestock raising with the recomposition of plant cover (such as systems described in Section 5).

Silvopastoral system: cattle on an ecological pasture. Santa Fé Ecological Farm, in Moquém, Nossa Senhora do Livramento, Mato Grosso.

Photo: Jurandir Melado

When agricultural and forest species are combined, either simultaneously or sequentially, with livestock raising, the systems are dubbed **agrosilvopastoral**, whereas **Agrosilvocultural systems** are characterized by intercropping annual agricultural crops with forest species.


Agrosilvocultural system


Agrosilvopastoral system

Successional or **biodiverse agroforests** can be similar to natural forest ecosystems as they are characterized by high plant diversity and managed in accordance with the natural succession of species. Ernst Götsch has been the main thrust behind the development and dissemination of such systems throughout Brazil's biomes [44, 48, 86]

Successional or biodiverse agroforest

Photo: Fabiana Peneireiro

Photo: Andrew Miccolis

Agroforestry homegarden

Agroforestry homegardens are an AFS that combines trees with agricultural and/or animal, medicinal and other domestic-use species. Located near homes, these systems normally are very productive and contribute in very important ways to families' food security and well-being.

For the purposes of this guidebook, our main reference will be the definition of agroforestry systems adopted in Brazil's legislation: "land use and occupation systems in which perennial woody species are managed in association with herbaceous, shrubby, arboreal, agricultural and forage plants in a single management unit, using a spatial and temporal arrangement, with a diversity of native species and interactions among these components." [19]

2.2 WHAT DOES ECOLOGICAL RESTORATION MEAN?

The most widely recognized definition of ecological restoration is proposed by the Society for Ecological Restoration (SER), which defines this practice as: "The process of assisting the recovery of an ecosystem that has been degraded, damaged, or destroyed."[129] Conceptually, a restored ecosystem contains a certain number of species that occur in the reference ecosystem. Functional groups (made up of species that carry out different ecological functions) are present or in the process of colonizing the area, while potential threats to the health and integrity of the ecosystem have been eliminated or reduced. In addition, the restored ecosystem is sufficiently resilient to withstand normal stressful events, it is self-sustaining, and it has the potential to survive indefinitely under existing environmental conditions.[129, 99]

SER's concept has evolved and, more recently, has been formulated as: *"the science, practice, and art of watching and managing the recovery of the ecological integrity of ecosystems, including a minimum level of biodiversity and variability in the structure and function of ecological processes, considering its ecological, economic and social values. [… It] seeks to ensure that the area will not return to its degraded condition, if duly protected and/or managed."*[130]

For Brazil's Ministry of the Environment, ecological restoration has a direct relation with the recovery of degraded areas (RDA) and matches the definition used by the SER.[131]

Some modern approaches to ecological restoration adopted by internationally recognized institutions embrace human wellbeing as a major outcome of restoration processes. For example, the Global Partnership on Forests and Landscapes Restoration (GPFLR) defines it as *"the process of regaining ecological integrity and enhancing human wellbeing in deforested and degraded forest landscapes."*[132]

Likewise, the definition used by the Ecological Restoration Alliance of Botanic Gardens stresses that *"Ecological restoration can and should be a fundamental component of conservation and sustainable development programs throughout the world by virtue of its inherent capacity to provide people with the opportunity to not only repair ecological damage, but also improve the human condition."*[133]

Other definitions focus more on ecological objectives, such as that of Brazil's National System of Conservation Units (SNUC): *"Restoration is a restitution process of a degraded ecosystem or a sylvan population to a condition as close as possible to the original."*[134]

Clearly there is no readymade formula for restoration, since each degraded environment has its own history and is subject to variables that call for specific strategies. From this standpoint, restoration actions should be broadly defined as those that reestablish ecological processes[158] based on a conceptual framework that defines the transition from a state of degradation according to forest dynamics and its implications in terms of management and human participation both spatially and temporally. This framework should be based on sustainability for restored areas that cover ecological, economic and social aspects that apply to landscapes with multiple land uses.[157] This means that even if human participation is not needed to restore areas that need to be preserved, it is essential for conserving them over time, particularly when agroforestry is a key strategy .

Ultimately, approaches to ecological restoration vary depending on the context and objectives to be achieved. For example, in restricted-use conservation units, where the objective is to restore, as much as possible, the composition and structure of the original plant community (even when that reference is hard to define), it is essential to establish local plant species, regardless of their socio-economic importance. In such cases, the use of exotic species is not recommended since it might conflict with the conservation objectives of that area.

In mosaic landscapes (mingling production and conservation), however, it is vital to include farmers or landowners at all stages of ecological restoration initiatives, from planning to implementation and management. In such landscapes, agroforestry systems can restore important ecological processes as well as ecosystem structures and functions, while also enabling economic returns and strengthening livelihoods and traditional knowledge in local cultures.[123, 135] In this approach, people are treated as integral parts of nature and players in the restoration process.[136, 137] This is the basic premise that underpins the principles, methods and recommendations of this guidebook.

2.3 AFS FOR RESTORATION AND CONSERVATION

The various inputs gathered for this study, including scientific studies and farmers' experiences, show that the types of AFS most recommended for environmental restoration and conservation are complex, biodiverse or successional systems, which most resemble the original local ecosystems' processes and functions and are managed based on the principles of natural succession. These AFS also entail adopting a broader concept of conservation that encompasses human beings as part of the ecological restoration of systems that provide food and other social benefits, including income, in addition to performing several important ecological functions. Lessons

> "The principles of nature are cooperation and not competition. Our biological function on this planet is to diperse seeds and make life processes more dynamic."
>
> Ernst Götsch

learned from many complex AFS lead us to conclude that the main factor underlying a sustainable AFS is the quality of its management, i.e. the work of human beings.

In Brazil, the degradation of ecosystems and life forms is often associated with grazing and other human actions. So areas requiring preservation are "protected" from humans, whose presence is banned or, when allowed, conditioned to strict controls.

In this book, we defend the idea that human activities are not necessarily harmful to the environment. They can in fact be beneficial, generating more life and resources, making people's presence helpful for the environment. The assumption is that the human species is part of nature. The issue at hand is the quality of human acts in the environment. Perceptions and attitudes regarding how to care for water, soils and all life forms must be developed, stimulated and enhanced among our fellow humans. Some forms of production impoverish the land and degrade the soil, while others enrich and protect the soil and its plant cover. It all depends on how farmers' world views lead them to work, on how they use and manage the land and its natural resources.

Brazil's current law for the protection of native vegetation (known as the "New Forest Law") allows for ecological restoration through agroforestry systems, as long as they maintain or improve the area's basic ecological functions. This means that the outcome of human interventions should benefit humans and all other living beings as well.

In practice, allying agriculture with conservation requires observing the principles of nature considering the vocations of people and place (socio-environmental conditions), as well as the function of each species (including humans), in order to choose the most efficient species and combine management practices that can accomplish different socio-environmental functions over time, thereby consolidating more life and resources in a given area. The ethics of care must therefore always be present in designing and planning solutions.

When ecological principles are followed, AFS can simultaneously generate social and environmental benefits on the same plot of land. In the following section, we summarize the main social and environmental benefits of AFS based on a review of scientific studies, mostly from Brazil but also from other regions of the world. We also discuss major challenges to the success of AFS and paths to overcome them.

> "Humans can include themselves, become part of the system and live off it without degrading resources for life (soil, water, biodiversity). Better yet, they can help increase them. When trying to include humans in conservation areas, other species must also be included to help make the environment livable. This means exotic species too and presumes human intervention with plants and pruning. The key concern must always be the original, natural ecosystem."
>
> Ernst Götsch

2.4 BENEFITS OF AFS

WHAT ARE THE BENEFITS OF AGROFORESTRY FOR THE ENVIRONMENT AND FOR PEOPLE?

Numerous studies throughout the world have identified multiple environmental, economic and social benefits of AFS, whose varying intensity and significance depending on the context, the type of system implemented and how it is managed over time. We know that AFS can perform various environmental functions. Those considered important for human beings are called socio-environmental benefits. AFS can help protect and enhance biodiversity, mitigate climate change and increase a system's capacity to adapt to its impacts. They can also help regulate the water cycle, control erosion, silting and the cycling of nutrients to increase soil fertility, improving its physical, biological and chemical properties. In addition, AFS generate many useful products for humans that can be sold, such as food, medicines, fibers, seeds, raw material for shelter and energy.

While few scientific studies have been published on AFS to restore conservation areas and on their impacts in the Cerrado and Caatinga, some studies on those biomes and on others in Brazil and worldwide show that AFS can contribute to conserving and restoring natural resources, and to strengthening farmer livelihoods. In this section, we summarize a broad review of scientific literature on the benefits and challenges of AFS, focusing on the Cerrado and Caatinga biomes.

Here, we highlight some of the countless benefits of agroforestry systems:

A) ENVIRONMENTAL BENEFITS AND ECOSYSTEM SERVICES

- Fight desertification
- Soil conservation
- Restoration of soil fertility and structure
- Shade and creation of microclimates
- Greater animal productivity due to well-being (shade) and the nutritional quality of pastures
- Ecological corridors
- Enhancement of overall biodiversity, including the presence of pollinizers
- Regulation of rain water and better water quality
- Mitigation and adaptation to climate change

AFS CONTRIBUTE TO STOCKING CARBON, ADAPTATION AND RESILIENCE

Scientific studies show that fully developed AFS can fix very significant volumes of carbon because increased metabolism and photosynthesis rates make plants absorb more carbon.[81, 115]

An agroforest's capacity to sequester carbon varies, depending on the type of system, the combination of species, the age of component species, its geographic location, environmental factors (such as climate and soil) and management practices.[56] AFS adopted by family farmers, especially the complex systems, can reach carbon sequestration rates close to those observed in tropical forests.[76]

A study to assess carbon dynamics in 4-15-year-old AFS, managed by family farmers in the Atlantic Forest in the State of São Paulo, identified an average annual volume of 6.6 tons of total carbon per hectare.[115] Another AFS study with African oil palm (*Elaeis guineensis*) in the State of Pará produced a high net accumulation of carbon in the first years (averaging 6.6-8.3 tons of carbon per hectare per year), more than a nearby 10-year-old secondary forest.[138]

Although carbon sequestration is fundamental to mitigating climate change, it should however not be a prevailing factor in decision-making on the best system to perform essential ecological functions. Eucalyptus monocrops, for example, store large volumes of carbon but do not necessarily contribute to the maintenance and enhancement of biodiversity.

Generally speaking, agroforests located in arid or semi-arid regions have lower potentials for carbon fixation than those in more humid regions. Although the climate is less favorable in regions with extended dry seasons, AFS in these regions can potentially sequester more carbon than surrounding areas with native plant cover.[81] In most cases, the greater the diversity of species and the denser the tree cover, the higher the potential for carbon sequestration in the soil.[56]

AFS are also considered highly resilient to climate change, since they have a longer harvest season, buffer the impacts of extreme events such as prolonged drought and floods, provide shade and shelter and act as alternative food sources in times of flood and drought.[57]

Agroforests are also able to change microclimates, protect crops sensitive to direct sunlight, reduce wind speeds as windbreaks, reduce temperatures and increase relative humidity.[54]

Figure 1 – AFS are environmentally beneficial and perform important ecosystem services such as maintaining biodiversity, protecting water resources and conserving soils.

AFS HELP MAINTAIN AND ENHANCE BIODIVERSITY

Areas planted with agroforests have a large potential for promoting greater biodiversity and helping reduce human pressure on native forests, due to their multifunctionality on farm and landscape scales.[55] They sustain the integrity of forest ecosystems, enabling the creation and expansion of ecological corridors and buffer zones[110] They thus provide habitats for species that tolerate a certain level of disturbance.

Some studies have also found an increase in native forest species and in the pace of their succession after the establishment of AFS modeled on forests in a secondary stage of succession[59] (secondary forests, or "*capoeiras*"). It should be noted, however, that this does not necessarily hold for savannah or shrubby types of plant cover.[34]

Evidence from other studies indicates a significant increase in the abundance of species in AFS, compared to neighboring forests.[15, 78]

Figure 2 – AFS have a great potential for enhancing biodiversity by combining conservation with production.

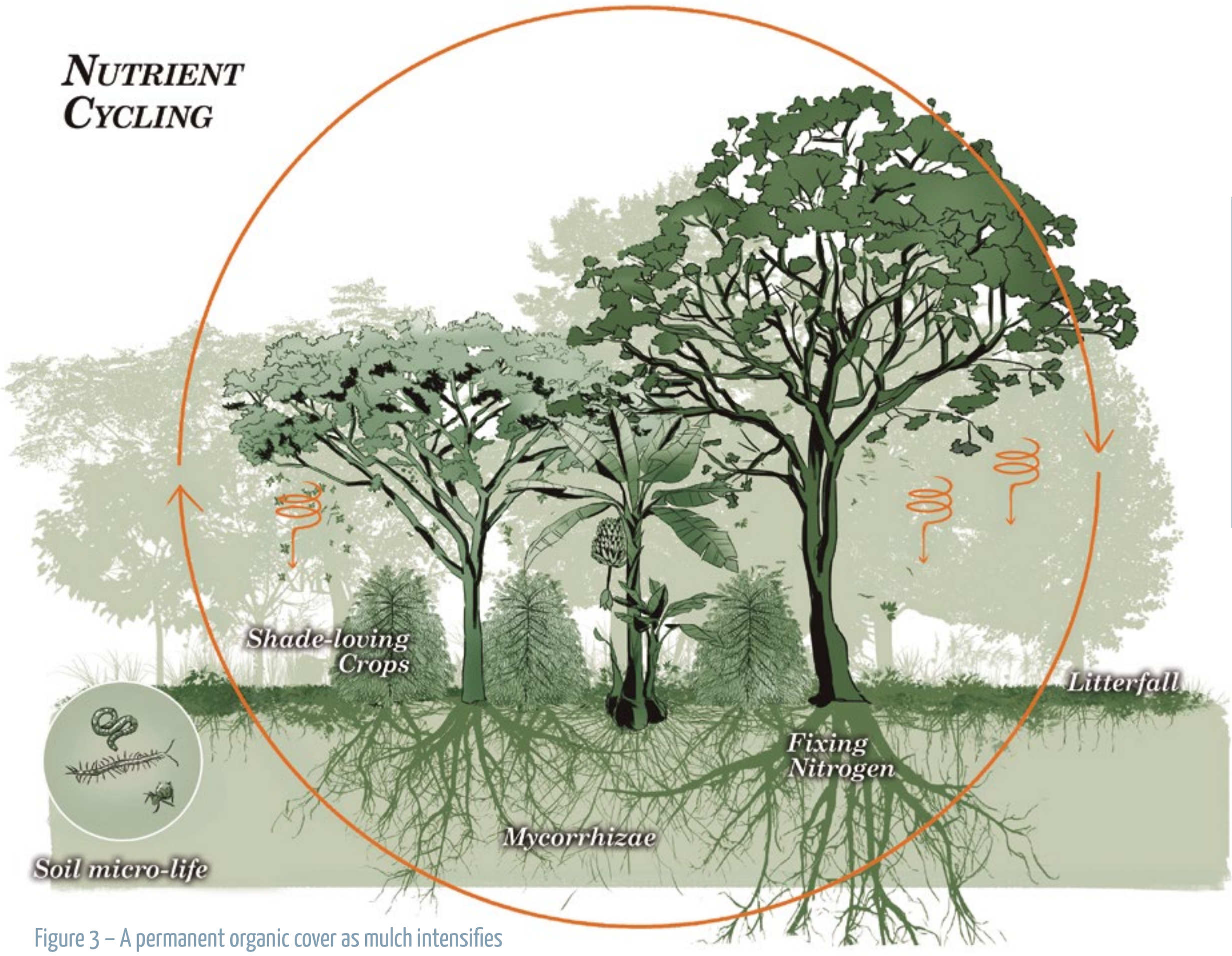


Figure 3 – A permanent organic cover as mulch intensifies soil life and promotes nutrient cycling.

AFS HELP CONSERVE AND MAINTAIN SOIL FERTILITY AND NUTRIENT CYCLING

The well-documented role of agroforestry systems in maintaining and improving the soil is often attributed to the use of biomass-generating species with a high capacity for making nutrients available. AFS can indeed help restore areas with low soil fertility[84, 123, 62] by offering substantial volumes of organic matter to promote nutrient cycling[41, 45] while reducing the risk of soil erosion and landslides.[39]

The more an agroforestry system resembles natural ecosystems, the more stable its structure and functions will be, making nutrient cycling more effective, as opposed to monocultures of either field crops or trees.[81] Complex, well managed AFS also enable good soil coverage, which is favorable to increasing microfauna populations and their action in the soil.[18] Such environments accelerate nutrient cycling as roots act in association with soil life and organic matter to provide nutrients.[8, 20]

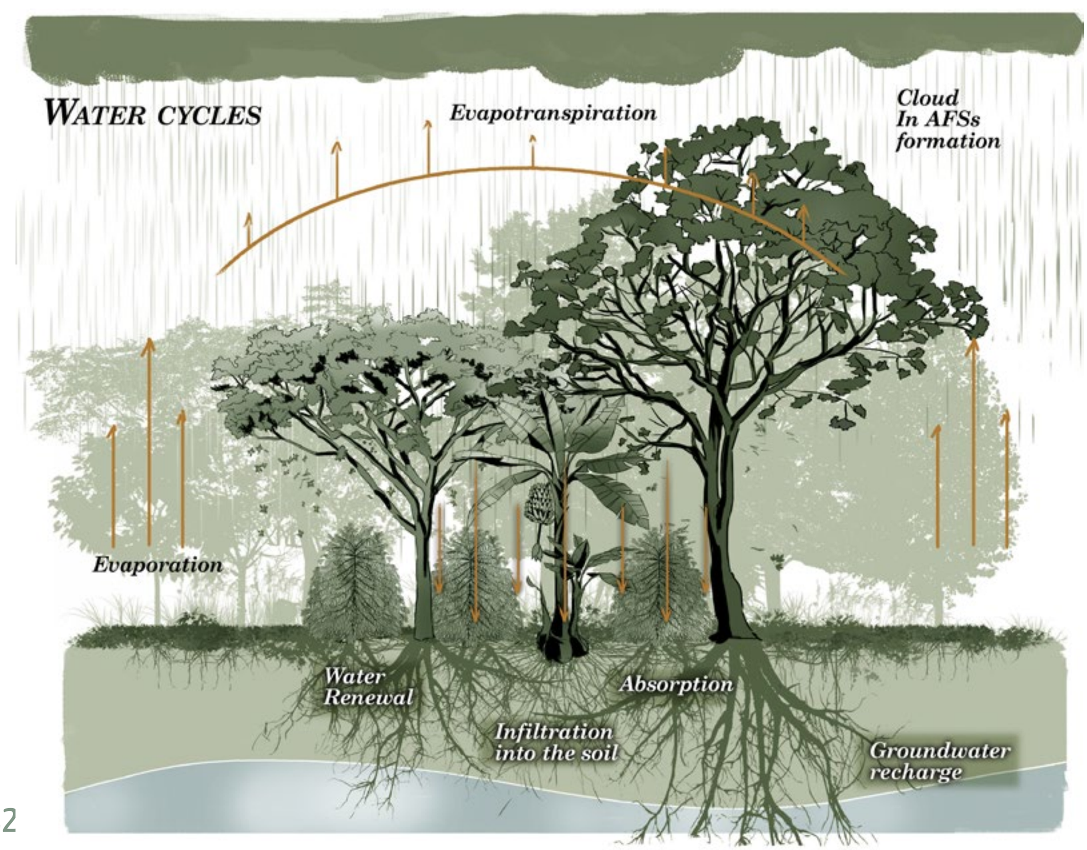
AFS HELP CONSERVE AND MAINTAIN WATER RESOURCES

The use of AFS has positive impacts on soil hydrological properties and exerts a direct influence on groundwater recharge. This should be recalled when assessing the impact of trees to be planted on a farm, especially in regions with prolonged droughts, such as the Caatinga and Cerrado.

The protection of water resources and the potential for regulating the volume and availability of water are positive outcomes observed in agroforests, which use a broad range of tree species favorable to faster infiltration of higher-quality water into the soil.[12, 139] Agroforests covered by tree species, with 100% closed canopies, can intercept up to 70% of the rainfall in some regions and help reduce superficial runoff, avoiding both erosion and flash floods.[37] AFS set up to protect rivers and creeks can also significantly reduce sediments and pollutants washed into water bodies.[107, 117]

In addition to their environmental benefits, AFS can also make major social and economic contributions, summarized here:

Figure 4 – The influence of AFS on maintaining water resources



B) SOCIAL AND ECONOMIC BENEFITS

- Enable the production of:
  - Food
  - Commodities such as coffee, cocoa and latex
  - Wood
  - Raw material for shelter (straw and wood)
  - Energy
  - Medicinal plants
  - Forage
  - Honey (beekeeping flora)
  - Raw material for handicrafts (seeds, fibers, etc.)
  - Cultural and spiritual goods
- Promote food and nutritional security and sovereignty
- Enhance honey production (Apis and native/stingless bees), as another food product along with others provided by AFS
- Greater efficiency in the use of production factors (water, light, nutrients)
- Reduce the purchase – and optimize use – of external inputs
- Fewer economic risks, due to lower sensitivity to negative price and climate fluctuations
- Generate and diversify income
- Manual labor distributed better throughout the year
- Greater cash-flow stability throughout the year and over the years, during the system's cycle
- Maintain and improve yields (higher production) over time
- Empowerment of women (when they have leading roles in agroforestry production) makes gender relations more equal
- Crops less vulnerable to pests and disease mean lower losses in production
- Higher quality working and living conditions (work in the shade)
- Stronger social organizations and more unity, consolidating community ties
- Maintain agro-biodiversity and associated knowledge
- Achieve ecological and forest restoration at a lower cost than conventional methods
- Enhance scenic beauty, providing possibilities for leisure and improving human well-being
- Recovery of traditional knowledge, solidarity and mutual-support activities, dignified remuneration and better quality of life
- Farmers can increase their sense of belonging in a restored area, compared to conventional restoration, since in AFS farmers tend to build relations with their areas, preventing events such as fires or the entry of animals that might seriously set back environmental recovery.

AFS CONTRIBUTE TO FOOD SECURITY AND LOWER RISKS

Agricultural landscapes that combine the cultivation of multifunctional forests with other land uses can give rise to interesting options and creative solutions for sustainable livelihoods.[14, 125, 22] Examples of socio-environmental services in AFS:

- More productive alternatives than conventional natural resource use systems[91]
- More favorable benefit/cost ratio compared to conventional forest restoration, due to management practices and the multiple uses of AFS products[75]
- More diverse production with a variety of intercropping combinations[38] spread harvests throughout the year as compared do seasonality of most farm systems[115], lowers the risk of pests and disease[67] and contributes to the production of more food and rural income, especially from forest products such as wood, fruit, seeds and oils.[114]

Figure 5 – Diversifying the biodiversity and timing of production lowers economic risks from seasonality and from "pests" and "disease"

A FARMER SPEAKS

A FARMER'S OUTLOOK ON AGROFORESTRY AND LIVESTOCK

"We know one hectare of grass feeds five head of cattle during the rainy season and one in the dry season here in the Araguaia region. Now, one hectare of cassava in the agroforest gives me 70 or 80 bags of flour. Today, a bag of flour goes for R$ 350 (which averages out to about R$ 26,250*). On the other hand, I can sell a head of 4-year-old cattle at the most for R$ 1,200 (which means R$ 300 per year). That's a big difference. Plus, for us who do both things and can compare, raising cattle has a lot of costs, but with cassava you just weed the field twice during the winter and that's it. Since the cassava grows in your agroforest, you take care of your seedlings at the same time, which will soon be generating income too.

People with a system like this always want to deepen their roots in the community. They never talk about selling their farm, just expanding it. People with nothing but cattle bring up selling their land a lot more. An agroforestry system gives people roots in the land.

The agroforest is the way I found to make a living and I'm happy there in my agroforest, which makes me an example for others to follow."

***Luiz Pereira Cirqueira** – Dom Pedro Settlement, São Félix do Araguaia, Mato Grosso. Source: Agricultores que cultivam árvores no Cerrado*[140]

**1 dollar = roughly 3.5 Reais.*

AFS CAN BE ECONOMICALLY VIABLE

In Brazil, agroforests have proven their economic viability in different contexts, although they depend on good economic planning, including market research and using the right techniques.[100, 102, 103]

In contrast to conventional restoration methods, which usually give no economic return on the money invested, AFS can potentially generate positive financial results that at least help pay for the costs of restoration. As we see in Table 1, conventional ecological restoration can be a major burden on a farmer due to high costs and the absence of any economic payback. AFS, on the other hand, clearly have a potential for turning the financial onus of restoration into a bonus. Indeed, the main challenge in ecological restoration is developing systems that reconcile economic returns with the environmental services expected of preserved areas. As we see in Table 1, successional AFS (with greater species diversity over time) produce more favorable financial results (according to the Net Present Value indicator) than simpler AFS. This confirms the importance of prioritizing those systems for ecological restoration, since they are also more favorable in terms of environmental services, as seen in the previous section.

TABLE 1: PUBLISHED DATA ON COSTS AND ECONOMIC RESULTS FOR DIFFERENT ECOLOGICAL RESTORATION METHODS IN PPAS AND LRS AND AGROFORESTRY SYSTEMS

Method of Ecological Restoration	Costs (R$/ha)	Financial return (R$/ha)	Source	Activities, place, year and reference for costs and economic results
Natural Regeneration	1.400,00	- 1.400,00	MMA (2015)[71]	Abandoned pastures in areas with low aptitude for agriculture or low yields, monitored during first 5 years. Estimate of average value done in different regions.
Assisted Regeneration – planting some seedlings and seeds	802,69	-802,69	Cury e Carvalho Jr. (2011)[28]	Forest restoration by planting native seedlings and tree species in islands, in Canarana, Mato Grosso, 2011. Costs refer only to initial establishment.
	2.131,09	- 2.131,09	Lira (2012)[60]	Drive and induce natural regeneration, including isolation of the area and removal of disrupting factors near the Rio Siriji Dam, PE, 2011. Costs refer to average values for the activities mentioned. Time of intervention not specified.

Method of Ecological Restoration	Costs (R$/ha)	Financial return (R$/ha)	Source	Activities, place, year and reference for costs and economic results
Natural restoration with mechanized planting of forest seeds	749,80	-749,80	Cury e Carvalho Jr. (2011)[28]	Direct mechanized sowing of seeds of native tree species and shrub and herbaceous legumes, region of Canarana, Mato Grosso. 2011. Costs refer only to establishment.
	5.375,00	-5.375,00	Hoffmann (2015)[47]	No-till mechanized planting of forest seeds (in soil covered with organic matter) from 2012 to 2015, carried out on farms in the municipality of Alta Floresta – Mato Grosso. Costs refer to installation and management until the 3rd year.
	4.298,85*	-4.298,85*	Campos-filho et al. (2013)[23]	Cost in dollars per hectare with no-till planting of a "*muvuca*" or mixture of seeds, with three years of maintenance in the area. Region of the Upper Xingu River, Mato Grosso. 2013. Costs refer to the average values of planting and management over three years on 26 farms.
Restoration by planting seedlings	5.122,33	-5.122,33	Chabaribery et al. (2008)[27]	Formation of riparian forest planted with native species, minimum soil tilling with digging of holes to plant seedlings and 1st maintenance. Municipality of Gabriel Monteiro, São Paulo. 2007. Costs for the 1st year.
	6.920,00	-6.920,00	Rodrigues (2009)[99]	Installation and maintenance of forest restoration project using native Atlantic Forest species, spaced 3x2m. Year not specified. Costs include planting and all forestry treatments required during two years after planting.
	10.000,00	-10.000,00	MMA (2015)[71]	Total planting (1,666 seedlings per hectare) based on average cost estimates in several regions of the country. Years not specified. Costs include implementation, management and follow-up over the first five years.

Method of Ecological Restoration	Costs (R$/ha)	Financial return (R$/ha)	Source	Activities, place, year and reference for costs and economic results
Restoration by planting seedlings and economic use	17.092,25	29,177.65	IIS (2013)[49]	Installation, maintenance and exploration of native species planted for economic use of timber products. Revenues from the planting model considering the most pessimistic scenario for prices of timber from native Atlantic Forest species. Costs and financial results projected for 40 years.
Simple AFSs	18.254,90	45.865,26	Gama (2003)[41]	System producing Brazil nuts, cupuaçu, bananas and black pepper. Machadinho do Oeste, Rondônia. 2002. Costs include establishment, management and harvesting services through the 10th year. Financial results refer to NPV (Net Present Value) for the same period.
	2.204,00 a 9.709,00	1.099,00 a 49.262,00	Hoffmann (2013)[48]	Less intensive and less diversified systems based on five experiences in different regions of Brazil. Number of species planted in these systems ranged from three to ten. Costs and financial results represent a range of all experiences, including installation and management costs in year 1 and NPV through year 10.
Successional AFSs	29.790,00	121.601,00	Hoffmann (2013)[48]	Successional agroforestry system with annual crops, semi-perennial fruit trees, native and exotic trees, grasses and other fertilizer species, in the Federal District. 2013. Costs include establishment, management and harvesting services. Costs and NPV are projected through the 10th year based on production data in the first two years.
	8.934,00	88.323,00	Hoffmann (2013)[48]	Successional agroforestry system with tubers, semi-perennial fruit trees, native and exotic trees and fertilizer species, in Southern Bahia. 2013. Costs include establishment, management and harvesting services. Costs and NPV are projected up to the 10th year based on production data from the first two years.

*Value converted in the reference year of the study; exchange rate = R$ 2.33/US$

DETAILS ON THE ECOLOGICAL RESTORATION METHODS PRESENTED IN TABLE 1

Assisted natural regeneration or active regeneration – Comprises the isolation of an area (with fences and firebreaks), enrichment with seedlings and seeds, when needed, and the removal of disruptive factors, allowing it to recover through the vegetation's natural dynamic.

Mechanized seed planting – Planting of native seeds with adapted farming machinery. Machines are used both to prepare the area and to sow the native seeds along with green manure species.

Planting of seedlings – Planting of seedlings, generally spaced 3x3m or 2x3m, depending on the forest succession, normally accompanied by liming and fertilization, surveillance and monitoring of seedlings, control of insects, weeding and the isolation and removal of disruptive factors.

Forest planting with economic use – Planting of native and exotic seedlings for profit, with varied spacing depending on the species chosen, either in rows or strips.

Simple AFS –Agroforestry systems composed of a limited variety of species. Generally, crops are planted in strips or rows to optimize production and generate revenue, whether agrosilvocultural, silvopastoral or agrosilvopastoral.

Successional AFS (also known as biodiverse or complex) – Agroforestry systems with much diversity of native and/or exotic species, with a (successional) management dynamic and the scaling up of production over time. This is a more complex system and demands more management and labor to generate abundance from the system and optimize agroforestry production.

When well planned, AFS can pay back investments and generate profits for farm families in a short time, depending on the kind of system they adopt. In some cases, this return can come in the first or second year, which is fundamental for family farming. In others, if no short-cycle crops are planted, the return on investment may take several years.[17]

> The income (or revenue) generated by 10 to 20 hectares in agroforestry systems is roughly the same as that of raising livestock on 400 to 1200 hectares (Pye-Smith, 2014)[93]

One important economic indicator for family farms, called "family labor remuneration" (FLR), expresses the value generated by a laborer's working day. Although there are AFS around the entire country, few publications provide enough data to analyze their FLRs, which depends on total production, labor employed over time and fixed and variable costs.

> FLR is an indicator that represents the value of the daily wage that an activity (in our case, the AFS) pays a family farmer. Measured in Reais per labor unit (LU) per day (Hoffmann, 2013)[48], it is equivalent to the value paid for the labor of a person in a day.

In an economic survey of 77 AFS experiences analyzed by several Brazilian researchers, they found six cases with complete primary data available for a period of more than eight years. In those cases, the FLR varied from R$ 53.00/daily LU to R$ 462.00/daily LU (these figures were corrected for inflation to the time when the minimum wage was R$ 680.00). Most of this variation was caused by the different cash crops and how they were managed. The study showed that the daily wage of agroforestry workers was higher than the average daily wage of farmworkers in general.[48]

The benefit/cost (B/C) indicator can be used for family farmers or large-scale projects as a ratio to express the value of benefits divided by the value of costs, corrected to the present value by the discount rate. The higher the B/C ratio the better the project. In other words, a benefit/cost ratio greater than 1 means the farmer gets more money back than what was invested. In those AFS in the survey, five of which had at least 25 years of data, there were also major variations in the results, from 1.8 to 10.2. All of them, however had favorable ratios for the farmer, i.e., greater than 1.

Besides the FLR and the B/C ratio, there are more significant financial indicators to assess the economic feasibility of AFS, including the Net Present Value (NPV), the Internal Rate of Return (IRR) and the Time to Return (TTR) on Investment. A project's economic feasibility, after all, depends on analyzing all of these indicators together, as we shall explain in greater detail in Section 4.3.

An AFS' potential for generating economic benefits also depends on the farmer's capacity to overcome barriers raised by adverse factors, some of which are structural bottlenecks in Brazil's agriculture and livestock sector, summarized in the next section.

2.5 CHALLENGES FOR SUCCESSFUL AFS IN THE CERRADO AND CAATINGA

Family farmers and extensionists interested in the benefits of agroforestry systems listed above face many barriers and limitations that must be overcome to scale up the adoption of restoration initiatives. Difficulties specific to local contexts demand practical solutions developed on the scale of the farm and landscape where they arise. Others are shared by the great majority of contexts and involve structural issues such as restricted access to rural development policies (rural extension, capacity building and credit), which depend on medium- to long-term governance solutions.

The most commonly observed causes of failure of AFS on a local scale in the Cerrado and Caatinga biomes are:

- Low access to knowledge;
- Low availability of labor;
- Limiting factors in the physical setting;
- Low access to inputs; and
- Lack of adequate agroforestry and economic planning.

ACCESS TO KNOWLEDGE

One major stumbling block on the path to success is limited access to knowledge and technical assistance on the best management practices required to enable and balance an AFS's various functions. In many cases, public extension services are unprepared to deal with AFS or agroecology, much less participatory approaches for farmers to help draft appropriate technological solutions for their own context.

More complex biodiverse or successional AFS provide more socio-environmental benefits than do simpler AFS, but they also pose major challenges due to the broad diversity of species and the complexities of management to maintain the system's productivity and resilience.

LABOR

High demand for labor can be another limiting factor for AFS, particularly biodiverse ones, because they tend to be labor-intensive and constant, and often there are not enough people in a rural community to meet the demand. This is often also a problem for the recovery of PPAs and LRs in conventional projects that plant native tree seedlings in their definitive spacing, where the cost of establishing and maintaining the area is high and economic paybacks are either non-existent or considered to be very low, as in extractivist activities or Payments for Environmental Services.[35]

Labor can also be a limiting factor in poorly planned or managed AFS that have been neglected by farmers who prioritize other productive activities that they master and that bring in short-term returns, such as annual crops, livestock, gardens or orchards.

Part of the high demand for labor in AFS can be covered by machinery, although there is still little machinery or equipment specifically designed for this purpose . Community or collective labor (known as *mutirão* in Brazil) can be an important strategy to mobilize a collective work force and strengthen social ties. For a collective system to work, though, the group must be quite cohesive and well organized.

ACCESS TO INPUTS AND ENVIRONMENTAL FACTORS

For many degraded areas, particularly where farmers have little access to inputs, another risk is low initial yields in food and cash crops. Even where inputs are available on the market, farmers may not be able to afford them, or their prices may vary with international market fluctuations, leaving farmers vulnerable to outside factors.

- Establishing a large-scale AFS requires large volumes of planting materials such as seeds, seedlings, cuttings and rhizomes, to ensure high density for the seedlings that survive in the first years. In many situations, where these materials are not available on-farm, they may be found locally, but usually there is no planning or logistics for collecting, storing and minimally processing a large volume of seeds or to produce seedlings.[91, 85]

- The physical context is also challenging in the Caatinga and Cerrado biomes, due to the poor distribution of rainfall, low levels of nutrients in degraded soil and hilly terrains that are frequently leached, compacted, acid and poor in organic matter. Such factors can be major limitations when combined with low access to inputs, labor and knowledge.

LACK OF AGROFORESTRY AND ECONOMIC PLANNING AND POOR MANAGEMENT

Several economic factors can cause an AFS to fail, such as high initial establishment costs compared to many monocrops, inefficient planning and human and economic resource management, lack of economic control, cash flow, limited diversification of AFS, inappropriate combinations or components in AFS and low prices for the chosen products.[89, 90]

In addition, AFS that are successful for the first few years can see the output of cash crops decline due to faulty or inadequate management. When fast-growing species that shade fruit trees are not pruned, for example, fruit yields will decline.

Here are some other structural bottlenecks to successful AFS related to socio-environmental policies and governance mechanisms, which vary from one context to another:

STRUCTURAL CONSTRAINTS TO THE DEVELOPMENT OF AFS

- Little access to rural extension services, generally under-staffed to meet the needs of family farmers. Few extensionists have enough training to help apply agroecological principles or guide restoration with agroforestry systems.[45, 91]
- Recommended production systems are often based on specific technological "packages" that farmers find difficult or unaffordable, and whose success depends on resources beyond their reach such as knowledge, inputs, labor, etc.
- Low access to rural credit for agroforestry and agroecological systems. Existing credit facilities are underused because small farmers are unaware of how to apply[41, 57] and few extensionists have enough experience and knowledge to help them draft AFS projects.[91]
- Difficulties in complying with complex tax and sanitary norms to be allowed to process and market products and to license processing plants.[91]
- Lack of consumer awareness about agroforestry, agroecological and agroextractivist products and their origin.
- Long distances, rough roads and lack of transportation to market production.
- Families, associations and cooperatives have insufficient technical and administrative capacities to do planning, organize production and manage processing and marketing.
- Absence of specific markets and overall consumer ignorance regarding the benefits of AFS.[68]

Based on farmers' and extension agents' practical experiences with AFS, here are several suggestions that may help overcome those challenges.

2.6 OVERCOMING CHALLENGES TO AFS: LESSONS AND RECOMMENDATIONS

AFS whose objective is both restoration and production are more likely to succeed when:

- Land-tenure issues are settled to ensure farmers feel comfortable investing in perennial crops.
- Proposals are developed jointly "with" and "among" farmers, considering their desires, vocations, objectives, knowledge and skills.
- Farmers' contexts are understood, including the landscape's limitations and opportunities.
- Good planning produces suitable choices based on correct diagnoses: the choice of the area to be restores considers its location in the landscape; the choice of species to plant responds to market access and demand issues, environmental conditions and farmers' vocations; recommendations for fertilizing and management are designed in accordance with farmers' access to labor and other inputs.
- Sinergy among species is achieved through proper combinations and interventions.
- Adequate soil preparation, with fertilizers if needed.
- Correct timing and methods fo**r planting and seeding** including depth, density and spacing**.**
- **Area protected** against fire and the entry of livestock.
- Ease of access to inputs such as organic fertilizers, seeds and seedlings.
- Correct management and upkeep of the AFS.
- Management able to reconcile food, market and environmental/ conservation objectives.
- Biodiversity enhanced through human intervention, by stimulating natural regeneration or with the introduction of seedlings and seeds of those species.
- Soil permanently covered with organic matter to keep it protected and enable nutrient cycling.
- Wind breaks used.
- Evolution of ecological succession with greater volume and quality of life.
- Exchange of experiences for farmers and extension agents to feel secure about intervening in the AFS.
- Sufficient high-quality technical assistance available over time.
- Value added to products, including certification and forms of economic solidarity.

The following principles were developed by experts and practitioners who have done restoration with AFS in the Cerrado and Caatinga.

- **Work together:** extension agents and farmers with experience in agroforests guide other agents and farmers.
- Collective efforts:
  "Working collectively helps everyone learn."
- Learn from what went right and wrong. Don't be afraid of mistakes, but don't repeat them.
  "Learn from nature and from people doing agroforestry."
- Get assistance from people who know how to do agroforestry.
  "Achieving change depends on training and organization."
- Occupy participatory spaces, exchanges, fairs and gatherings.
- Promote dialog between traditional and scientific knowledge (at universities, NGOs, companies and research institutes).
- Encourage exchanges of experiences among farmers.
  "Use the farmer-to-farmer method, based on the dialog of outlooks."
- Plan seed gathering and exchanges, and make them a habit.
- Give preference to local, landrace varieties that can be reproduced later (avoid hybrids and never use transgenic seeds).
  "When you have diversity, you don't need to bring in fertilizer."
- Work in partnerships.
  "Environmental agencies have to get involved."
- Get youth involved. Create community spaces to share knowledge, including with city people.
  "Learning comes with practice. Observing and reflecting on the outcome of interventions is the best way to learn."
- Train multipliers.
  "The greatest tool for convincing people is having an experience to show, or else organizing the exchange of experiences."
- Promote community organizing.

- The human component is fundamental! Whoever is taking care of the system must identify with it and be free to intervene.

- Working with participatory certification in the CSA (Community Supported Agriculture) system adds value to products and is a learning experience.
- Projects and extension agencies should encourage farmers' contributions.

A FARMER SPEAKS

MOTIVATION TO WORK WITH AGROFORESTRY

"When I took it over, this area was very ugly, really degraded, because there was nothing here. I lived here, but I moved away. I lived here with my parents and my whole family. In my father's very traditional system you burned everything, nothing left, just uproot and burn it all. That's why this was all nearly desertified. It was burn and plant, burn and plant, just take away, produce and take away. There was a fallow time, but what happens to fallow land if you don't feed it, don't protect it, out in the sun all day … When I met Chico and Elviro, who were working with AFS, I started getting involved with them, about ten years ago. I'd lived outside the farm already and seen a lot, other farms, and I came back to our area where we had never even cultivated our own food, and I started working. My dream was to produce food both for me and for nature too, where any natural species could feed here without running any risk. A bird eating a mango or cashew fruit with no guns around to shoot them."

Ernaldo Expedito de Sá *– Tianguá, in the Ibiapaba Environmental Protection Area, Ceará.*

A FARMWOMAN SPEAKS

WORKING WITH LOVE

"Work with love. Believe it's good!" "If you keep the forest alive, you never worry about the dead volume (technical reserve in water reservoirs)."

Fátima Cabral *– Pipiripau, Federal District (Brasília)*

2.7 PRINCIPLES AND CRITERIA TO RECONCILE SOCIAL AND ECOLOGICAL FUNCTIONS IN AFS

To provide a basis for agroforestry interventions and practices in a broad range of contexts, a number of principles and criteria aimed at combining social and environmental concerns were listed by a variety of people with experience in AFS. Those principles were first discussed at tehe *Conservation with Agroforests Seminar: pathways to restoration with family farms*, held in May 2015, and are summarized here. The list of participants is on page 49.

General principles to reconcile social and environmental objectivs in AFS:

i. conservation of water resources, the soil and biodiversity;
ii. preserve the farmers' ways of life.

Those principles can be broken down into more specific principles and criteria:

A) REGARDING ECOLOGICAL FUNCTIONS

i. Consider the farm as a whole and its function in the landscape before planning the priority areas for Legal Reserves, Permanent Protection Areas and others with special aptitudes for AFS;
ii. Use no synthetic fertilizers or pesticides, prioritizing local inputs, green manure, animal manure, rock dust, natural or homemade products to control "pests" and disease that are allowed by organic agriculture standards;
iii. Recomposition and maintenance of the original plant cover's physiognomy, while managing natural regeneration and dense planting with high rates of biodiversity and species suitable to the context (native, introduced and exotic), will be keys to a successful AFS and require good planning and management;
iv. Optimize exposure to sunlight by using stratification;
v. Ensure that soil preparation has no negative impacts such as compaction or susceptibility to erosion;
vi. Use erosion-control methods when necessary;
vii. Keep the soil covered permanently with organic matter;
viii. Keep drivers of degradation under control, such as livestock (restricting their grazing area), fires (use firebreaks and refrain from slash-and-burn in nearby areas) and pesticide drift (if used in nearby areas, only at times when there is no wind, and ensuring a buffer strip);
ix. Manage species with the goal of successfully establishing the system over time.

and ...

B) REGARDING SOCIAL FUNCTIONS

i. Provide for the farm families' ways of life, i.e., contribute to their food and nutritional security and sovereignty, as well as income for their livelihoods;
ii. Promote farmers' autonomy by minimizing their dependence on outside inputs, prioritizing the use of local resources, emphasizing traditional knowledge and exchanges between traditional and scientific knowledge and creating new knowledge collectively;
iii. Get farmers involved in the conception of the system, including the choice of species, and ensure sensitivity to gender and generational concerns;
iv. Consider the interests of the family as a whole;

v. Take culture, world views and spirituality into account in the development of agroforests;
vi. Choose species and design the AFS based on available resources and each family's management capabilities;
vii. Choose species based on their socio-environmental multifunctionality (food, ornamental, green manure, medicinal, cultural and spiritual values, biomass production to raise other species, water storage, etc.);
viii. Promote agrobiodiversity, prioritizing the use of local landrace seeds.

LIST OF PARTICIPANTS AT THE SEMINAR IN BRASÍLIA, MAY 2015

Alana Casagrande, Alexandra Ferreira Pedroso, Ana Elena Muler, André Brunckhorst, Antonio Weber, Cainã Feraz e Silva, Carolina Guyot, Claudia Zulmira Cardoso Oliveira, Claudionísio de Souza Araújo, Cosmo Nunes da Paixão, Delman de Almeida Gonçalves, Denise Barbosa, Donald Sawyer, Eduardo Barroso de Souza, Elder Stival Cezaretti, Fábio Vaz Ribeiro de Almeida, Fátima Cecília Paim Kaiser Cabral, Fernanda de Paula, Francisco Antonio de Sousa, Ginercina de Oliveira Silva, Guilherme Mamede, Helena Maria Maltez, Isabel Figueiredo, Renato Araújo, Igor Aveline, Igor de Carvalho, Ítalo Veras Eduardo, Jéssica Lívio, Joangela Oliveira de Moura, Joel Araújo Sirqueira, José Augusto da Silva, José Fernando dos Santos Rebello, José Melchior, José Moacir dos Santos, Leosmar Antônio Terena, Mara Vanessa Fonseca Dutra, Marcelino Barberato, Márcio José de Sousa, Márcio Silveira Armando, Marcos Rugnitz Tito, Mariana Aparecida Carvalhaes, Martin Meier, Mateus Motter Dala Senta, Paulo José Alves de Santana, Pedro Oliveira de Souza, Raimundo Deusdará Filho, Regina Helena Rosa Sambuichi, Renata Zambello de Pinho, Ricardo Ribeiro Rodrigues, Rivelino da Silva, Robert Ramsay Garcia, Rodrigo Mauro Freire, Sandra Regina Afonso, Selma Yuki Ishii, Silvia Teixeira da Silva, Tatiana Rehder, Thomas Ludewigs, Welligton Gouveia de Morais, Gabriela Berbigier Gonçalves Grisolia, Lia Mendes Cruz, Daniel Costa Carneiro, Daniel Mascia Vieira, Fabiana Mongeli Peneireiro, Andrew Miccolis, Henrique Rodrigues Marques, Ana Cláudia, Fernanda Oliveira do Nascimento, Artur de Paula Souza, Caio Sampaio, Silvana Bastos.

Photo: Andrew Miccolis

3. HOW TO PRODUCE AGROFORESTRY SYSTEMS FOR RESTORATION

3.1 SOCIO-ENVIRONMENTAL DIAGNOSIS

A participatory socio-environmental diagnosis is intended to analyze and understand a family's main **objectives/vocation**, what resources are available to them and, if they have access, what **strategies** the family adopts to uses those **resources** and achieve their objectives, and how they deal with stress and disturbances (such as drought, market variations, health, etc.) to reduce their vulnerabilities. The diagnosis is the basis for planning actions.

Figure 6: A good diagnosis and participatory planning are essential for the success of AFS.

3.1.1 TOOLS FOR THE PARTICIPATORY DIAGNOSIS

The socio-environmental diagnosis should be carried out together with the farmer, using the following participatory tools:

A "MAP" OF THE FARM (OR OF THE MICRO-REGION)

This can be a playful activity, hopefully involving the entire family. It stimulates everyone's spatial perception of the farm, how the land is used, connections among land-use units (called agro-ecosystems) and relations with neighboring areas. It is suggested that the family draw a map of their farm, showing the areas and how they are used. It may also be useful to describe land uses and conditions in neighboring areas, including geography, socio-economic variables, production, environmental factors, etc.

ANALYZE AN AERIAL IMAGE OF THE FARM AND ITS SURROUNDINGS

This image can be obtained on a computer using the Google Earth™ program. Compare the family's "map" with the Google EarthTM image to find more elements and perceive the landscape, possible connections among fragments and the location of degraded areas, water sources, areas with native vegetation, etc.

A CROSS-CUTTING WALK AROUND THE FARM

This technique involves walking around the houses and the whole farm, considering the history of how the area has been used, the logic and dynamics of its occupation over time and the kind of production carried out today. This cross-cutting walk also helps understand strategies involving water, waste management and work flows on the farm, as well as the farm's situation in terms of compliance with environmental laws.

Full knowledge of the gardens, fields and reserve areas is key to understanding the family's vulnerabilities and the strategies they have adopted. One must then observe what kind of plants and animals are produced, and how they are managed and used, to then be able to assess to what extent the people are making use of locally available resources. Comparing that information with the farmers' objectives, we can tell whether their livelihoods strategies are the best approach to address the location's specific problems.

The walk provides information through direct observation. Seeing and grasping the soil shows many of its characteristics. Observing the animals shows their states of health and nutrition. Exploring the area to be restored reveals any soil erosion, where the rainwater runs and the indicator plants. A look at the waterways shows how much silting there is. The makeup of the family allows for an estimate of how many hands there are to do the work.

SEMI-STRUCTURED INTERVIEW AND A CASUAL CONVERSATION

To complete the process, a semi-structured interview or a casual conversation in the farmer's own setting is often more effective than asking a person to fill out a complex questionnaire. The conversation's success will depend on the listener being sensitive and attentive. A feeling of trust and shared interests will bring out much information that could be lost to a dry questionnaire. To that end, a visit with a presentation by the extension agent, a conversation about the work to be done, about the family, its origins and history, etc. will open doors and favor closer relations between the farmer and the extensionist, based on a rapport of mutual confidence.closer relations between the farmer and the extensionist, based on a rapport of mutual confidence.

Dialog is the main tool for a good diagnosis.

3.1.2 CONTENTS OF THE DIAGNOSIS

THE FAMILY'S OBJECTIVES, ASPIRATIONS AND DREAMS

Farmers are the key component of any AFS, since they put in the personal energy to make it work. To motivate them to try something new, their own objectives and aspirations must be part of the systems designed and guide the selection of species.

This means that the dialog with the family must begin with a conversation about their **objectives**, their **vocation** and their **dreams**, preferably involving different members of the family: women, men, youth and the elderly. This not only helps cover the needs of the different family members as the system is designed and the species selected, it increases their likelihood of really committing themselves to the project.

First, we ask what the different member s of the family would like to do with their area, about their overall vision of the whole farm and of specific areas inside it (including the PPA and the LR). It is helpful to know not only what they want to plant and produce but also what they see as the future of that area.

From the outset, the process of planning, designing systems and developing technical solutions must be carried out together with the farmers or whoever will actually be working the land, making decisions and feeling the impacts. During the process, they will be able to propose ways to achieve their objectives and materialize their visions, the extensionist will provide information and new ideas about how to make those objectives practical, while ensuring other environmental functions that the area must provide to comply with the law.

The next step is a survey of the resources on the farm and in the micro-region, and how accessible and affordable they are for the family. This will help reveal points where the family may be vulnerable, as well as identifying certain potentials they were not aware of.

To find out about the family's objectives, the following questions can be useful:

What does the family want?

Is the AFS aimed more at:

- Conservation/restoration?
- Food and nutritional security and sovereignty?
- Return on their economic investment?
- A combination of the above?
- What is the vocation of the persons who will work on the AFS?
- What species does the farmer want to produce?

ACCESS TO RESOURCES AND LIVELIHOODS STRATEGIES

Here, we must understand whether and how people use different resources to achieve their objectives and materialize their vision of the future, and to what extent those strategies have been successful or not. This means identifying how the lack of access or misuse of resources can make farmers more **vulnerable**. It is also important to observe whether different strategies for using resources are making the farmer more or less vulnerable to certain risks and threats, such as climate change and extreme events, market fluctuations (product prices and the cost of inputs going up or down), pest or disease attacks and changes in public or private policies.

The analysis of resources can give rise to a dialog on longer-term trends, whether the supply of each individual resource has risen or fallen and the general availability of resources. This analysis helps asses the impacts of current land-use strategies, the consequences of different management strategies and possible changes of direction.

In the next section, we explain the different kinds of resources, focusing mainly on their implications for managing the agroforest. These concepts about resources were first developed by researchers at the Institute of Development Studies (IDS) in the UK[142,31] as part of the Sustainable Livelihoods Approach.[126]

HUMAN RESOURCES

Human resources include knowledge, skills, health and other less material but significant aspects such as faith, hope, solidarity and spirituality.

The design of an AFS and the choice of the species and the production system's degree of complexity are directly related to those resources, especially the availability of labor and access to knowledge. The quantity and quality of labor available are decisive when designing and choosing management practices suitable to a family's situation. For example, in situations with little available labor, more easily manageable species should be prioritized, depending on the skills and possibilities of the family members. In addition, when the farmers are knowledgeable about the species and agroforestry practices, their confidence and skills in working the AFS will increase their likelihood of success.

Photo: Daniel Vieira

To identify potentials for working in the AFS, it is important to ask:

- Who will do the planting? How much time do they have available?
- Who will do the management? How much time to they have available?
- What are the laborers' physical conditions? What skills do they have?
- Are there people able to process the products?
- Do the people who will work in the AFS have knowledge about the species and agroforestry practices?

Photo: Daniel Vieira

SOCIAL RESOURCES

Social resources, i.e. the farm family's relationship with a collective (local and regional communities and society), are also factors for the success or failure of an agroforestry project. These resources include social organizations (a group, association or cooperative), representation, access to public policies such as rural extension and rural credit, solidarity activities (collective work days, mutual aid habits), support from the community, among others.

To identify aspects related to this kind of resource, the diagnosis should investigate the following issues:

- What is the farm family's degree of social organization?
- Do they have access to public policies directly or indirectly related to AFS (such as credit, government-supported direct procurement markets, distribution of seeds and seedlings)?
- Do they have access to extension services? How frequently, and what kind of assistance is provided by extensionists to the family?
- Are there solidarity activities such as collective work days, mutual aid, labor swaps, etc.?
- Are there activities in which a collective supports the farm family (such as someone in the community to represent the farmer at markets)?
- Are they involved in spheres of social participation (committees, commissions, fora, etc.)?

NATURAL RESOURCES

Natural resources are everything that comes from nature and may be available in varying degrees to people who live in an area, including the air, water, plants, animals, soil, sunlight and others. Knowing the state and availability of these resources allows us to analyze an area's main limitations and potentials when picking species and designing systems suitable to local environmental conditions at the time of the intervention.

In ecological restoration initiatives, it is particularly important to assess the state of the spontaneous plant cover and soil conditions, to introduce plants adapted to those conditions that can produce without depending on many outside inputs. The vegetation that flourishes in conserved soil is a reference for the biomass situation and the AFS structure we can achieve. To that end, we need to assess the area's **ecological resilience**, in terms of its regenerative capacity and the stage of natural succession of the native plant cover, through the presence of regenerates (seeds or even living root stocks). That assessment will indicate any need for enrichment or for management by selective weeding and pruning, when the resilience is medium or high, or to introduce species important for succession in the area, when resilience is low with a prevalence of exotic grasses.

Some **indicator plants** help assess soil conditions. Arrowleaf sida (*Sida rhombifolia*), for example, indicates compacted soil. Cogon grass (*Imperata cilindrica*), *rabo de burro* grass (*Andropogon bicornis*) and ferns (*Pteridium* sp.) indicate acid and degraded soils. Whitemouth dayflower (*Commelina erecta*), purslane (*Portulaca oleracea*) and fameflower (*Talinum patens*) are plants that indicate soil with medium to high fertility. Many farmers can tell from the presence of certain species whether the soil will be productive or not for crops, and that information is valuable. It is helpful to survey the crops adapted to the regional ecosystem or raised on local farms, taking note of specific microclimates of a given farm, in addition to crop varieties bred by research institutes and traditional varieties that are well adapted and produce high yields.

In planning an AFS it is vital to survey the **local sources of nutrients** (lime, rock dust, manure, ashes, saw dust and food-processing residues such as castor bean cake, coffee husks, etc.) to supply the planted areas and thereby lower costs and boost output. This information can even influence which type of AFS will be most suitable and the best management approach in a given context. Even so, it is important to bear in mind that some species native to the biome do not accept excessive fertilization, when they have already "adapted" to the acid and unfertile soil in the area. The souari nut (*Caryocar brasiliense*), for example, is intolerant to lime on the seedlings.

Surveying potential planting material present on the farm, environs or microregion (seeds, seedlings, rhizomes and cuttings) can substantially reduce the cost of establishing AFS and also enhance the diversity of species being introduced. It is thus a good idea to map out the location of such sources and the season when they produce seeds, to include the gathering of this material as a vital step in planning.

Important questions to ask about the local environment and natural resources:

- What is the average rainfall in the area?
- When is the rainy season and what are the best months for planting?
- Are there prevailing winds? From which direction? During which seasons?
- Is the soil degraded? If so, how much?
- How fertile is the soil?
- What crops are grown in the region under similar conditions?
- Which species occur spontaneously in degraded environments?
- What are the opportunities for connecting to forest fragments?
- Is there native vegetation nearby?
- Is any natural regeneration taking place?
- How intense is that regeneration?
- Does the ground get soaked?
- Is the terrain hilly or not?
- Is the soil compacted or not?
- Is the soil well drained or not?
- Is there a spring nearby?
- Is there a source for nutrients nearby (lime, rock dust, saw dust, manure, food-processing waste, ashes)?
- Is there a nearby source for planting material (seeds, seedlings, shoots)?
- Does the farm comply with environmental regulations?
- Has the farm been included in the Rural Environmental Registry?

PHYSICAL RESOURCES

Information must also be gathered on the physical assets, such as buildings, equipment and tools. That information will also help choose the species and design, establish and manage the AFS. For example, if the workforce is limited but there is a bush cutter, the size of the area and the kind of management may be different from a situation with the same labor available but no bush cutter. Likewise, the presence of electric power allows farmers to process products into frozen fruit pulp, for example, which would otherwise be out of the question, just as water in abundance for irrigation significantly expands their capacity to grow water-dependent greens and fruit.

Important questions about physical resources:

- What are the main facilities and equipment available on the farm (fences, barns, running water, electric power, etc.)?
- What tools and equipment are available, to produce, store and process products?

FINANCIAL RESOURCES

Financial resources mean the capacity to invest, buy things or "save" not only money but things like livestock or timber trees, as sources of income, as well as having access to credit and to a market. In addition to transportation, the distance from points of sale and road conditions, it is also important to be aware of what the market demands.

A survey of short food supply chains in local markets can be valuable, for example in the main markets in nearby cities and towns, as well as vegetable and fruit markets, covering factors such as: existing and missing products, retail prices, sale volumes, quality standards and untapped demand.

That study will provide a profile of local markets in terms of demand, supply, prices, marketing strategies and delivery logistics.

Important questions about market access:

- How do people access the market: street markets, home delivery, institutional markets through government programs (school lunch procurement, etc.)?
- How far away are the markets?
- What transportation is available and how are the roads?
- Which products sell best in the market?
- Where would the products be sold?
- Does the product's market price cover the costs, including labor, inputs and others?
- What is the volume of demand for each product (on local and regional markets)?
- What is the selling price for the farmer (both for direct sale and for resale through middlemen)?
- What is the accepted quality standard for the product?

The information from this diagnosis will help identify major vulnerabilities facing one's resources and livelihood strategies, as well as potentials that might otherwise be overlooked. These are the main variables to be considered in decisions on the next stage of planning. Our intention is to design systems and solutions that reduce both socio-environmental and economic vulnerabilities, while ensuring that the plan's various social and environmental functions will be performed. Ultimately, the discussion should be about managing multiple resources (human, social, natural, physical and financial) so that the increase (or reduction) of one resource will not undermine the resource base as a whole.

Alongside the diagnosis, it is also very helpful to be aware of model experiences with AFS-based restoration, preferably by farmers in the same region. One strategy to encourage farmers to establish AFS is to set up jointly-planned experimental areas, or else to begin by enriching homegardens, and then expand into larger areas. This approach reduces the risks in each initiative and allows the systems to be adapted and adjusted.

3.2 DECISION-MAKING ON A LANDSCAPE SCALE

The scope of restoration and conservation initiatives reaches far beyond the farm because impacts and interactions among drivers of degradation and environmental variables play out at a landscape scale, in watersheds or even in entire micro-regions. This scale requires participatory natural-resource management strategies involving the different players present in the context and reliable information on the diversity of land uses and their impacts on environmental services and socio-economic factors. There are several tools and methods that can be extremely useful to support negotiations and decision-making processes involving land use at the landscape scale.

One methodology, developed by IUCN and partners, known as **ROAM** (Restoration Opportunities Assessment Methodology)[119], is very useful to identify opportunities and establish restoration priorities at sub-national or national levels, by achieving shared understandings among various stakeholders.

Over the years, ICRAF has developed a toolkit that combines advanced remote sensing methods with participatory methods also linked to decision-making science, to simulate development scenarios and enable land use planning at the scale of landscapes, states or entire regions.

One such tool is **LDSF** – Land Degradation Surveillance Framework, which uses advanced GIS and soil analysis technology to assess and inform the extent of degradation and restoration in each area and to support decision-making on land use, and monitoring and evaluation of impacts.[121]

Another is **LUMENS** – Land Use Planning for Multiple Environmental Services[30], which supports negotiations on decision making by simulating, through modeling, different development scenarios for a specific region and their likely consequences, thus enabling assessments of tradeoffs for environmental service indicators such as carbon, biodiversity and water resources.[122]

For more information on these and other tools and methodologies, see ICRAF's Negotiation Support Toolkit[122]:

http://blog.worldagroforestry.org/index.php/2013/12/20/negotiation-support-toolkitfor-learning-landscapes/w

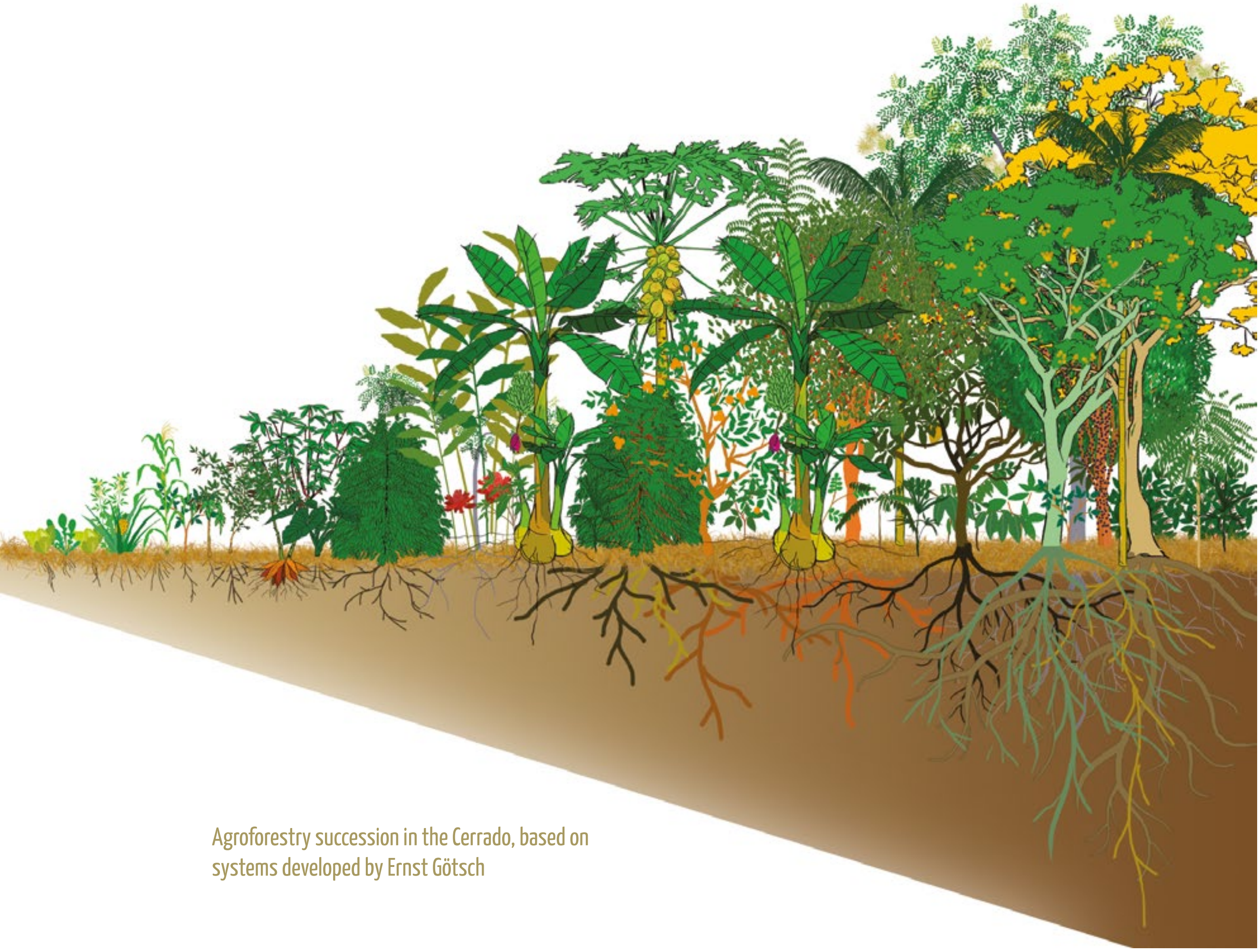
Photo: Daniel Vieira

4. PLANNING AND DESIGNING AGROFORESTRY SYSTEMS

Planning agroforestry systems that balance social and environmental functions requires understanding the movement of nature itself. **Ecological succession** drives the development of ecosystems and expands resources available for life. It is also the road home for an ecosystem after a disturbance or degradation.

In this process, different groupings of species succeed each other over time. Species emerge, develop, take hold, reproduce and die out, changing the environment for others that come next. These dynamics arise from species with different life cycles, eco-physiological needs (favorable environmental conditions for their development: light, humidity, temperature, nutrients, etc.) and environmental colonization capacities. Species with similar life cycles make up successional groups. As they interact with the environment, they perform different functions and modify it. Plants with shorter life cycles develop with plants that live longer and, when they are pruned or complete their life cycle, they leave behind the benefits of their presence. Those benefits include all the material they leave in the soil and the results of their interactions with other plant, animal and microbial species, which make nutrients available and improve the soil's structure, fertility and moisture.

Each species occupies a story or layer in the vegetation based on the relative height of different plants and each species' need for sunlight as an adult. Plants in the emergent story need direct sunlight the entire day, while high canopy layer plants tolerate partial shade for parts of the day, and plants in the medium story tolerate a little more shade and those in the understory perform photosynthesis in denser shade, with light filtered by the overstory trees. When different species from different stories grow together, they optimize the space they occupy and thus the use of resources (water, light, nutrients and "companion" organisms such as beneficial fungi and bacteria). This optimization makes it possible for AFS to be successfully established.



Agroforestry succession in the Cerrado, based on systems developed by Ernst Götsch

Another important consideration with sunlight is the forest dynamics in each context, where native species have co-evolved over thousands of years. In climates with a well-defined dry season, for example, the forest is deciduous, i.e. canopy species drop their leaves every year. The middle- and lower-layer plants, which thus receive much more direct sunlight, are physiologically adapted to that dynamic. Coffee bushes, for example, need a "shock" from direct sunlight to induce flowering, after which fruits can grow under the shelter of the budding leaves. So management practices must be in sync with local climate-induced changes that forests (and agroforests) go through over the course of a year, as opposed to static percentage rates of shade for a given species or kind of plant.

Other species are typical in forests that undergo disturbance on a regular basis, such as riparian zones or places with high winds, generally low or medium-layer species, which still depend, however, on regular openings in the canopy, like the *jabuticaba* or Brazilian grapetree *(Plinia cauliflora).*

In short, we must consider each plant's life cycle and the story it will occupy to plan efficient AFS, especially to include plants that meet the needs of family farmers.

In addition to different sunlight needs, plants also have different demands in terms of soil fertility and water availability. Some plants require very fertile soil, while others do well in relatively poor soil. Some need more water and others have adapted to conditions with little water available. In regions with little water for long periods of time, there are plants that store water in their own structure, adapting to such conditions while also helping other plants grow. Many native plants more adapted to such conditions can contribute to the success of AFS. The choice of different combinations or arrangements of such plants will therefore depend on the context and the main limitations and potentials found in each situation.

The presence of herbaceous and shrub species (which may be agricultural or native) is very important as a

Figure 7: Good planning of forest layers will optimize resources: water, sunlight and nutrients

natural nursery to establish trees from seeds. This is the case, for example, of pineapple, manioc, jack beans and pigeon peas, known as “nurse plants” or “mother plants”. We can use species that are very efficient at producing biomass as sources of organic matter to be chopped into green manure for better fertility, to accelerate soil life dynamics and maintain moisture for other species in the ecological succession process.

When planning and designing AFS, we must therefore pay attention to how the species and their respective functions are distributed over space and time. First and foremost, systems must be designed based on lessons and observations from the socio-environmental diagnosis and in compliance with criteria and guidelines for each step, beginning with site selection.

4.1 PLOT SELECTION AND PLANNING: PLACEMENT IN THE LANDSCAPE AND DESIGN ELEMENTS

For any plot to be developed, the planning must look first at its role and links to other elements in the socio-ecological context, including:

- **SOCIO-ENVIRONMENTAL FUNCTIONS OF THE CHOSEN AREA**

  PPA, LR, wind-break, crop fields, strip to separate two production areas. Design and species selection depend on the function of the chosen area. Areas that prioritize preservation (PPAs) should be managed with lower-impact operations and require mostly native species.

- **CONNECTIONS WITHIN THE LANDSCAPE**

  Observe the location of native plant fragments and try to connect them in the AFS design to facilitate the movement of wild animals and enhance the benefits of ecological services for the AFS, such as natural “pest” control and production of organic matter. AFS can be also be established along the edges of such fragments to facilitate colonizing altered areas. In such cases, native plants along the edges are pruned or coppiced to avoid the influence of old trees on the seedlings in the AFS. The biomass pruned from the edges is then used to cover the soil as mulch in the newly planted, neighboring area.

- **SUNLIGHT**

  The sun’s path over the area should be observed in the agroforest’s position and direction to ensure more hours of sunlight for some species and less for others such as young saplings that need shade from midday onwards when the sun is hottest. For example, when garden beds or islands of vegetables are planted on the edge of an AFS, they should initially be placed on the side receiving the cooler morning sun but then protected by taller plants that enjoy the afternoon sun. Shrubs and trees with longer cycles that grow more slowly will not block the short-cycle vegetables. Another example is the placing of cuttings, which should point to the setting sun (west) parallel to the sun's paths to keep the stems from being scorched in the hot afternoon sun.

- **WATER**

Observe which way the water flows and any points where erosion is possible to divert it and enhance absorption by the soil, using terraces (swales) or small ponds to help the water soak in and stay there. Small ditches can also be key to draining waterlogged soils when needed to establish trees. Where more water is needed, especially during droughts, covering the soil with more organic matter keeps any humidity from dew in the soil from evaporating. Another key strategy is to use windbreaks, which also substantially reduce moisture loss.

- **SLOPES**

Observing the direction and steepness of slopes is key to planning successful planting, management and harvesting activities. The relation between hillsides and the angle of sunlight is also important. In Brazil (and the southern hemisphere as a whole), north-facing slopes receive more sunlight in the winter and south-facing slopes in the summer. Contour planting, swales and terraces, which can vary in width and length, are highly recommended to avoid erosion. The most important technique in such contexts is covering the entire area with a generous layer of organic matter.

PRACTICAL TIPS

On steep slopes, water will soak better into the soil and nutrients can be retained by digging swales or small terraces in following the contour of the entire terrain to contain water flowing downhill. The organic matter must also be properly organized along the contour lines to hold back rainwater.

- **SOIL CONDITIONS**

Check the soil texture: is it sandy or clayey? Sandy soil drains water more easily whereas clayey soil retains it and can be prone to waterlogging. The soil's organic matter content can be gauged by observing its color, smell and texture. Good soil, with more organic matter, is generally darker and has a neutral, pleasant smell of humus, with a granular structure that makes it soft and porous. Compacted soil, on the other hand, can create a serious barrier to plant growth, with heavy machinery leaving soil compacted 20-30 cm below the surface. There are simple ways to assess soil conditions that do not depend on expensive laboratory analyses and can be performed locally by the farmer and extensionist. Most experienced farmers are good at gauging soil conditions, so when in doubt ask them.[13]

- **WIND**

Observing the direction(s) of the strongest prevailing winds shows where to place wind-breaks and to plant species more sensitive to heat behind others that can bear more, to protect them from the wind. Wind can break plants or cause water stress, because it reduces moisture, until the plants close their stomata.

> **Stomata:** Small apertures on leaves through which gases and water are exchanged with the environment.

Since the wind can also transport insects, like white flies, and the seeds of undesirable species into a system, it is important to protect plants and the area from strong winds. A good wind-break can significantly enhance the production of an agroforest or a vegetable plantation.

- **FIRE**

When relevant, observe possible directions fire may approach and plan systems accordingly with fire breaks (weeded strips) and hedges to block them, preferably using species that don't easily catch fire. Examples of such species include the aveloz/firestick (*Euphorbia tirucalli*), janaúba/milk shrub (*Synadenium grantii*), different types of sisal (*Agave americana L*), leaf cactus (*Pereskia aculeata*), Mexican sunflower (or tree marigold) (*Tithonia diversifolia*), pear cactus (*Opuntia ficus indica*) and sabiá (*Mimosa caesalpiniaefolia*), among others.

- **LOGISTICS**

Access to and movement within the area is key to bringing in inputs and taking out products. Decide where the entry and exit to the area will be located, and whether roads will be needed to move machinery in the area. Plan strategically to avoid trampling and machinery moving inside the planted areas.

- **LIVELIHOODS CONSIDERATIONS**

  How will peoples' lives change when they move from one production system to another, from one plant species to another in the same system? How will each choice affect the farm and family resources and vulnerabilities identified in the diagnosis? The selection of species and of management practices must consider not only economic and environmental gains (for example, carbon or biodiversity), but also the system's overall resilience, plant and animal health (both wild and domestic) and the wellbeing of the people involved in the process.

To decide on the best **spacing and fertilization** for each species or establishment technique, it is important to recall all the factors identified in the diagnostic appraisal, especially: soil fertility; availability of planting material (seeds, cuttings, seedlings); sources of organic matter (leaves, branches, wood) and fertilizer (manure, ashes, compost, rock dust, saw dust, etc.); availability of manual labor for fieldwork and the main functions of each species within the system (fertilization, biomass production, fruit, shading, etc.)

Spacing: The general rule is to respect the same spacing recommended for each crop (especially for fruit trees), when planted in orchards or monocrops.

PRACTICAL TIPS FOR SPACING:

- For low-fertility areas, "fertilizer" species should be planted densely, and fruit trees closer together, since they will grow smaller than in more fertile soil conditions.
- When you are short on seeds or seedlings of very important species, plant them to grow in their final spacing arrangement.
- When there is little material to propagate a species (seeds and/or seedlings) it is better to plant in a smaller area but completely covered than to space more thinly in a larger area, unless the species is able to spread well and occupy nearby empty spaces.
- Do not worry about planting too densely where it will be possible to thin the area later. In any case, natural thinning may also be performed by ants, termites, caterpillars, etc.
- Avoid planting species that occupy the same story vertical space for access to sunlight) next to each other at the same time.
- Leave enough room between rows of plants (trees and others) to allow for management.
- Measure the width of beds, islands or groupings to keep them within arm's length of the people who will manage them.

- Trees and shrubs planted for their biomass potential can be planted alongside other trees that will spend more time in the system (lumber, fruit trees), as long as they can be regularly pruned or coppiced.

TIPS FOR FERTILIZATION

- In PPAs, organic fertilizer and agroecological techniques should be used to control pests and disease.
- Fertilization should be guided by soil fertility, the plants' needs and on how much is available on the farm or nearby.
- Calculate whether the investment in fertilizer will be compensated by a higher yield of that species. As a rule of thumb, if a species needs a large volume of fertilizer to produce well, it may not be the right species for that location at that time. In many situations, choosing a less demanding species may be the safer choice. More demanding species may be incorporated into the system over time, as the soil's fertility improves.
- Plan fertilization to benefit different species at different times. For example: vegetables, followed by other herbaceous plants, shrubs and trees.
- In the long term, the best fertilizer to restore soil is the local vegetation chopped and spread on the ground, particularly the wood decomposed by fungi, bacteria and insects, which provides nutrients needed to maintain yields.
- Always consider which plants, or groups of plants, will fertilize the system at different moments in its future development.

PRACTICAL TIPS

FERTILIZATION

One technique used in both flooded and dry areas is "organic fertilization," as practiced by Luizão. The fertilization is done by piling dry material around the foot of a tree. "The circle is to keep it moist. This is green manure, with jack beans and a layer of grass. When we lay it on the ground they grow faster." This fertilization is for trees, even when they are seedlings.

Farmers can pick up saw dust for fertilizer during their trips to town spread it as is, with no need to ferment it: *"Just throw it around the tree and it'll rot by itself. It heats up the trunk and the rawer it comes the more the plant grows and thickens. The more it heats up, the more the termites and ants run away; they can't take it inside. The buriti (Mauritia flexuosa) and the cupuaçu (Theobroma grandiflorum) both grow fast with this fertilizer. Orange trees don't like it much, though."*

The grass that grows around the tree and green manure is slashed periodically and worked back into the compost. *"When I cut the grass, I throw it all back on top. The best time is the rainy season, to consume it all. When it rains, it rots, and the plant grows. During the drought, it stops."* No one mows during the drought, when the mulch cover slowly decomposes and thins. *"Then the rain comes, and I slash before it gets difficult, but only around the plant. In between I let it grow. The closer you leave the grass, the better it takes the drought. The nearby grass is good, but the sawdust is better."*

***Luiz Pereira Cirqueira** – Dom Pedro Settlement, São Félix do Araguaia – Mato Grosso.*

Source: Farmers who plant trees in the Cerrado[140]

4.2 SELECTING THE SPECIES

MOST SUITABLE SPECIES FOR SPECIFIC CONTEXTS

Some species are particularly strategic for agroforest restoration projects due to features that enable the arrival of other species by enhancing soil conditions and water availability.

For AFS to effectively balance different social and environmental functions, it is vital to include species from the outset that comply with the following criteria. Any species that meets several of these criteria is considered a **key species**.

Priority should thus 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 highly efficient at improving the soil and the environment through various functions over time (short, medium and long term);
- The farmer can manage given the locally available work force and skills;
- Have a potential for marketing, especially when this is an objective; and
- Fits well with other species in the AFS guild in terms of the space it occupies over time and throughout its own life cycle.

Several multifunctional species are listed among those recommended for restoration in the Cerrado and Caatinga, in Table 8, Section 5.4

Above all, the species chosen must be compatible with local conditions **and with the interests and desires of the farmers**. For example, in areas where there is flooding, it is important to choose species tolerant to waterlogging. If the system focuses on both restoration and making money, the species must have a commercial value. On degraded soil, the choice must be for species able to fertilize the soil efficiently, and so on.

Species able to **store water** can be vital for situations with extreme water shortage, including most of the Caatinga and Cerrado regions, where the yearly dry season is well-defined and prolonged. Succulent plants that swell to absorb water in their structures, such as cacti (pear cactus, *mandacaru* and *xique-xique*) are sources of water for animals, plants and even people. They keep the landscape green when all the rest has turned grey.

Pear cactus (or forage palm) in the Caatinga.
Source: maisbahia.com.br site - https://goo.gl/ygQTtl

Mandacaru: stays green during the drought in the Caatinga.
Source: http://www.panoramio.com/photo/61423522

Other plants have root structures that are veritable water tanks. The *mamuí* (or *jaracatiá - Jacaratia spinosa* (Aubli) A. DC), the *umbu* (*Spondias tuberosa*) and the *cajá-mirim* (*Spondias purpurea* var. *lutea*) have such underground storage structures, called xylopods, that help them make it through prolonged droughts.

Root of an umbu tree. Source: maisbahia.com.br site - https://goo.gl/ygQTtl

Xylopods, veritable water tanks. Source: https://goo.gl/0x4Q0z

In the Cerrado biome, palm trees store water in their trunks and leaves and thus remain green during the dry season. Some examples of the many native palm trees in the Cerrado are the *buriti (Mauritia flexuosa), macaúba (Acrocomia aculeata), indaiá (Attalea oleifera), coquinho azedo (Butia capitata), coquinho babão* or *jerivá (Syagrus romanzoffiana), babaçu (Orbignya speciosa), guariroba* or *gueroba (Syagrus oleracea), brejaúba (Astrocaryum aculeatissimum),* and *juçara* (*Euterpe edulis*).

Photo: Henrique Marques

Area with several juçara (*Euterpe edulis*) palm trees, which help increase resilience during droughts in the Cerrado. Geranium Farm, Brasília, DF.

Photo: Andrew Miccolis

Banana trunks cut in half and arranged to cover the soil. Sítio Semente, Brasília, DF.

Banana plants are also very efficient at storing and providing water for the system. When cut in half and arranged on the ground, their pseudo stem (trunk) holds in the moisture while also providing important nutrients such as potassium, and improving soil life.

Other desirable features are **high production of biomass** and **good response to pruning**. Species that produce particularly good volumes of biomass for the system favor **nutrient cycling**, protection and soil life. Examples of such species in the Cerrado include the eucalyptus, *inga*, *mutamba* (*Guazuma ulmifolia*) and Mexican sunflower (*Tithonia diversifolia*) trees and some grassy species. In the Caatinga, we have the Gliricidia (*Gliricidia sepium*), mesquite (*Prosopis juliflora* (SW) DC), *sabiá* (*Mimosa caesalpiniaefolia* Benth.), sisal and pear cactus (forage palm). These species may be constantly cut to spread their material on the ground, protecting against erosion and improving soil fertility. Some key species with these features are exotic to the Caatinga and the Cerrado biomes but well adapted to these soil and climate conditions and can thus be extremely beneficial to enhance local biological resources.

PRACTICAL TIPS

MESQUITE OR CAROB TREE (*PROSOPIS JULIFLORA* (SW.) D.C.)

The mesquite is an active colonizer that can cover an area quickly and uniformly. Over time, this cover thins out by itself when weaker, smaller plants die out. Moacir explains how the mesquite grows fast. Just a year after removing all the individuals with a machete and chainsaw, the secondary growth covered the entire area with brush that was, on the average, four meters high. With their intense regrowth capacity, cutting them down is not enough and they sprout back from the roots. In this area, the intention is to facilitate the natural return of native plants and to plant more.

The *braúna* (*Melanoxylon brauna*) is a species that manages to live and compete with the mesquite, as opposed to the majority of species in the region. Some individual *braúna* trees remain in the area. Mesquite demands annual treatment to keep it from invading nearby areas. It likes moist environments and is prone to taking over creek and river banks.

In another area, thinning was used to create a silvopastoral system, using the Embrapa Caprinos model, with grass and mesquite. Mesquite plants were spaced 20 meters apart. Once all the material from the initial thinning is on the ground, it will decompose and improve soil conditions.

The system then goes through an annual thinning, removing the largest and oldest trees and selling the mesquite wood, which earns a good price in markets. The younger plants can also be removed during maintenance. Once all the material is withdrawn, new species can appear, and it is time to plant grass. When the grass has grown considerably, some animals may be released in the area for controlled grazing.

In this system, the mesquite pods are a good source of feed for the animals. The pods are collected on the ground, after they fall or are knocked down onto a tarp. Mesquite pods are sold on the local market for about ten reais a bag (2015 price), and a plant with a 10-meter crown can produce a bag and a half per season. The production takes place during the drought. By spacing the plants 20 meters apart (50 plants per hectare), after the second year it is possible to produce a yearly average of 50 bags of pods per hectare.

Moacir dos Santos – *Training Center at the Regional Appropriate Small Farming Institute (IRPAA), Juazeiro, Bahia*

Photo: Daniel Vieira

Mesquite - *Prosopis juliflora*

On the other hand, the tremendous competitive advantage of some of these species means they can spread through a landscape and dominate ecosystems, inhibiting the establishment of native species in a process known as biological invasion. Some examples include the Mexican sunflower (*Tithonia diversifolia*) and leucena (*Leucaena leucocephala or diversifolia*) in the Cerrado, the mesquite (*Prosopis juliflora*) in the Caatinga, and some grassy species such as *Panicum maximum*, *Brachiaria decumbens* and *Andropogon gayanus*. We therefore recommend using these invasive species only in managed systems, with periodic, well-timed pruning, to keep them under control.

In degraded environments, when periodic management is possible, these efficient biomass producers are highly recommended despite their invasive potential, as long as they are suitably managed or grown in areas where these species are already widespread. Close to conservation units or to remnants of native vegetation that have not been invaded by these species, and in areas where intensive management is not feasible, their use is not recommended for restoration with agroforests. In these cases, we recommend the identification of native species that are also efficient biomass producers. Even when invasive species are well-managed, there is always a risk of losing control, leading to the suppression of native plants in nearby areas with natural vegetation or on neighboring production areas where such species' presence may not be desirable. We must therefore be very careful when using them.

The choice of species must also consider their usefulness when interspersed with others, for example the season when they drop their leaves (letting in light for shorter plants below them), shading (intensity and type), potential for regrowth, etc.

If there are animals in the system, the plant species must be **compatible with the livestock**, i.e, produce forage and co-exist well with forage plants and native species. In addition to grass, animals eat other plants, even shrubs and trees. *Sabiá* (*Mimosa caesalpiniaefolia*), for example, is an excellent species for raising goats. Trees whose shade is not very dense and that can fix nitrogen are excellent for providing shade in pastures in silvopastoral systems. Trees bearing fruit that animals eat, such as souari nut (*Caryocar brasiliense*), jackfruit, mangos, *baru* nut and yellow mombin (*cajá mirim*), are also well suited for association with pastures.

Figure 8: Silvopastoral system – cattle in the shade are more comfortable and feed on a variety of sources

PRACTICAL TIPS

To avoid negative impacts on the soil and vegetation in systems with animals, plants should be pruned or coppiced and fed to animals separately, rather than giving them access to the plants themselves. This also facilitates collection of their manure, which should be returned to the production area to recycle the nutrients. In addition to returning the nutrients, manure makes them readily available and fosters the soil's microbial activity.

When selecting species, also look for **short-cycle crops that can be sown during the rainy season "window."** This expands your productive period and increases the overall yield and financial payback. In the Cerrado region, for example, sesame, beans, peanuts and sorghum can be sown from the middle to the end of the rainy season, after the maize, squash and others, and then harvested early in the dry season.

Some **crops with greater energy potential** can provide firewood, like the *sabiá*, *carvoeiro* (*Tachigali paniculata* Aubl.), *mutamba* (*Guazuma ulmifolia*), or *murici* (*Byrsonima crassifolia*), as well as oils, like the castor oil plant, the *pequi* (*Caryocar brasiliense*) and others. Demand for this energy can come from both farmers and the market.

Species should ideally have **multiple uses**, as food, feed, for beekeeping, biomass production, etc. Pigeon peas (*Cajanus cajan*) are a good example, since they can be eaten either green or ripe and are a significant protein source for people and livestock. Their biomass, rich in nutrients, can be used as **green manure**, to cover and loosen the soil, they tolerate the dry season well, and are well established in people's culture in the Caatinga. The *sabiá* is another multipurpose crop well-known in the region and very useful for animal feed, firewood, fence posts and green manure.

Green manures are crops that help produce high-quality biomass to be cut and spread out to cover the soil. Examples include jack beans, pigeon peas, crotolaria (rattlepods), velvet beans (*Mucuna pruriens*), Stylo (*Stylosanthes guianensis*), millet, sorghum, castor beans and Mexican sunflower (*Tithonia diversifolia*).

PRACTICAL TIPS

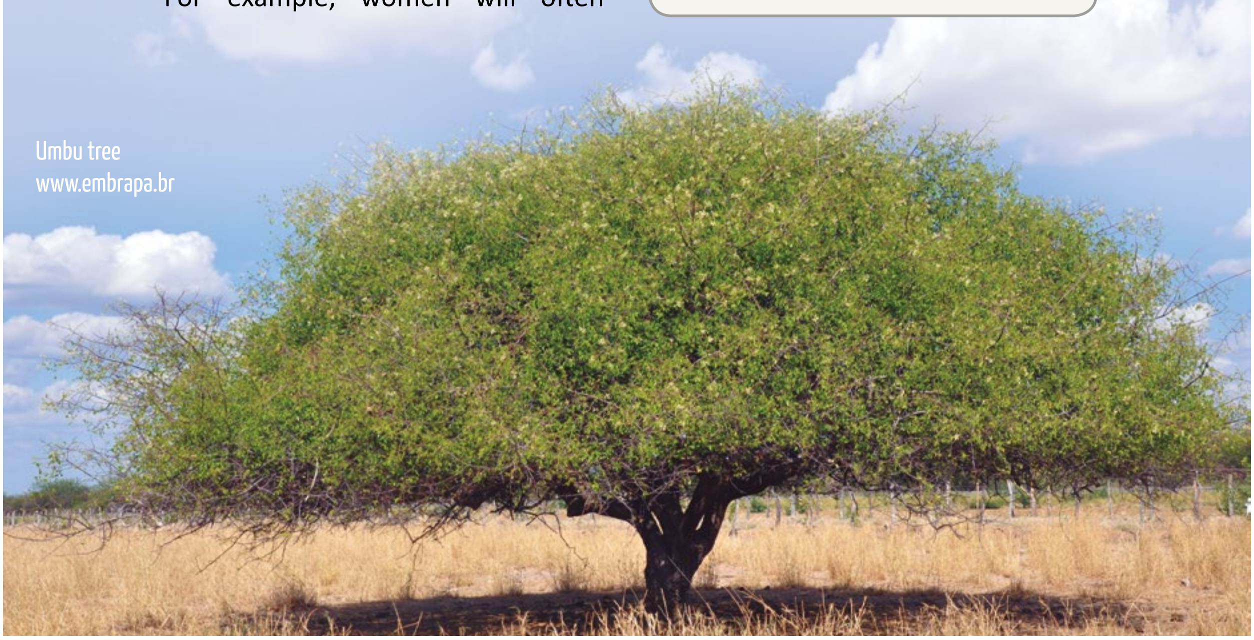
THE UMBU TREE (*SPONDIAS TUBEROSA*) AND THE LICURI (OR *OURICURI*) PALM (*SYAGRUS CORONATA*): KEY PLANTS IN THE SEMI-ARID

Licuri palms and *umbu* trees are left in the middle of the fields because they are adapted to the climate, provide fruit and favor other species. *"People used to drill through the trunk to see whether the core had a kind of heart of palm inside. Those that did were cut down and split down the middle to remove the core. Then they would grind it and make flour to eat. People were hungry then, with nothing to eat." Licuri* oil is also used to make soap. The *umbu* tree has a very dense crown and both people and animals eat its fruit.

Alberto Cardoso de Souza ***– Salgado Community, Casserengue, Paraíba***

It is also important that the species be **suitable to family farmers' socio-cultural context**, for example with multipurpose functions that fit into their culture.[150, 151, 152] **Prefer species already known** and used in the region, for which technical assistance is not essential. Consider species whose benefits are already clearly recognized by local residents. For example, women will often choose different species than men do, such as medicinal plants, certain foods and others that may be useful for handicrafts. All these possibilities should be considered.

See some key species for recovering degraded areas in the Cerrado and Caatinga in Section 5.4.



Umbu tree
www.embrapa.br

4.3 ECONOMIC PLANNING

Once the main species to plant in the AFS have been chosen, it is time to begin economic planning. This requires knowledge on how to manage the various products of local biodiversity, to pay back the cost of ecological restoration and generate an economic surplus, both for family farmers and for larger farms with Legal Reserves and productive areas, wherever production is to be allied with environmental conservation.

Systems that comply with environmental criteria can also include many species that generate benefits for the family, such as food security and sovereignty, medicine, fibers, energy and building materials (see Section 2.4 on Benefits). This involves marketable species with other significant functions for farmers in different successional groups.

Ecological restoration of protected areas on farms can be done with more passive and generally less expensive methods, such as environmental preservation and protection actions that enable natural regeneration, or with more active systems that may be more expensive, such as reforestation, forest restoration or agroforests that are planted and intensively managed. The greatest challenge when planning agroforests in protected areas is to come up with the right selection, composition and management of species over time to maintain necessary ecological functions and balance them with production and the social objectives planned for the area, including economic profit.

Family farmers who decide to develop agroforestry systems for mostly economic motives should prioritize areas that are not PPAs or LRs. Even so, ecological restoration can also be allied with production in such preservation areas (PPAs and LRs), in compliance with the Forest Code.

4.3.1 STEP-BY-STEP FINANCIAL PLANNING FOR AGROFORESTRY PROJECTS

The financial planning process for agroforestry projects is gradual and depends on learning agroforestry techniques. For efficient planning to underpin farmers' decision-making, we suggest these basic steps:

- The socioenvironmental diagnosis describes the farm's context: family makeup, origins, availability of skilled farm labor, edaphoclimatic conditions, local infrastructure and logistics, soil fertility and physical characteristics, annual rainfall data, rainy/dry seasons, months with extreme temperatures, altitude, occurrence of winds that might harm crops, landscape relief, quality and intensity of sunlight throughout the year, distance from the farm to markets and road conditions throughout the year.

- The socioenvironmental and economic diagnosis provides inputs to building the agroforest arrangement table (as explained below) to compose the successional groups (production cycle and stories), with species to produce biomass and species for market objectives, agricultural crops and others. Select high-yielding species (vegetables, ornamentals, medicinal, fruit and wood) and list their respective uses and potential markets.

- Map out a blueprint of the area to be planted, with spacing and rows. Space species with the same production cycle and story as if they were a single species. Species from different successional groups can be placed closer to each other. Spacing of economic species can generally follow recommendations for monocrops but should also bear in mind percentage of cover depending on the story it occupies. Fertilizer species, including trees, should be planted more densely, to allow for their pruning, coppicing, thinning and incorporation as organic matter.

- Calculate the demand for labor, its seasonality and the family's own labor pool. Set up a calendar for the season when each species will produce and its respective management needs.

- Make a list of activities and associated revenues and costs as fundamental data for your financial analysis. For revenue (income), survey the sale prices for AFS products and estimate yields in each period (Tables 2 and 3, below). To calculate costs (expenses), list all the activities required in the AFS: preparation of the area, planting, replanting, cleaning, management and maintenance of the species, as well as harvesting and marketing (Table 4).

- Obtaining technical coefficients (CTs): after detailing field activities for each species in the AFS, note the estimated time required to perform and frequency of activities, thus defining the technical coefficient based on values for labor and inputs. For labor, the estimated time is represented as a daily wage, i.e., how many persons have worked in a given area (1 hectare, for example) to carry out a given activity (clearing or planting, for example) in one day (Table 5). If the farmer uses machinery, the

Sítio Semente – Brasília

Photo: Andrew Miccolis

technical coefficient is expressed in machine-hours, and for inputs the TC units vary for each product (kg/ha, t/ha, l/ha, m³/ha, for example).

- To record and analyze financial flows with this data, the useful "AmazonSAF" spreadsheet can be accessed at a link shown below. This tool allows one to model the agroforestry arrangement and switch spacing and cash crops in order to achieve the best cash flow, while maintaining the system's ecological functions.

- Analyze the project's competitiveness by comparing the production costs (R$/kg) and market prices (R$/kg) in the desired market channels.

- Define the amount of financing required to invest in production, facilities, machinery and equipment. Assess the investment's turnaround time, i.e., the time it will take for the project's cash flow to become positive.

- Define financial, technical and business strategies required for the project, especially to get past the break-even point, in hectares, volume of production and monthly sales.

DIAGNOSIS → PLANNING OF ARRANGEMENT → ANALYSIS OF INDICATORS → STRATEGIC DECISIONS

PRACTICAL TIPS

THE "CASADÃO" SYSTEM TURNS PASTURES INTO AFS

Photo: Abílio Vinícius

The first step to turn a pasture into an agroforest is to keep out the cattle. Once they have been removed, use slash-and-burn, setting the fire during a dry spell (*veranico*) in the rainy season. The planting experience begins with crops like maize, cassava, watermelons and other plants with biannual cycles. Then come plants with intermediate cycles like pineapples, bananas and the native Cerrado *cajuzinho* (*Anacardium humile*). As the system evolves, longer-term fruit trees come in, like *cupuaçu* (*Theobroma grandiflorum*), cocoa and stinkingtoe (*Hymenaea courbaril*), as well as timber trees.

Valdo uses slash-and-burn before moving into a system with trees, locally known as the *Casadão* (coupling) system. "The advantage of *Casadão* is to get something different or have a cash crop. I have cassava, so I have a bag of flour, which now goes for R$ 300.00. The advantage of the trees is the fruit, the timber and, for me, there is also the learning. I can watch each one develop."

Valdo also explains that "Spacing at the beginning was wider, but now I use zero-by-zero spacing, depending on the purpose of each crop. We try to use agroecology principles like green manure and the decomposing stubble from other crops, compost and other options. Our management avoids using fire during the drought, and we do pruning, slashing, mulch the seedlings or weed only when necessary."

Valdo da Silva*, farmer, poet and activist. Porto Alegre do Norte, Mato Grosso. Source: "Agricultores que cultivam árvores no Cerrado"*[140]

4.3.2 PLANNING THE AGROFOREST ARRANGEMENT

The agroforest composition chosen (based on the participatory diagnosis above) can be organized in a chart of main productive species, with their different cycles and forest layers, as illustrated in Chart 2.

TABLE 2: EXAMPLE OF HOW TO PLAN AN AGROFOREST ARRANGEMENT, WITH THE SUCCESSIONAL GROUPS INCLUDING CASH CROPS ECOLOGICAL FUNCTIONS IN THE DIFFERENT PRODUCTION CYCLES AND STORIES

Production cycle and Strata	Shading %	Less than 6 months	1-3 years	3-10 years	10-20 years	20-50 years	More than 50 years
Emerging	15%	Maize or sorgum	Papaya or Castor beans	Nettletree (*Trema micrantha*), Tobacco weed (*Solanum mauritianum*) or Eucalyptus (fenceposts)	Mutamba (fruit and firewood) Tamanqueiro (*Alchornea glandulosa*) Carvoeiro (*Sclerolobium paniculatum*) for firewood Cajá-mirim (*Spondias purpurea var. lutea*) for fruit and live fence posts	Pepper tree (*Schinus terebinthifolius*) for fence posts, Eucalyptus (timber) Chinaberry (*Melia azedarach*) Mandiocão (*Schefflera morototoni*) Carvoeiro (*Sclerolobium paniculatum*) for firewood	Pepper tree (*Schinus terebinthifolius*), Stinkingtoe (*Hymenaea courbaril*), Pink Trumpet (*Handroanthus impetiginosus*) or Pau Rei (*Basiloxylon brasiliensis*)
High	35%	Jack beans or cow peas	Cassava, pigeon pea or Cavendish bnana	Ice-cream-bean (*Inga edulis*) or “prata” banana	Avocado Pepper tree (fruit) Stinkingtoe (fruit)	Indaiá (*Attalea dubia*) or mango	Copaíba (*Copaifera langsdorffii*)
Medium	45%	Eggplant + tree seedlings	Tree seedlings	Achiote or Surinam cherry	Citrus	Citrus	Sapodilla (*Manilkara zapota*)
Low	80%	Squash + tree seedlings	Taro or ginger + tree seedlings	Turmeric, arrowleaf elephant ear, coffee or heliconia	Coffee or hiconia	Jabuticaba (*Plinia cauliflora*) or coffee	Jabuticaba (*Plinia cauliflora*) or coffee

Source: Drafted by the authors using the cycle and story “successional group” classification approach developed by Ernst Götsch.

Economic planning of agroforest arrangements should contain at least one species with market value in each successional group to allow for production to be spread out over time. Each species or crop should also occupy a different story, or layer, in the forest, making up the forest structure, which also means planning how each layer will be managed, harvested and shaded at different times. In other words, optimizing the use of space and resources over time, with different stories and successional groups occupied, is the key to a system's economic feasibility.

4.3.3 FINANCIAL ANALYSIS

Financial analysis begins even before we look at the numbers. We must be certain that the AFS has been suitably designed, in compliance with social, biophysical and ecophysiological requirements. A good design will minimize undesirable outcomes.

A farmer and extensionist can organize the field information for their financial analysis with a tool to plan expenses and income for each phase of the different species' development, beginning with the preparation of the area, then planting, maintenance and finally the harvest and marketing of products. The farmer thus avoids waste and optimizes revenue by identifying the costliest activities and when they take place, as well as critical moments for labor demand, for example. With a clear outlook, activities or species that do not fit a farmer's desires can be corrected or even replaced. The farmer can verify whether actual income will meet expectations in this plan, i.e., whether the main species in the system will generate enough revenue to cover costs, and when exactly this will happen.

Based on the agroforest arrangement (Table 2, above), yields, market prices for each product and spending on inputs and services to establish and manage the AFS, it is possible to calculate financial indicators. We recommend using the spreadsheets from the AmazonSAF program[10], developed by Embrapa researchers Marcelo Arco-Verde and George Amaro, which analyze cash flows and other financial indicators.

The full cash flow is the difference between all income and expenses, with updated values accumulated during the project's desired lifetime.

This tool enables a forecast of costs to establish the AFS, when it will be paid back, and the investments needed to ensure its ongoing success. The financial indicator analysis also allows extensionists and farmers to monitor profitability, labor remuneration and thus the feasibility of their project.

For further information on AFS financial analyses and the AmazonSAF tool, see: https://www.infoteca.cnptia.embrapa.br/infoteca/bitstream/doc/1014392/1/Doc.274ArcoVerde.pdf

Also see updated spreadsheets at: https://www.embrapa.br/codigo-florestal/sistemasagroflorestais-safs

The data comes from three sources: (a) direct measurement of tasks to establish and maintain the AFS; (b) data gathered from extensionists and farmers; and (c) bibliographical data. It is very practical, and also an enriching experience, to apply this tool in a workshop environment that enables exchanges of knowledge among farmers and extensionists on their activities and production systems, costs, markets and other factors important to them.

Profitability analysis uses income cash flows (revenue or benefits from each crop in the AFS) and expenses (costs for each crop in the AFS).

Figure 9: Good financial analysis demands reliable information on production, costs and revenue. Stimulating farmers to record this data in a notebook greatly reduces the margin of error for their financial indicators.

The following tables show examples of sales prices, yields and costs of planting different products from an AFS:

TABLE 3 – SAMPLE SPREADSHEET WITH PRICE DATA FOR PRODUCTS SOLD

SPECIES	SALE PRICE OF PRODUCTS		
	PRODUCT	UNIT	PRICE
Maize	**grain**	kg	R$ 1.00
Brown beans	**beans**	kg	R$ 10.00
Pigeon peas	**peas**	kg	R$ 6.00
Cassava	**roots**	kg	R$ 0.70
Banana	**bananas**	kg	R$ 3.50
Achiote	**seeds**	kg	R$ 4.00
Turmeric	**powder**	kg	R$ 3.50
Coffee	**beans**	bag	R$ 432.00
Cajá mirim	**pulp**	kg	R$ 10.00

Source: By the authors, using the AmazonSAF tool

TABLE 4 – SAMPLE SPREADSHEET WITH CROP YIELDS DURING THE AFS ASSESSMENT PERIODS

		PERIOD									
		1	2	3	4	5	6	7	8	9	10
PRODUCTS	UNIT										
Maize grain	**Kg/ha**	750.00									
Brown beans	**Kg/ha**	1,000.00		200.00	300.00	100.00					
Pigeon peas	**Kg/ha**	300.00	150.00								
Cassava root	**Kg/ha**		4,000.00								
Bananas	**Kg/ha**		500.00	1,000.00	750.00						
Achiote seeds	**Kg/ha**				150.00	300.00	500.00	500.00			
Turmeric powder	**Kg/ha**			50.00	50.00	50.00	50.00				
Yellow mombin pulp	**Kg/ha**				8.00	10.00	12.00	12.00	12.00	12.00	12.00

Source: By the authors, using the AmazonSAF tool

TABLE 5 – SAMPLE SPREADSHEET WITH TASKS BEHIND LABOR AND INPUT COSTS AND THEIR RESPECTIVE TECHNICAL COEFFICIENTS DURING THE AFS ASSESSMENT PERIODS FOR A SINGLE CROP (BANANAS)

DESCRIPTION	UNIT	PRICE	1	2	3	4	5
ACTIVITIES			822.50	105.00	455.00	455.00	455.00
Seedling management	**worker/day**	70.00	2.50				
Signposting	**worker/day**	70.00	0.25				
Seedling hole digging	**worker/day**	70.00	6.00				
Planting	**worker/day**	70.00	3.00				
Harvest	**worker/day**	70.00		1.50	1.50	1.50	1.50
Cover fertilization	**worker/day**	70.00				5.00	
Pruning	**worker/day**	70.00			5.00		5.00
INPUTS			835.00	0.00	0.00	300.00	0.00
Cattle manure	**l**	0.06	10,000.00			5,000.00	
Rock dust	**t**	600.00	0.10				
Yoorin fertilizer	**unit**	45.00	3.00				
Lime	**unit**	20.00	2.00				

Source: By the authors, using the AmazonSAF tool

With the system's annual cash flow in hand, we begin the production systems' financial analysis, using the following technical indicators: (a) Net Present Value (NPV), (b) Benefit/Cost Ratio (B/C), (c) Internal Rate of Return (IRR) and (d) Return on Investment (ROI).[143, 83]

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Photo: Andrew Miccolis

MAIN INDICATORS FOR FINANCIAL ANALYSIS

Net Present Value (NPV) is the project's net worth, adjusted to its initial moment, minus the project's initial investment. When the NPV is greater than zero, the project is considered economically feasible. Since NPV includes the effect of time in its calculation, discounting its financial value, it is sensitive to interest rates.

The **Equivalent Annual Value Annuity (EAA)** is the constant, periodic installment needed to earn an amount equal to the NPV. The higher the calculated EAA, the greater the project's feasibility.

The **Benefit-Cost Ratio (B/C)** shows how much benefits surpass or fall short of total costs. The criteria for a project to be found feasible, according to Börner (2009), is that the benefits be greater than or equal to the value of the costs.

The **Internal Rate of Return (IRR)** is the percentage rate of return on capital invested in a project. If the IRR is greater than the discount rate required for the investment, the project is considered feasible.

The **time for Return on Investment (ROI), or payback period (PP)**, is the time it takes to pay back the capital invested in the project, i.e., the time between the initial investment and the moment when accumulated net profits are equal to the amount invested.

Source: Adapted from Arco-Verde and Amaro 2015.[143]

In financial analyses, it is important to observe and compare the overall outcomes of these indicators, to have a good grasp on a project's financial situation. One common mistake in financial analyses is to underestimate costs and overestimate revenue. We identify those mistakes through the cash flow and when we compare the outcomes of the indicators.

As a rule of thumb, a project is deemed feasible when its NPV and EAA are positive, the B/C ratio is greater than one and the IRR is higher than the market rate. The payback period (PP) may vary from one project to another, but one hopes it will be as short as possible.

What can be done to reduce the payback period? Some project design and management features for agroforestry systems can be helpful:

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- Intensify the use of annual crops in agroforestry models. Improve management techniques for each species, optimize the use of fertilizers and labor and select the varieties most suitable to each location.
- For perennials, select high-value marketable species that can be stored for long periods and will not be damaged during transportation. An AFS can be designed for the components' density to be favorably proportional between species with higher and lower economic value, within the limits of edaphoclimatic, biophysical and other criteria for the selection of those species.
- Plant annual crops more frequently. Normally, annual crops are feasible into the third year of an AFS, when canopies from tree species will shade them out. Annual crops can be optimized, especially during the first three years, always paying close attention to soil conditions to ensure their nutritional needs.
- Do a detailed analysis of the species in the AFS, to establish it within three years. This helps distribute implementation and labor costs better, with more intense use of annual crops.
- Design and make permanent lanes throughout the agroforestry systems, to facilitate annual crop production throughout the entire AFS cycle.

In addition to the financial feasibility indicators, another important indicator is the break-even point for the agroforestry project, which helps define project development strategies until it gets past the point when the costs have been paid and the farmer starts to receive the first monetary profits.

4.3.4 INTEGRATED ANALYSIS OF FINANCIAL INDICATORS

Very few scientific studies provide an integrated analysis of all these major financial indicators, which is vital for better economic planning to achieve the farmers' objectives in their systems. Table 5 presents the outcomes of a few studies that analyzed NPV, B/C, IRR and PP indicators for four different AFS.

TABLE 6 – NET PRESENT VALUE (NPV), BENEFIT/COST RATIO (B/C), INTERNAL RATE OF RETURN (IRR) AND PAYBACK PERIOD (PP) FOR DIFFERENT AGROFORESTRY MODELS, EVALUATED FOR 20 YEARS

FINANCIAL INDICATORS	AGROFORESTRY SYSTEMS			
	AFS 1	AFS 2	AFS 3	AFS 4
Net Present Value (NPV) R$	3,134.00	7,006.00	29,453.00	90,400.00
Benefit/Cost Ratio (B/C)	1.46	1.89	1.6	2.4
Internal Rate of Return (IRR) %	14.83	23.00	28.66	75.00
Payback Period (PP) years	11	8	7	3
REFERENCES	Arco-Verde (2008)[9]	Arco-Verde (2008)[9]	Arco-Verde (2015). Unpublished	Anna Kharine (2016). Unpublished

Obs: All indicators were assessed for a 1-hectare area.
AFS 1: Located in Roraima, with Brazil-nut, peach palm, cupuaçu, bananas, inga, rice, cassava. Area prepared with soil harrowing and correction of soil fertility and acidity.
AFS 2: Located in Roraima, with Brazil-nut, peach palm, cupuaçu, bananas, inga, rice, cassava. Area prepared with no-till planting.
AFS 3: Located in Rondônia, with Brazil-nut, peach palm, cupuaçu, rice, cassava.
AFS 4: Located in Pará, with andiroba, paricá, cupuaçu, açaí palm, black pepper.

Table 6 displays a great variability of values for each of the financial indicators. The NPV for these AFS varies from a little over R$3,000 for AFS 1 to some R$90,000 for AFS 4. To shed light on such differences, we must consider the soil-preparation and species-management activities, the intensity and scale of demand for labor over time, the degree of mechanization, lower crop yields due to weather, pests and blight, product storage and transportation and marketing processes. One must also consider the amount of time and project area to be correlated with the value of the project.

The NPV is the net amount earned over the entire period of the project, while the EAA gives the average net value for each year of the project. The EAA gives a better understanding of the project but we cannot assume that it will be positive from the first to the last year. For detailed information, we must analyze the present value of both the yearly and accumulated cash flow.

Other studies have found values comparable to these in Table 6. In 2000, three agroforestry models were analyzed in the Mixed and Dense Economic Restoration Project (RECA), in Nova California, Rondônia.[100] With a 9% interest rate for a 20-year period, the NPV was found to be R$11,761.89 per hectare, with a B/C ratio of 1.92 for a one-hectare agroforestry model containing 238 *cupuaçu* trees, 60 peach palm trees and 60 Brazil nut trees, which was 60% more than the outcome for AFS 2 (in Table 5). The other two AFS studied, with the same species described above, produced NPVs of approximately R$3,600 per hectare, comparable to AFS 1 in Table 5. In these latter two AFS in the RECA study[100], the B/C ratios were 1.56 and 1.52. The best B/C and NPL values were in agroforests with a larger share of *cupuaçu* trees compared to other components.[*]

[*] The exchange rate during these sudies was roughly 3.5 Reais to one Dollar.

In Machadinho d´Oeste, Rondônia, a study published in 2003 followed three agroforest arrangements over a period of 15 years.[40] The first one, T_1, had Brazil nuts, bananas, black pepper and *cupuaçu*. The second, T_2, had laurel, bananas, black pepper and *cupuaçu*, and the third, T_3, had peach palm, bananas, black pepper and *cupuaçu*. With a 10% annual interest rate, that study calculated NPVs of R$35,883.65/ha, R$5,334.85/ha and R$6,584.64/ha in systems T_1, T_2 and T_3, respectively. Of the three, T_3 had the NPV closest to that of AFS 2 in Table 5, and model T_1 was closest to AFS 3. The B/C ratios for the T_2 and T_3 arrangements were 1.44 and 1.51, respectively, similar to those observed in AFS 1 (1.46) and AFS 3 (1.6), but lower than AFS 2 (1.89), while T_1 was the highest of all (4.08). The authors explained that the lower profit rates in systems T_2 and T_3, compared to T_1, were due to lower yields in the first years as a result of combinations of species, their density and spacing.

Yet another study assessed agroforestry systems located in the municipality of Tomé Açu, in the state of Pará, with an 8% interest rate for 15 years.[144] These AFS, with black pepper, passion fruit, cacao, *cupuaçu*, mahogany and Brazil nut, had NPVs of R$15,373.11/ha and a B/C ratio of 1.87. These values were simulated for an agroforestry model selected for farmers living in the same municipality. That same experience had an IRR of 87% for the same 15-year period, nearly four times greater than AFS 2, but close to the value found for AFS 4, located in the same region of Pará. The Internal Rate of Return is the project rate, compared to a market rate, used in all phases of the project. The goal is to achieve IRR values higher than the market rate (savings accounts, investment funds or others).

In the municipality of Benevides, Pará, with an 8% interest rate, the IRR varied from one agroforestry model to another.[145] In the cacao and peach palm model, the IRR was 28.3% and in the AFS with cacao and *açaí* palms, it was 19.5%.

One indicator, the investment Payback Period (PP), raises many doubts for farmers and extensionists. It refers to the time it takes for the project to pay for itself, i.e., when it will become profitable. That moment occurs when the sum of revenue accumulated is greater than the sum of accumulated expenses. The PP for AFS 2, in Table 6, was 8 years, meaning that for 7 years the project establishment and management costs were greater than the income. From the eighth to the twentieth years in the study, all the annual expenses were paid for by the project's own income. In the AFS 4 (PP=3), the farmer recovers his entire investment five years earlier than a farmer in the AFS 2 (PP=8). The PPs in agroforestry models studied in Benevides, Pará, varied depending on the makeup of the agroforest.[145] In the model with cacao and peach palm, the PP was six years, and in the AFS with cacao and *açaí* palm it was nine years.

This all means that to fully understand the outcome of a financial analysis, one must look at all the financial indicators together and grasp the whole, to assess financial feasibility and study possible changes that might optimize revenue and reduce expenses, while also trying to meet the farmer's own objectives and constraints (for example, the available labor pool), which may also change over time.

In addition to the financial indicators, it is thus also important to observe the distribution of revenue and expenses over time, to avoid periods with no income and/or when there may be major variations in the farmer's income and expenses.

We can conclude, based on those studies, that AFS can be economically feasible. That feasibility, however, may vary tremendously depending on the makeup of the species, arrangements chosen by a farmer and management practices over time.

Does this mean that the most profitable system based on this financial analysis is necessarily the best choice for the farmer?

At the end of the day, a feasibility assessment must look beyond financial factors to social issues. It is key to gain an in depth understanding of what is most important for the farmer, since the financial indicators may not look that favorable at first sight, but what is produced by the system and how this is done may still be suited to the farmer's own desires and priorities. Planting short-term crops like maize, rice and beans, for example, may not look very attractive in financial terms nowadays, but they can be extremely beneficial for a family's food security and autonomy, especially in situations where poor local transportation conditions are an obstacle to marketing or for a family that does not always have enough cash available to buy food or feed in town. Annual crops also often play a major role in local culture and may complement the production of feed for domestic animals, which are often essential for a family's diet, as well as representing a "savings account" or backup for times of hardship or emergencies.

Once we have planned the agroforest's arrangement to meet the farmer's objectives, the available labor pool, expected financial return and other benefits desired from the AFS, it is time to implement it.

4.4 IMPLEMENTATION

At this point, organize all the material you need, such as seeds, seedlings, cuttings and tools, and identify who will participate in the planting (members of the family, hired labor or as a collective effort). The participation of the extensionist guiding the farmer on practical aspects of implementation is of the utmost importance to ensure attention to practical details. Implementation should take place step by step, as follows:

4.4.1 PREPARATION: MATERIAL, TOOLS AND LABOR

GATHER, ACQUIRE AND PREPARE PLANTING MATERIAL: SEEDS, SEEDLINGS, CUTTINGS, RIZOMES

Biodiverse and complex AFS need a large volume and great genetic diversity of propagation material for planting. This requires significant investment (which normally would be spent on buying material from shops) in collecting seeds and cuttings and in producing seedlings. Once the main species to be planted have been chosen, the location of parent plants must be identified while bearing in mind the quality of the fruit, their adaptation to local conditions or other desired traits. To ensure the success of planting where fewer individuals will remain after several years of

Photo: Andrew Miccolis

management and natural selection, the seeds collected must come from different parent trees in different conditions in order to enhance their genetic variability and thereby the outlook for plants more adapted or with more desirable functional traits. Whenever possible, local parent stock already adapted to the farm's climate and soil conditions should be preferred. The choice of parent stock also depends on desirable traits such as yield, heartiness, resistance to pests and disease, fruit quality, and so on.[149]

SEED STORAGE

The best way to use a seed is to place back in the ground where it can produce more seeds and be multiplied time and again. If it is necessary, however, to store seeds until the planting season, it is important to ensure they are kept in a dry, cool, dark place. Plastic PET bottles are excellent recipients to hold the seeds. Ideally, the bottle should be filled to the top to reduce oxygen available inside the bottle. Another suggestion is to fill the space between the seeds with ash, black pepper or leaf powder from plants that repel insects, such as eucalyptus, Gliricidia or basil. Seeds with dormancy, normally with hard shells, such as the pacara earpod tree, achiote, white leadtree, stinkingtoe and *carvoeiro*, can be stored for extended periods. On the other hand, seeds that soon lose their germination potential, such as Surinam cherry trees, *mangaba*, *ingá* and *ipê*, cannot be stored for long and must be planted shortly after they are picked, either directly in the ground or in sacks or tubes, and kept in seedling nurseries.[149]

BREAKING SEED DORMANCY (SCARIFICATION AND HEAT SHOCK)

To speed up the germination of seeds with dormancy, such as stinkingtoe, pacara earpod tree, West Indian elm, *sabiá*, white leadtree, *carvoeiro*, and others, the seed's impermeable shell must be punctured or broken for water to get inside. There are physical, mechanical and chemical ways to do this. One is to make a small cut in the seed husk with pruning shears or pliers, or else file it down manually or on a grinding stone. Another possibility is to immerse the seeds in boiling water for a few seconds (until they crack) and then move them into cold water. The heat shock cracks the shell, facilitating the entry of water for the seed to sprout.[149]

SUITABLE TOOLS

Good tools that are well sharpened and correctly chosen for each task are essential to work with quality, speed and ease. It is also essential to make correct use of the tools for agroforestry. A dull or poorly used machete, for example, can take much longer to prune a tree, make the whole operation useless or even damage the tree in the process, inhibiting new sprouts and promoting the entry of disease and insect pests.

Commonly used tools for implementation are machetes, hoes, shovels, spades, picks, levers, trowels, rakes, pitch forks, sickles and wheelbarrows. The machinery most widely adopted to prepare areas for AFS includes brush cutters, bed shapers, gardening tractors, tractors with ploughs, tractors with rotating hoes and tractors with harrow ploughs. Pruning saws or shears and chainsaws can also be useful when planting an AFS when trees and shrubs in or near the area must be pruned or coppiced. A shredder is useful to turn woody material into mulch. In addition to the equipment, it is also fundamental to use personal protection equipment (PPE), including gloves, boots, safety glasses, hat and leg protectors where there may be snakes. In situations where tall trees must be cut, it is also important to use ropes and ladders.

WORK AND TECHNICAL STRATEGIC PLANNING: WHO DOES WHAT, ORDER OF OPERATIONS, LOGISTICS FOR IMPLEMENTATION

- **WHO DOES WHAT:** To decide who will do what, we must always consider the person's desires, skills and physical condition. Some tasks demand physical strength, and others more attention to detail. By planning and assigning all the operations in advance, people can identify the activity where they feel they can be most useful.

- **WHEN (SEQUENCE OF OPERATIONS):** Certain approaches to a task bring better results than others, and with less work. Organizing the tasks in the right order makes a big difference, to avoid redoing the same task and the waste of time and resources, besides making the process more enjoyable. For example, when enriching a secondary growth area with material from pruned or coppiced trees, first plant the species that will emerge from below that material (such as tree seeds, banana rhizomes or cassava cuttings to be buried), to avoid having to lift away the organic ground cover. When planting tree seedlings, as well as pineapples, sisal and cuttings, do the coppicing first so they will not be damaged by falling branches. It is all the more important to make this kind of operational organization clear when you plan to establish areas in collective groups or courses, so the people are mobilized for the rights tasks at the right time.

- **WHAT AND HOW (IMPLEMENTATION LOGISTICS):** Ensure that all the inputs, tools, machinery and equipment are ready to use, close to the area. The tools must be sharpened, with sturdy handles. Make sure that seedlings to be planted are well protected, in the shade and moist when the area is to be established. Seeds must be packaged to avoid moisture and not be exposed to heat before going into the ground. Cuttings and rhizomes must also be in a shaded, humid place before being planted.

4.4.2 METHODS TO ESTABLISH AFS

The following techniques can be used to establish different combinations of trees, grains, roots, vegetables and green-manure crops, depending on what is affordable and in different biophysical contexts.

AGROFOREST GARDEN: VEGETABLE BEDS WITH TREES

Vegetable gardens can be a good place to grow trees, especially in degraded areas, where the large volume of inputs

Sítio Semente, Brasília

Photo: Andrew Miccolis

needed to grow vegetables (labor, fertilizer, water) creates very favorable conditions for trees to grow as well. With this technique, locally-suitable native tree seedlings or seeds are planted inside the garden beds along with the vegetables, preferably at the same time, although the trees may also be planted after the first cycle of vegetables.

Most of the time, vegetables are grown for a year or two until the native and fruit trees grow enough to overshade the beds. At this point, other herbaceous crops tolerant to this amount of shade can be introduced, such as parsley, mint, arrowleaf elephant ear, turmeric, ginger or others. If you plan to return and reuse the same space for vegetables or grains in the future, the trees can be thinned, pruned or coppiced at different heights, bringing more light into the systems and nutrients through the biomass used to cover the beds and paths, thus enabling the introduction of other desirable trees into the system. This strategy is ideal for occupying pastures and other degraded areas with trees that would normally find it difficult to grow there, as long as inputs are available. It is also recommended where there is little labor and/or space available to plant vegetables and trees separately. The garden thus allows trees to grow which, once cut, return the nutrients needed to grow vegetables again in the future. When planting vegetables with seeds, always make sure that the mulch allows the seedlings to break through instead of stifling their growth. Whenever there is too much biomass on the ground, move it away from the furrow or keep the layer of coverage thin enough to let the new plantlets through.

FERTILITY ISLANDS

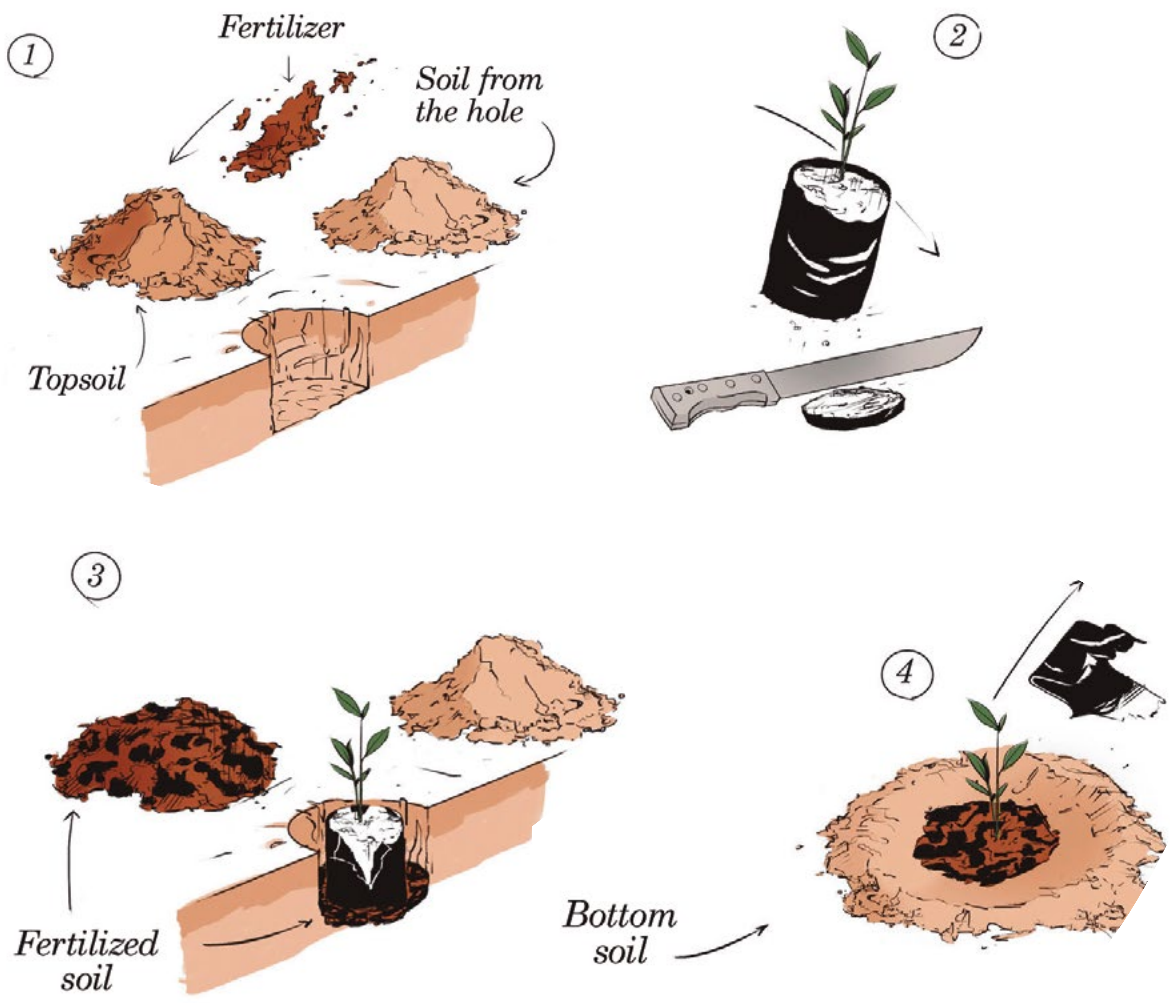
These are made up of banana trees and seedlings or seeds of native and exotic trees (of different species in the right proportion to the specific context), as well as vegetables, cassava (in situations with limited access to inputs), legumes and vines. This technique involves the following operations:

1. PREPARING THE AREA: In the space to be opened for the island, remove all the soil cover (living and dead). The removal must follow some criteria. For example, if the area has brachiaria, first cut the grass at ground level and set it aside. Then, with a sharp spade, remove only the rhizome (the thicker, white part between the roots and the leaves) and separate them to plant later.

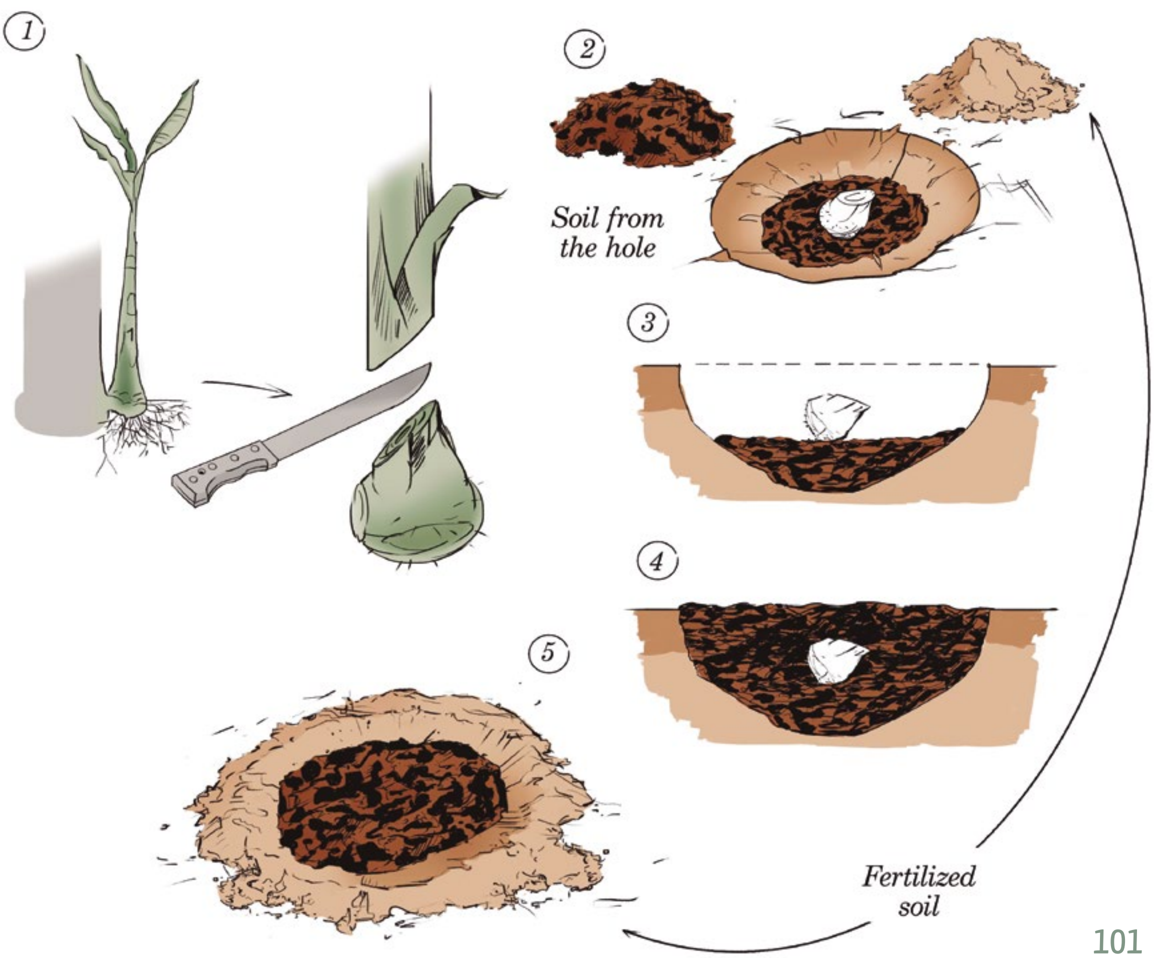
2. PREPARING THE HOLE: Once the area is clear, scrape away the vegetation on the surface (in a larger area than will be used to dig the hole), and dig out the topsoil layer with a hole digger or spade, separating it into a separate pile on the uphill side of the hole. Since this topsoil is more fertile and richer in organic material, it is then used to fill the hole back up along with fertilizers, including manure, rock dust, lime, etc. should be mixed into the piles before filling the holes. The pile with the bottom layer of poorer soil should be spread on the downhill part of the hole to help channel surface runoff and dew to the seedling. The size of the hole depends on the size of the seedling's clod of earth. When placing the earth around the clod, it is important to press with your finger tips to remove any air pockets that might block the growth of the roots.

Photo: Andrew Miccolis

3. PLANTING TREE SEEDLINGS: We recommend cutting the bottom of the planting bag with a sharp machete to keep the tips of the roots, which might be entangled, from strangling over time. Measure the depth of the hole to align the root collar (the transition between the tree-stem and the root-stem) with the surrounding soil surface. Some species may be planted with the collar a little above the soil surface, such as citrus trees, while others go a little below, like palm trees. Finally, cover the soil with organic material to form a concave basin or nest around the seedling, for water to accumulate closer to the plant. Cover the area with branches in contact with the soil and leaves on top of that layer. Be careful not to pile organic material up the stem of the seedling.



4. PLANTING BANANA TREES: The holes should be about 60-80 cm in diameter, dvepending on the size of the rhizome (sucker) and the quality of the soil. Weaker soils should have bigger and better fertilized holes. After planting the rhizomes, cover the soil with organic matter (using brachiaria hey, if it was previously removed from this area), shaped like a nest (see illustration). The grass rhizomes set aside earlier can then be used in the bottom of the banana holes, to keep them from regrowing and help nourish the banana seedling. When planting the banana seedlings in the same area as seed crops, the seedlings must go in first to keep the digging from disturbing the seeds. Do not forget to mark the seedling and the hole with a stake, to make them easier to find. The dug-up soil is also a good opportunity to plant seeds for other tree, vegetable and/or green manure plants. Finally, cover the soil in a concave shape.



OBSERVATIONS

Bananas can be planted from tissue culture in tubes or bags, like tree seedlings but placed a little below the soil surface level, or else using suckers cut from the banana tree's rhizome, or corm. In the latter case, one can use the suckers or bits from the corm, but always clean the corm carefully, cutting away all the old roots and looking out for holes opened by beetle-larvae borers. Then, when planting suckers, cut off the head and plant the rhizome, with the side cut from the mother plant turned upwards. If the mother plant has a large corm with several eyes, it can be chopped into pieces, with at least one eye in each piece. The pieces should be turned downwards when planted.

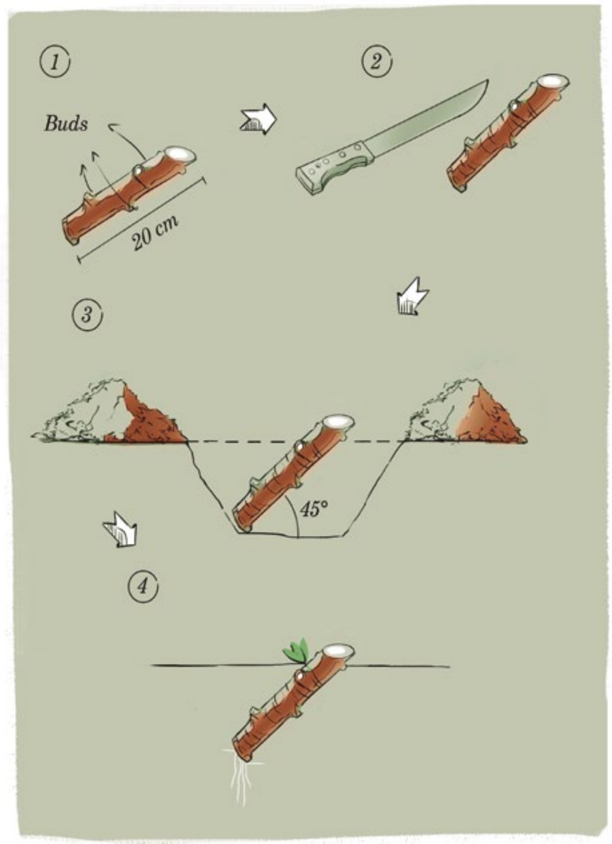
Photo: www.agencia.cnptia.embrapa.br

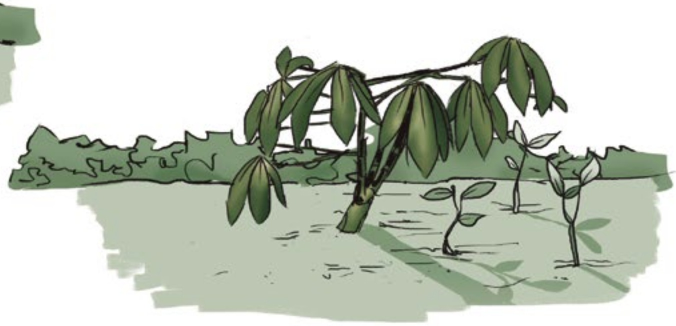
Photo: Fabiana Peneireiro.

Banana plants in an agroforest in the Altiplano Village, Brasília.

5. PLANTING CASSAVA WITH TREES: If they are to be used to grow trees, the cuttings should be planted at a slant, so that when the cassava is harvested it will not yank the tree out of the ground. The cutting, about 20 cm long and with at least 3 or 4 buds, should be planted with the bottom tip downwards, at a 45º angle. Cut a few slits with a machete to stimulate root growth (see illustration), and make sure the buds are pointing upwards.

The trees seeds should be sown just in front of and below the cutting tips





6. PLANTING MAIZE WITH TREES: Where labor or material for tree seedlings is in short supply, trees can be planted with seeds in the same hole as corn. First weed the area, dig the seed hole, fertilize with manure or compost and then plant two maize seeds at a depth of 5 cm along with a more rustic vegetable (gherkins, okra, squash or cucumbers). The tree seeds are laid on the surface and covered with a little fertilized soil. In addition to protecting the tree plantlets, the corn and vegetables make it easier to find and manage the trees afterwards. Include pigeon pea seeds in the mixture so that, after the maize and vegetable harvest, the pigeon peas will continue to protect the small trees.

Photo: Andrew Miccolis

7. PREPARING BEDS, PATCHES OR ISLANDS: This operation uses the same logic as in the cases described above. Clear the terrain, separating the organic matter, plant the tree seedlings (if this is the plan) and soften the bed or patch soil mixing in the fertilizer. Cover the bed with organic matter, plant seedlings and vegetables (if this is the plan) and plant seeds in small grooves (for green vegetables) or with the machete tip (for tree, maize and other seeds). If there is little organic material available, fill the bed with vegetable, green manure, bean or sweet potato seeds, depending on the plan. A bed is a long strip to be planted. Patches are round and smaller than the beds. A tree seedling or a few seedlings are generally planted in the middle of a patch, or else a banana sucker, with or without a tree seedling, and around them we plant cassava, tree or herbaceous seeds (vegetables, maize, beans or pigeon peas, depending on the plan). Islands can be even smaller than the patches, with a tree or a banana plant in the middle and herbaceous plants around it.

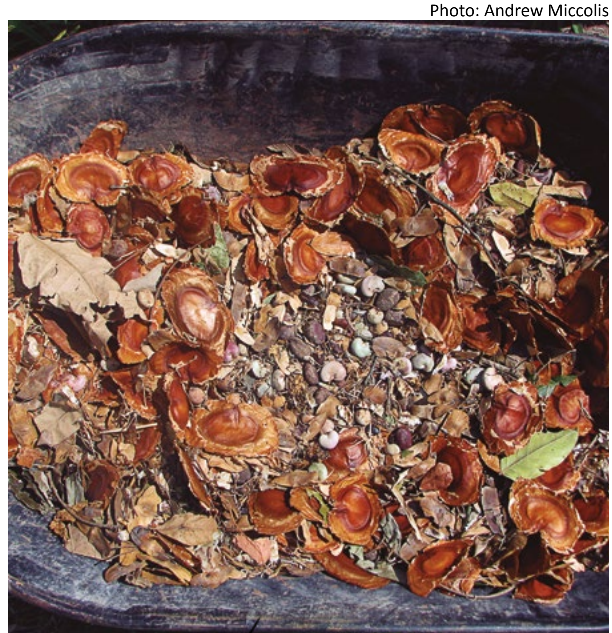
Photo: Andrew Miccolis

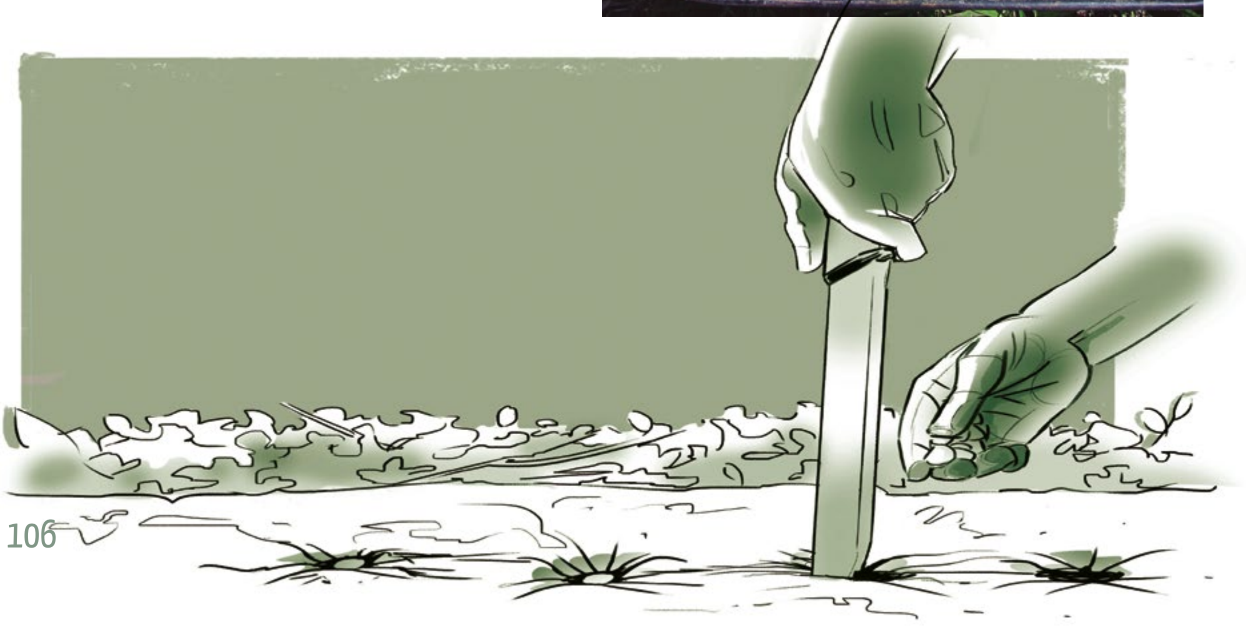
DIRECT SEEDING

Tree seeds can be planted in the ground using a mixture (with several kinds of seeds, with or without soil and/or manure to gain volume) spread over prepared soil or with the help of the tip of a machete or any other planting implement.

The species to be sown should be suitable to the local context (see Section 4.2). Large seeds, such as mangoes, avocados, *baru* or *tingui*, are sown separately from the mixture. Tree seeds can be planted densely, to be thinned later keeping the healthiest plants, with the diversity and spacing desired for the system. Seeds with dormancy must be “woken up” before planting (as described above). Seed depth depends on the seed size. Larger seeds can be sown deeper. Maize, for example, should be sown 5 cm deep, to keep the stem from tipping over.

Photo: Andrew Miccolis





PRACTICAL TIPS

DIRECT SEEDING

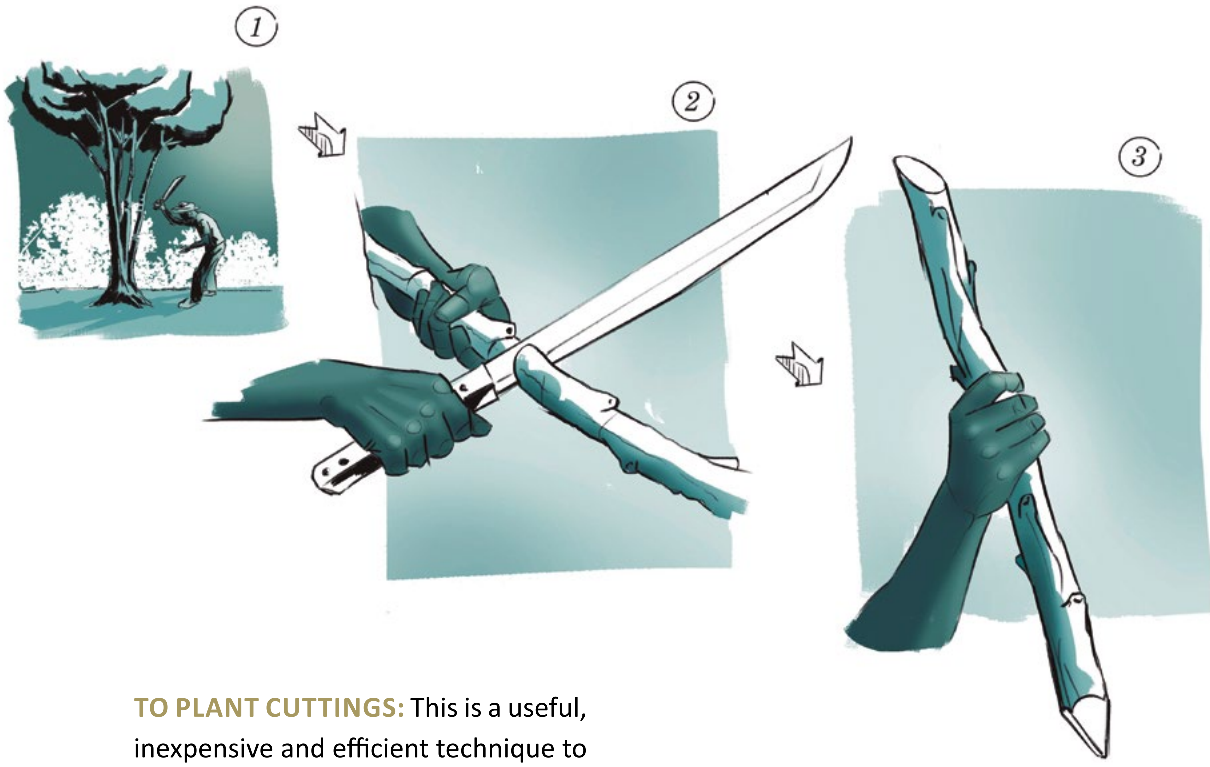
"We don't use seedlings much; it's more just seeds. We toss the seeds by hand, and only the most sensitive seeds are planted next to the pineapple, where we know they'll be protected when people walk around and might stomp on them. So wherever there is a pineapple growing, you know there's a seed to avoid stepping on or weeding away." After harvesting the maize, squash and cassava plants, "the work gets lighter after two years, but you still have to weed and mulch the seedlings."

Valdo da Silva*, farmer. Porto Alegre do Norte, Mato Grosso State. Source: Agricultores que cultivam árvores no Cerrado.*[140]

As a rule of thumb, the seeding depth is twice the size of the seed. Some seeds will germinate with a layer of organic matter on top, like beans, for example. Others, however, are inhibited by a think layer of mulch, like vegetables and other small seeds.

For more information on direct seeding, see *Guia de Restauração do Cerrado*, Volume 1. *Semeadura direta de sementes*.[101]

Photo: Andrew Miccolis



TO PLANT CUTTINGS: This is a useful, inexpensive and efficient technique to establish an AFS, since cuttings sprout quickly to establish individual shrubs or trees in the area. Long cuttings work better in areas with grass, since they sprout higher than the grass and are not stifled. Another advantage is that birds can perch on them, and deposit seeds from other trees to populate the area. Moreover, they are abundant and easy to replicate. With well-prepared cuttings, it takes little work to cover large areas. To prepare a good cutting, use a sharp machete and make a diagonal cut from the bottom upwards, to avoid splitting the plant from which it is being taken. Before planting, make a downward cut in the tip from which the roots are to grow (normally the thicker end, which was attached to the original plant), so the cutting will not split when shoved into the ground.

When the cutting is to be stuck into the ground, sharpen the tip like a pencil, to make it easier to penetrate without harming its bark, also enhancing its chances of taking root. Make sure the cutting is inserted in the right direction, like it was in its mother plant (bottom down, buds up). Plant diagonally, with at least about 1/3 of its length underground, tightly placed (not loose in the soil), to help it successfully “take”. Some examples of species that take well by cutting are yellow mombin, mulberries, *seriguela*, *umbu*, *cajá-manga*, hibiscus, Gliricidia, Mexican sunflower, Argentine cedar, *sabiá* and other species.

The cutting technique can be used alongside trees planted with seedlings and/or seeds.

4.5 MANAGEMENT: HOW TO DO IT?

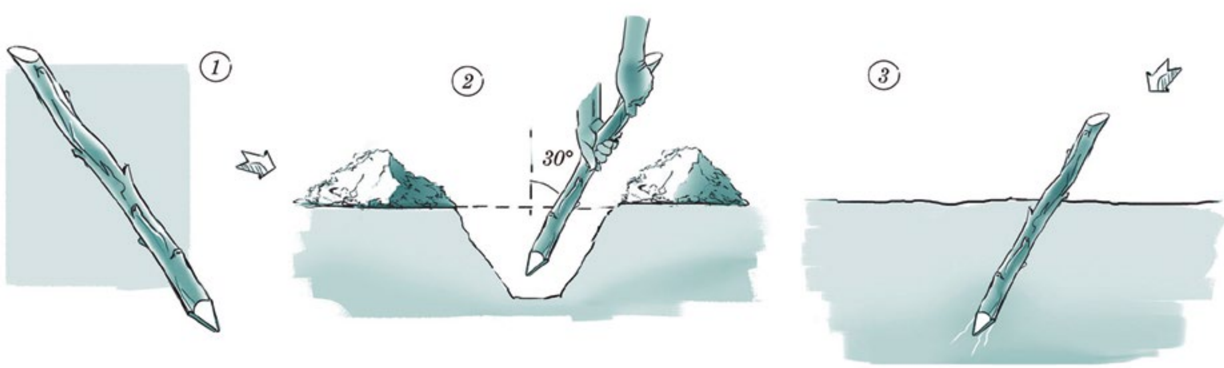
4.5.1 MANAGEMENT TECHNIQUES

The main techniques used in AFS are: (i) clearing, (ii) selective weeding, (iii) thinning and (iv) pruning/coppicing/pollarding.

Clearing involves cutting green manure plants like grasses and Mexican sunflowers. It can be done manually or with machinery. With machinery, this generally involves a trimmer or a chainsaw, and manually people use machetes, scythes, saws, pruning scissors or even axes (these latter three especially for Mexican sunflowers). Important species in the natural regeneration should be identified to ensure they are not cut inadvertently during clearing.

Selective weeding means pulling out or cutting herbaceous or grassy plants that grow near seedlings, in a selective manner to leave other plants in the area. The plants can be pulled by hand or cut with a machete or shears. This is delicate work and demands close observation of and knowledge about the plants, many of them spontaneous. Removing or cutting back aging herbaceous plants can accelerate succession and enhance the development of trees.

It is important to decide whether it is necessary to manage creeping plants that hold back the development of desired crops and native trees. "Weeds" are often treated like villains



in conventional restoration, but grass in an agroforest may help supply large volumes of biomass during the initial stages of succession, as long as it is well managed.

When you want to establish new crops in areas covered with grass, it should be uprooted, shaken, turned upside down and piled on the pruned material, to avoid rooting again and

regrowing in the crop area. Where grass is a strategic provider of biomass, it should be cleared periodically and laid out in planted areas as soil cover.

Thinning is done in areas that have been planted densely. The plants are selected to leave only the strongest and healthiest individuals, and the weaker ones are cut at ground level. Thinning is generally performed when the canopies of trees in the same story start to overlap, causing competition for sunlight.

All plantations need periodical care to maintain the yields and health of the overall system (plants, soil, animals and water). In agroforests, **pruning** plays an important role for yields and for ecological functions key to

Photo: Henrique Marques

conservation. First of all, more sunlight means more plant growth in the different layers. The pruned material also provides nutrients and enhances soil structure, improving its fertility and quality, along with the system's capacity to adapt to extreme climate events like droughts and torrential rain. It is also important for the enrichment of secondary growth forests, through the introduction of other species not yet present in the area, using seeds or seedlings, as plantlets are allowed to flourish on the forest floor. Periodic pruning in the AFS thus intensifies and enhances naturally-occurring renewal processes caused by the wind, lightning, floods and the intervention of other species (ants, termites, beetles, etc.). We can accelerate some of these processes while respecting each plant's cycle and layer and observing the moment in ecological succession of the system as a whole.

4.5.2 PRUNING MANAGEMENT CONSIDERATIONS

Different plants have different functions based on their structure and other features, at different stages of an agroforest's development. In the early stages of restoration in degraded areas, hearty colonizing plants are important to recover the soil's fertility and structure. Fast-growing pioneer plants are important for initial shading and the survival of future species, which stay longer in the AFS. By observing their interactions, we differentiate plants that overshade others, species that do not have the right size or structure and plants that compete for sunlight and nutrients. It is important to observe and take note of which factors are holding back a system's performance (inadequate fertilization, soil correction, water stress, excessive pruning or the wrong shading, insufficient organic soil cover, etc.). A good analysis of those factors, based on frequent observations throughout the year, will enable better management of pruning operations.

PRACTICAL TIPS

PLANTING IN THE SHADE

Certain species, like *cupuaçu*, cocoa and coffee enjoy a certain amount of shade. In one experience, planting pigeon peas with trumpet trees (*ipe, androanthus sp*.), after two years the pigeon peas died and the trumpet trees didn't have enough time to grow and shade the *cupuaçu*. "Here we plant in the shade, like little houses. So it won't die at that time, with three palm leaves over it like a cabin, for plants that need shade not to be killed by direct sunlight. The shade tree is this one, the trumpet tree. The pigeon peas were shading the *cupuaçu*, but the pigeon peas died and that's why we're planting achiote, whose function is also to provide organic fertilizer and seeds to sell to the Seed Network." In this system, pigeon peas are essential, providing shade, fertilizing and loosening the soil. Its life cycle is two to three years, after which it is replanted or replaced with another, like achiote, that survives longer.

Luiz Pereira Cirqueira – *Dom Pedro Settlement, São Félix do Araguaia, Mato Grosso State. Source: Agricultores que cultivam árvores no Cerrado.*[140]

In dynamic and productive systems, pruning may be done frequently, but there is no pat rule for all situations, since pruning must be managed to be timely, in line with environmental factors and the system's objectives. Once the system has well developed trees and shrubs, pruning can focus on their upper segments. The tools can be chainsaws or pruning saws, or even shears or a sharp machete (for people skilled in its use). The pruned material should be cut up or shredded. Placing the woody branches on the ground with the leaves and twigs on top accelerates their decomposition and provides good soil cover, and also makes better use of the organic material's nutrients and moisture.

Photo: Andrew Miccolis

PRACTICAL TIPS

MANAGING MULTI-PURPOSE TREES (ENRICHMENT)

"When I moved here, there were cashew trees, and I started including other fruit trees and managing the existing trees. There was already a good diversity of native plants and I have tried to manage them for different purposes. In addition to feeding the animals, they provide timber."

The trees that regenerate naturally in the area are managed by pruning, but they are also selected, and some are removed. Quince trees proliferate a lot, and they're always being cut down, mostly for firewood. Others, like the *rabuja* (*Machaerium acutifolium*) and *mororó* (*Bauhinia cheilantha*), are good for timber and produce a lot of organic material or fodder, so they are kept.

Antônio José Morais *– Fazenda Flor de Jasmin, Juá dos Vieiras Community, Viçosa do Ceará, Ceará.*

Each species in an agroforest has distinct characteristics and functions, which farmers should understand in advance in order to intervene at the right time, in the right way. Pruning must respect the seasons and be done in ways that do not threaten each species' functions.

Don't be afraid to experiment. See what happens and learn with experience, since you don't always get the best way to prune a plant right the first time.

4.5.3 TIPS ON MANAGEMENT PRACTICES FOR PRUNING

- Pruning during the moon's waxing and full phases is not recommended because the moon affects plants, and their sap (their "blood") is more present in their stems, branches and leaves during those phases. Pruning at those times weakens the plant, whereas pruning during waning moon increases new root growth, before the regrowth of the aerial part of the plant.

- Consider the plant as a whole, both in terms of its architecture (form) and the purpose of pruning (production, renovation, formation, cleaning, topping, etc.)

- Be aware of when each species flowers and bears fruit every year. These are generally not favorable times for pruning.

- The preferred season for pruning is late in the dry season or during the first rains, when the plants' sap is generally less active, and they are more tolerant to pruning. If the objective is to promote regrowth, early in the rainy season is the best time.

- Some plants that bear fruit from the middle to the end of the rainy season, like mangos, biribá and yellow mombin, for example, can also be pruned after bearing their fruit, since they will enter a dormant period until the beginning of the next rainy season. This kind of pruning is also suitable to favor the planting of annual crops or

Figure 10 – The moon's influence on sap dynamics in plants

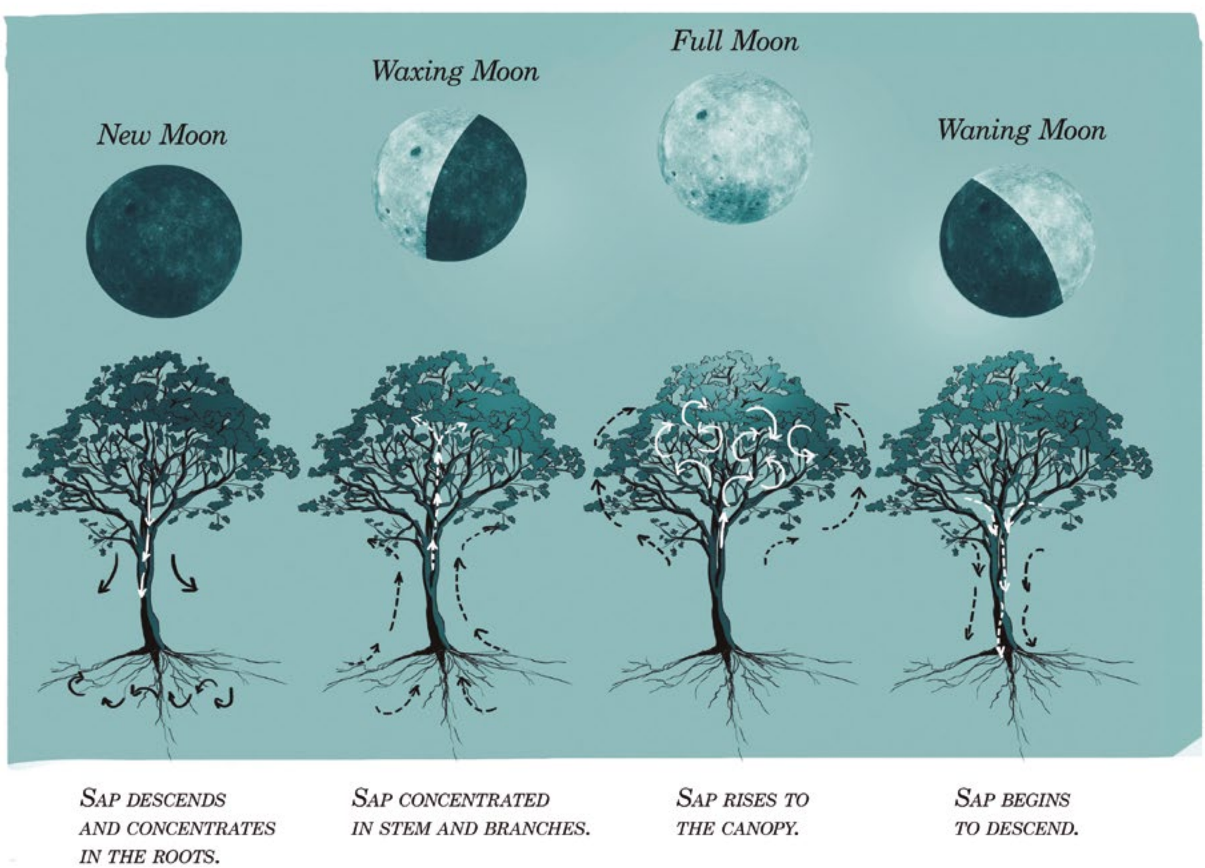


Figure 11 – Organizing pruned material on the ground

other plants that demand sunlight and nutrients a few months later, during the next rainy season, when the finer organic matter will have decomposed.

- Do the pruning step by step, first removing lighter branches, and moving from the extremities to the center of the plant.
- Intense pruning in taller trees (pollarding) demands greater knowledge and caution. Use ropes to secure heavy branches, and always use safety equipment.
- Use appropriate tools and equipment (shears, saws, billhooks, machetes, chainsaws, gloves, ropes and others), for your own safety and to avoid harming the plant.
- Verify whether all the woody material that was pruned is well organized and laid directly on the ground, to favor its decomposition and the micro-biota in the soil, as well as making it easier to walk in the area afterwards.

4.5.4 WAYS TO PRUNE

There are different types of pruning. One is formative pruning, highly recommended for fruit trees, on which we want broad canopies with horizontal branches, to favor fruit bearing and facilitate the harvest. For trees mostly intended to produce lumber, pruning removes lateral branches to lengthen the straight trunk. Pruning can also stratify a tree to adjust the position of canopies of different species in relation to each other, as well as pruning for fertilizer and biomass, when we want the tree to regrow vigorously with many leafy branches, at the same time when the species coming next begin to demand nutrients and sunlight. Suitable management of organic matter (with crowning and windrowing, for example) is important to concentrate nutrients and to keep the ground moist for more demanding species that are important to farmers and to the entire system.

FORMATIVE AND STRATIFYING PRUNING – Lateral and lower branches are pruned to structure the crown into the most suitable form for the system, to guide the trunk's growth and give form to the canopy. They can also help synchronize the system, when the intention is to plant crops under the pruned trees.

Photo: Andrew Miccolis

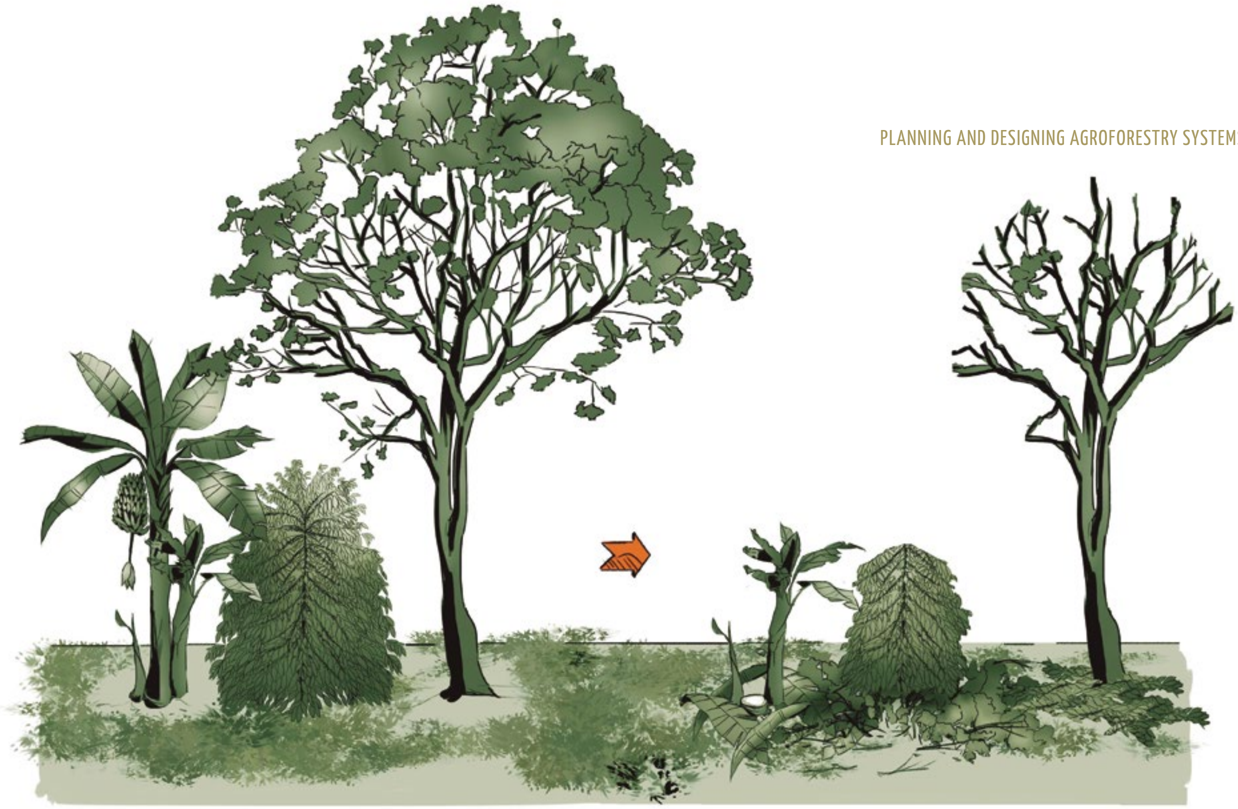


Figure 12: Formative and stratifying pruning

CLEANING – This is a simple kind of pruning, to remove dried and dying parts of the tree, yellow leaves and diseased branches, in order to rejuvenate the individual and eliminate entry points for disease.

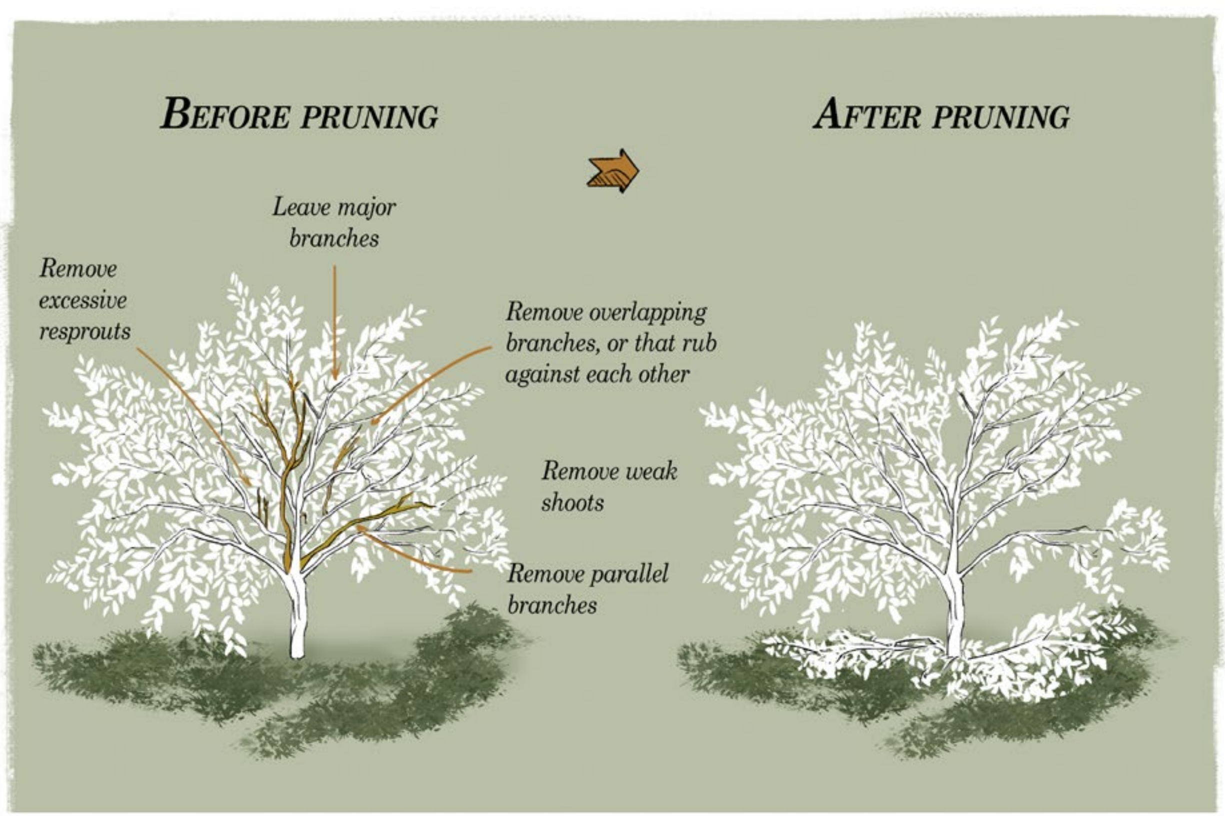


Figure 13 – Orientation for a cleansing pruning.

PRUNING FOR PRODUCTION OR FRUIT-BEARING – This type of pruning is generally done on fruit trees, to increase yields, usually after the fruit is ripe or at post-harvest. The purpose is to remove secondary branches that "drain" sap from the main trunk in order to reduce the number of fruit-bearing branches and channel the sap's energy to those that will produce more and better fruit. It also helps free up branches that rub against, pressure or overlap each other.

PRUNING FOR RENEWAL AND REGENERATION – This involves more intense work on the whole system, to produce a large volume of biomass, with several types of pruning (pollarding to lower the crown, cleaning, stratification, etc.) with the purpose of increasing the amount of organic matter in the soil, let more direct sunlight in, promote the rapid recycling of nutrients and enhance soil fertility. Often it is done to open room for other light- and nutrient-demanding species to flourish, including cassava, maize, squash and other annual and short-cycle species, or else to allow future species like timber and fruit trees to emerge from the understory and occupy higher layers in lieu of the initial pioneer species. This kind of pruning

Figure 14 – Pruning for renewal and regeneration

can synchronize the system and accelerate its overall development.

When **pruning for renewal or regeneration** is required to enrich the system, the first step is to plant the new species before pruning then organize the pruned material to cover the soil in the planted area. When organizing this material, it is important to cut the wood (trunks and branches) in sizes and shapes that allow it to be in direct contact with the ground, before being covered with leaves and twigs. When planting around established trees, pruning must help synchronize their development with that of the new plants, in addition to providing organic matter for soil cover. Plants growing under pruned trees are more vigorous than those under unpruned adults.

PRACTICAL TIPS

THE IMPORTANCE OF COVERING THE SOIL WITH PRUNING RESIDUES

Tall trees help nurse medium-sized trees by depositing a lot of material on the ground. The pacara earpod tree is a good example of this relationship. The *pajeú* (*Triplaris weigeltiana* (Rchb.) Kuntze) produces a lot of residue. I also grow black olives and I like *assa peixe* a lot. I like the pacara earpod because it decomposes fast – you shred it, cover the soil, it disappears, and the trunk very soon sprouts again. *Gliricídia* is another one we use to cover the soil.

The maize, beans and fava fields are always managed to be kept clear to cultivate every year. We protect the soil with species that are cut and shred. “I take the maize, but I leave the cobs and return the straw.” Coconut husks from the coconut plantation down the hill are also brought in to cover the ground. *Gliricídia* is planted all over, with no specific spacing, and is constantly pruned for soil cover, especially on the weaker soil. *Gliricídia* biomass is the main source of fertilizer for the field. We keep the *sabiá* well pruned, but it doesn’t produce much residue. It is mostly used as wood for posts and chips. We plant the *gliricídia*, but the *sabiá* often emerges spontaneously.

Ernaldo Expedito de Sá*, farmer – Tianguá, Ibiapaba Mountain Range Protected Area, Ceará.*

4.5.5 MANAGEMENT GUIDELINES

To choose the best species and right time for management, the following questions provide helpful guidelines at different stages in the development of agroforestry systems:

- Are some species competing for the same space, or else stifling and inhibiting the development of others?
- Is there enough formation and maintenance of dry, green matter to cover the soil, or at least to mulch around the seedlings?
- Are there undesirable species in the area and are they being duly controlled, with selective weeding, pruning or thinning?
- Do species need formative pruning to produce biomass or to strengthen their own structure and produce wood?
- Do species need pruning to enhance fruit production?
- Is there any impact from external factors, for example on the edges of the agroforestry system? Is any intervention needed to control such factors?
- Are any animals, insects or diseases harming the plants? Where, and what are the possible causes?
- Is there enough plant diversity and volume to achieve the system's original objectives (for example, restoration or production)?
- Considering local conditions, are the planted species healthy and are they developing within their life expectancy?

In situations where the PPA is recovering native vegetation (secondary growth) to avoid distorting the native plant cover or sacrificing the area's ecological function, in compliance with current legislation, it is important to distinguish between two types of management:

- Focused on enriching secondary growth (areas with vegetation being recovered) to increase biodiversity and cultivate short-term food crops at the same time, and

- Focused on maintaining the entire system's productivity and

- ecological functions, along with medium- to long-term social interests. In this situation, we do not recommend interventions that involve clear cutting or slash-and-burn.

Periodic pruning should certainly be allowed, as long as the trees' canopies are recovered once they sprout back, and the vegetation's natural successional dynamic and structure are maintained. In practical terms, this means keeping individuals and species occupying different stories over time. It also makes sense to suppress some senescent or declining individuals (in their final stages of life, with an aging crown and a hollow or insect-infested trunk) or whose population has become too dense. This kind of intervention promotes succession and helps maintain a system's ecological functions. Management of these areas must ultimately prioritize gains in biological diversity and the maintenance of environmental functions, such as: production of biomass for soil cover and erosion control, nutrient cycling, production of fruit for the fauna to consume, ecological corridors and infiltration of rainwater, among others.

In situations with limited presence of native plant species and little regeneration, where ecological resilience is low and the soil is degraded, some key species can be decisive to recover soils and create the conditions needed to favor the introduction of other species in the future, including native species. Those species are described in Section 5.4

Photo: Andrew Miccolis

5. AFS OPTIONS FOR DIFFERENT CONTEXTS

Scaling up adoption is one of the greatest barriers to the success of AFS. It depends on developing technological options adaptable to specific contexts with solutions that fit farmers' objectives and their resource limitations, as well as local environmental conditions. The options must also be flexible enough to adjust to similar situations with different features, if they are to be adopted on a larger scale.

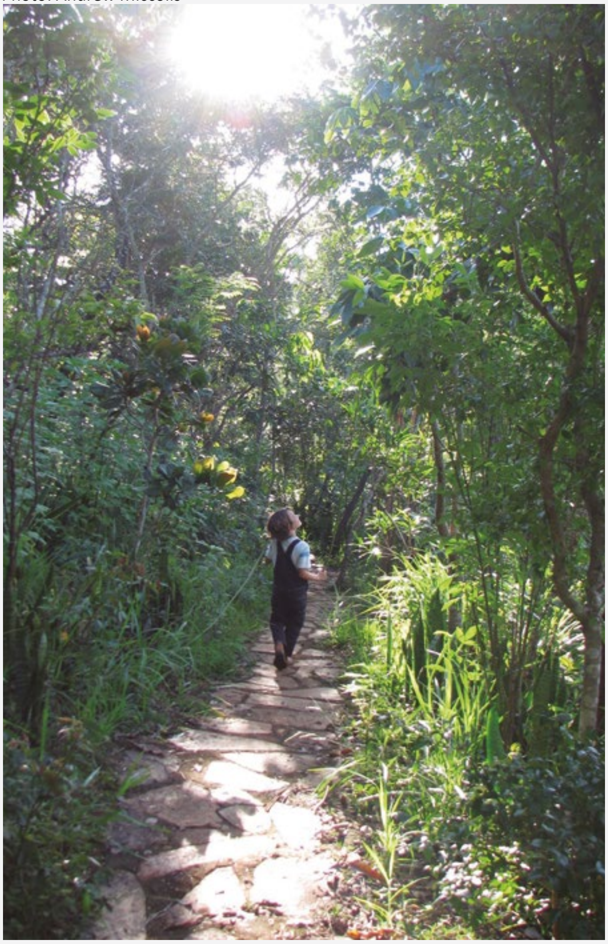
Photo: Andrew Miccolis

5.1 AFS IN THE CERRADO AND THE CAATINGA: LEARNING FROM ACTUAL EXPERIENCES

While there are few studies on ecological restoration with AFS in the Caatinga and the Cerrado regions, some do provide options and arrangements for AFS in different contexts within these biomes. In Ceará's semi-arid region, some studies recommend the use of **silvopastoral systems** to maintain soil quality and food production. In these systems, animals play a key role as they interact with trees, shrubs and herbaceous plants, mostly in pastures, and which provide forage for trough feeding.[97,58] **Agrosilvopastoral systems** are also recommended in these contexts for the interaction they promote among animal, agricultural and forest components in their composition. Such combinations may be temporary, in rotation or in guilds.

In some of these systems, forage is produced and supplied for the animals kept separately (on pastures or confined). In others, the animals are

Photo: Andrew Miccolis



set loose to forage in areas where crops have been introduced, followed by timber and/or fruit trees. The **Crop Livestock Forest Integration (ILPF)** approach, promoted by Embrapa, generally involves a tree species such as eucalyptus (*Eucalyptus* spp.), teak (*Tectona grandis*), African mahogany (*Khaya senegalensis*) or others, planted in widely spaced rows (usually around 25m) with grain, grass and cattle in the middle.[58]

Agroforestry homegardens are frequently found on small farms. Highly productive, these systems produce a wide diversity of fruit, honey, vegetable and medicinal species, often together with small animals (chickens, pigs).[24, 37, 2] The basic objective of these systems, located near homes, is to contribute to a family's food security and sovereignty, to their health and wellbeing. Women often play key roles in maintaining and managing agroforestry homegardens.[46]

Agrosilvocultural systems consist of intercropping tree and agricultural crops. In the Caatinga, some studies found a predominance of drought-resistant crops, especially those with xylopods to store plant nutrients during dry seasons.[7] Those systems are also used in the Cerrado, such as the AFS focused on *gueroba* (*Syagrus oleraceae*), mahogany (*Swietenia macrophylla*) and neem (*Azadirachta indica*).[11]

Successional (or regenerative) **biodiverse agroforests** are a more advanced approach in terms of structure and function as compared to other AFS mentioned here. They demand more intense management with

selective weeding and pruning, as the successional process progresses. The successional agroforest concept was developed by the farmer-researcher Ernst Götsch and has provided promising experiences[44,48,79,86] in Brazil's Cerrado, Caatinga, Atlantic Forest and Amazon regions, among others.

Different contexts, therefore, require different intervention strategies, depending on access to inputs and the stage of succession observed in each area.

5.2 AFS OPTIONS FOR DIFFERENT CONTEXTS

In this section we have organized some of these AFS strategies as technological options whose general structures are associated with specific techniques (detailed above in Sections 4.5 and 4.6), to be adapted to specificities in each context. Some options may be more suitable for PPAs and others for LRs, but all of them can also be adopted in production areas outside these protected areas in order to reconcile production with environmental objectives. While certain options are recommended for a given biome, they can be adopted in others as well, as long as the species and management practices ate suitable to that biome. We present some of the most common contexts and possibilities for intervention without, of course, exhausting all possible solutions. Flexibility is thus fundamental, along with a critical eye and creativity when combining these options with the techniques and management approaches presented above, as well as others which may have been successful in local practice.

OPTION 1: SUCCESSIONAL AGROFORESTRY FOR THE CERRADO WITH INTENSIVE MANAGEMENT

This option is based on the AFS established by Juã Pereira, at the Sítio Semente in the Núcleo Rural Lago Oeste in Brasília. He and Carolina Guyot systematized this experience, inspired by the teaching and guidance of Ernst Götsch.

Context: Degraded soil, little regeneration, predominance of exotic grasses like gamba grass and brachiaria; well-drained soil, LR or production areas, Cerrado biome, ample labor supply, easy market access. In this context, whatever the ecological resilience (regenerative capacity) and stage of natural succession, i.e. degraded soils, conditions are favorable for the implementation of complex systems, with a high volume of outside inputs.

Main objective: Commercial production.

Photo: Fabiana Peneireiro

Successional beds with annual crops and vegetables intercropped with rows of fertilizer and native species. Location: Sítio Semente, Brasília, DF

Secondary objectives: Food security and restoration of plant cover.

Overview: In these conditions it is possible to produce vegetables, grain, roots and fruit in the first years, to rapidly pay back investments in establishing the future trees (which will last the longest in the AFS), as well as to accelerate the restoration process, while generating income in the short and medium term.

System design components: This AFS features a repetitive pattern of 5x40 meter strips, each with four beds, one with a row of trees and fruit along with vegetables, and the other three containing exclusively intercrops of vegetables and annual crops. The plots are repeated sequentially throughout the area, allowing for different species to be planted in each. Short-cycle species create conditions for future native and fruit trees, which are either transplanted or planted by seed during the first three years. After three or four years, vegetables dependent on sunlight are withdrawn, while the emerging trees and shrubs remain. In the beds with only vegetables and annual crops, smaller trees or shrubs such as coffee are introduced.

Photo: Andrew Miccolis

Sítio Semente, Brasília/DF.

Bananas, coffee, citrus and eucalyptus trees planted in rows along with native with native and other fruit trees are the basis of the system. Seeds of fruit and timber trees are planted near the eucalyptus trees (e.g. stinkingtoe, *copaíba*, Argentine cedar, *xixá*, cashew, mahogany, mango, jackfruit, chinaberry/*Melia azedarach*). Bananas are planted in these rows every 3 m, and eucalyptus and cofee every 1.5 m, and various other fruit species every 3-6 m.

Between the rows of native and fruit trees the three beds are used to intercrop annual crops, whose choice will depend on the time of year, local markets and – above all – the farmer's interest. There is always a root crop underlying the guild (e.g. cassava, taro or sweet potato), accompanied by three or four vegetable crops (e.g. rocket/*Eruca sativa*, lettuce, kale, maize, broccoli, cauliflower, tomatoes, etc.). Cassava and corn are spaced 1 m apart, and lettuce and kale planted every 0.5 m. Rocket on the edge of the bed is spaced at 0.25 m, and in the middle of the bed at 0.5 m.

Three months after a plot is set up the vegetables (rocket, kale, lettuce) are harvested. The maize is harvested

Photo: Andrew Miccolis

Sítio Semente, Brasília/DF.

after four months and the cassava after ten months. Then the planting cycle is repeated. This allows for three to six intercrops to be harvested from the three rows in the middle of the strip, depending on the size of the root crop (e.g., taro is harvested six months after planting), before the native and fruit trees begin to shade the middle beds.

Criteria for species selection: high-yielding species and varieties, with high economic value and other conservation-related advantages, and species with a high potential for biomass production.

Key species: Eucalyptus, chinaberry, bananas, coffee, citrus, native and other fruit trees (e.g. native or exotic, such as lychee, Brazilian grapetree, Surinam cherry, etc.)

Implementation: The soil can be prepared with a tiller to raise the beds and mix in the fertilizer, or manually. Given the low soil fertility on this farm, the first fertilization was done with 500 grams/m² of rock dust, 10 liters/m² of composted chicken manure, 500 grams/m² of ash and 300 grams/m² of bone meal (over the bed). When replanting the same bed, the same fertilizers were repeated, except for the rock powder. Over time, though, the volume will tend to be reduced since the system will start feeding itself, mostly from biomass produced by pruning the eucalyptus and bananas. Soil analysis is important to gauge the dose of fertilizers.

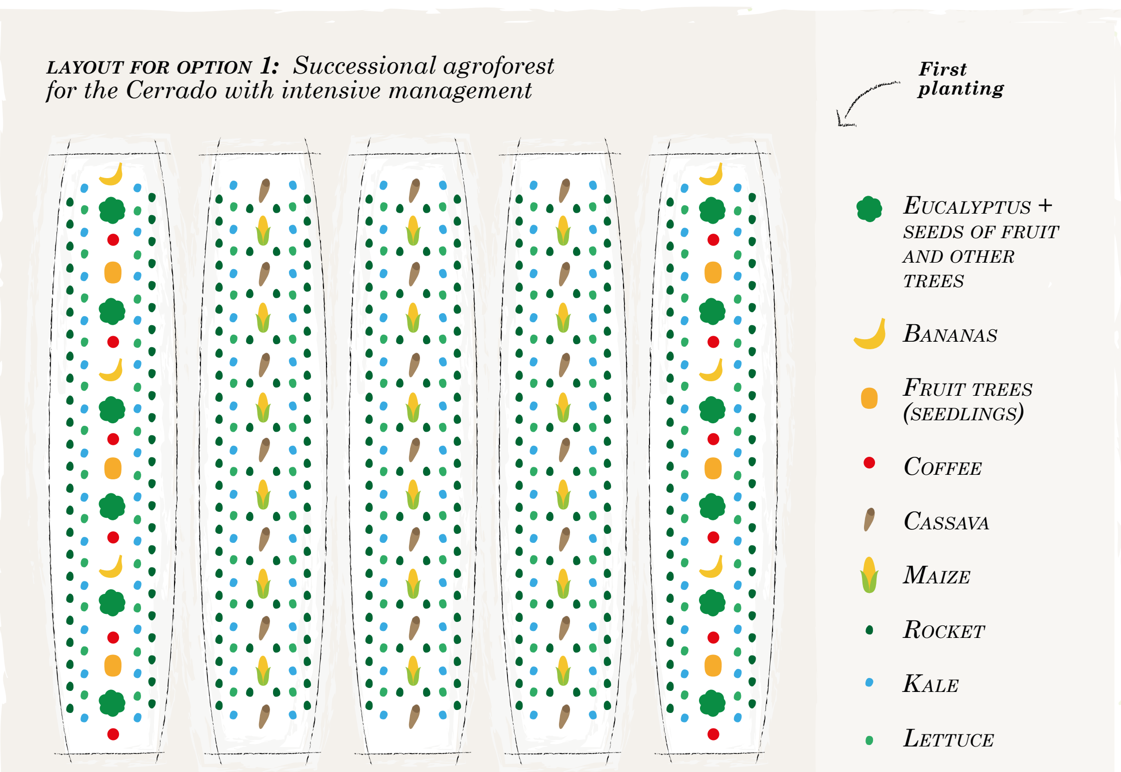
Management: This system's management rests on the concentration of biomass, particularly from pruning the trees and bananas, whose material is cut up or shredded and spread over the soil on both the beds and the paths in between them.

At the beginning, when the system is still not producing enough biomass for this coverage, the farmer must bring in material from outside the system. One may use the grass initially mowed from the same area to cover the ground, if there is no outside source. Once the eucalyptus and bananas can be pruned, there is less need for off-farm material to cover the soil. Pruning the trees and fruit trees at least twice a year is essential for the system's success. If the eucalyptus cannot be pruned that often, the system can be adapted by increasing the spacing between the eucalyptus and commercial fruit trees and relying on other biomass sources for soil cover. Decisions on pruning depend mostly on what the family needs at the time. If it needs more sunlight for the garden, it is time to prune. When the farmer decides to re-build the whole system, all the plant cover in the area must be cut down, or at least 80% of it, to ensure enough sunlight for the garden to flourish again. At this point, the soil is in much better shape than at the beginning since the species have been enriching it over time.

Weeding, in this system, must be selective and done manually every three or four months, depending on the state of the system, which must be slashed around the edges and firebreaks cleared to protect against forest fires.

This system is managed using equipment such as backpack brush cutters (to clear the edges and open firebreaks), chainsaws (for pruning and cutting wood) and shredders (to shred wood that will optimize and feed back into the system).

Beginning in the system's third year, once the transplanted or native and exotic species planted by seed have established themselves in the area, native plant species spread by dispersers, like *copaiba*, cecropia (*Cecropia pachystachya*), *pimenta de macaco* (*Xylopia aromatica*), *landim* (*Calophyllum brasiliense Cambess.*) and several others will sprout throughout the area. If this dynamic is allowed to continue, in the future many other species will be present as well. To that end, the management approach must facilitate the establishment of native trees



2 TO 3 YEARS

7 TO 10 YEARS

OPTION 1: SUCCESSIONAL AGROFOREST FOR THE CERRADO WITH INTENSIVE MANAGEMENT | **NORTH-SOUTH VIEW**

brought in by dispersers. In practice, this may involve some selective thinning of regenerating native species.

Long-term management/system configuration: Open canopy and biomass accumulation during the first five years of intensive management. 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 one crown touches the next, when they can either be allowed to close the canopy or be managed for the production of commercial species in the middle and lower strata. In a production area or LR, once

2 to 3 years

7 to 10 years

OPTION 1: SUCCESSIONAL AGROFOREST FOR THE CERRADO WITH INTENSIVE MANAGEMENT | **EAST-WEST VIEW**

the trees have grown (in about five to ten years), the system can be renewed with some drastic pruning and relaunching a production cycle with annual crops, until the canopy closes in again.

This system is highly recommended both for LRs and for production-oriented areas.

OPTION 2: BIODIVERSE AGROFORESTRY FOR PPA RESTORATION

One example of this option is an AFS established by Marcelino Barberato, at the Sítio Geranium in Taguatinga, Brasília. His experience was inspired by the teaching and guidance of Ernst Götsch.

Context: Medium to highly fertile soil; low regeneration; predominance of exotic grasses like brachiaria, guinea grass and Napier grass (elephant grass); good to medium drainage; riparian PPA; Cerrado biome; low to medium availability of labor; easy market access.

Main objective: Market production.

Secondary objectives: food security and restoration.

Overview: Restoration of the riparian PPA, with flower, food and medicinal plant production. No agrochemicals (pesticides or chemical fertilizers) or heavy machinery should be used in these areas. A row of fruit, wood and biomass trees (as well as bananas), followed by rows of ornamental plants, food crops and medicinal herbs. Many of these species also play an important role in occupying the lower stories, maintaining a microclimate and replacing the grass as a major contribution to preventing forest fires. They can also be a complementary income source for the family farmer.

System design components: The rows of trees are spaced 5 m from each other, with 1.5 m between plants in the row (planted both by seedlings and seeds), later selected according to their development and farmer choices. Ornamental, medicinal and food species are planted between the rows of trees and can be arranged in single-species rows to facilitate management and plant growth. If torch flowers (*Etlingera elatior*) are planted between the rows of trees, their rhizomes should be planted in double rows with 2 m between them and 1.5 m between plants in the row. If the choice is heliconia (*Heliconia rostrata*), their rhizomes can be planted in triple rows at 1.5 x 1.5 m, with the same spacing for *jaborandi* (*Pilocarpus*). Food and medicinal crops can be planted in between the rows of trees, including taro, turmeric, ginger and cardamom, with around 60-80 cm between plants. These species can also be planted in the 1.5-meter spaces between the trees in the row, with two rhizomes of taro, turmeric or ginger planted between every two trees. Maize can also be planted during the initial phase, covering the total area with a spacing of 1 m x 0.5 m (three seeds per hole, 5 cm deep). All these understory crops, except for taro and turmeric, should be introduced in the second year, when the trees and bananas start providing some shade. First-year crops include maize, cassava, squash and hearty greens (bur cucumber/ *Cucumis anguria*, mustard, okra, parsley).

Species selection criteria: Species selected for the ground level should be adapted to shaded conditions after the first years and should require less intensive and frequent management.

Key species for crops and other economic purposes: Ornamentals: heliconia, torch ginger; food, cooking and medicinal crops: maize, cassava, hearty greens (in the first years), ginger, turmeric, taro, arrowroot, cardamom, arrowleaf elephant ear and *jaborandi*.

Key species of trees: The row of trees should include multi-purpose species, particularly for environmental services. For the main objective of producing biomass from pruning, the recommendation is ice-cream bean and other riparian *ingás*, achiote, *capororoca, sangra d´água, pau pombo, tapiá* and *pimenta de macaco*. To

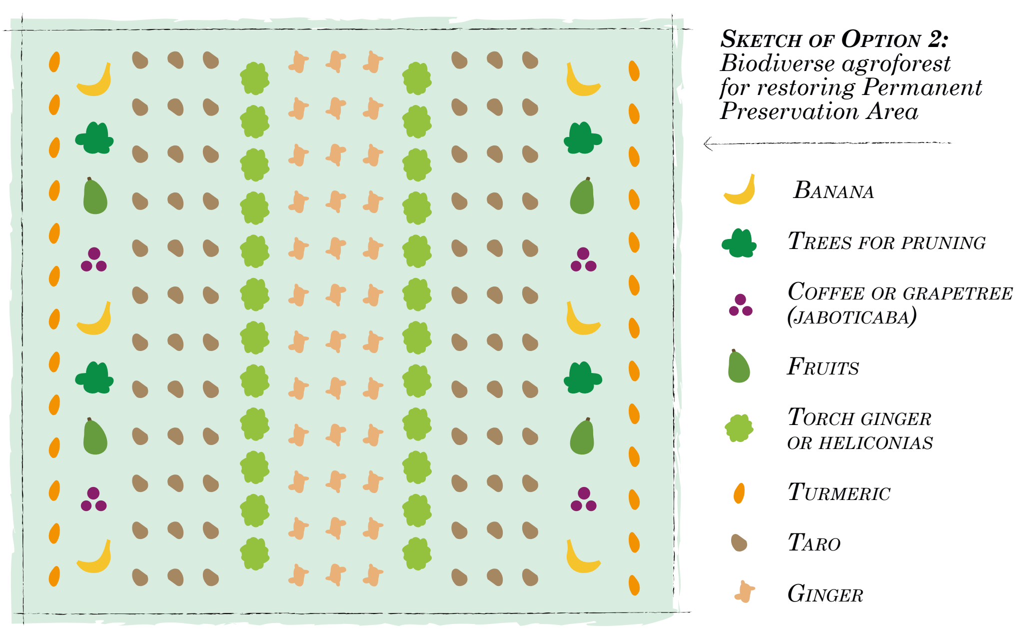
Photo: Marcelino Barberato

Agroforest with ornamental and food species.
location: Sítio Geranium, Samambaia-DF.

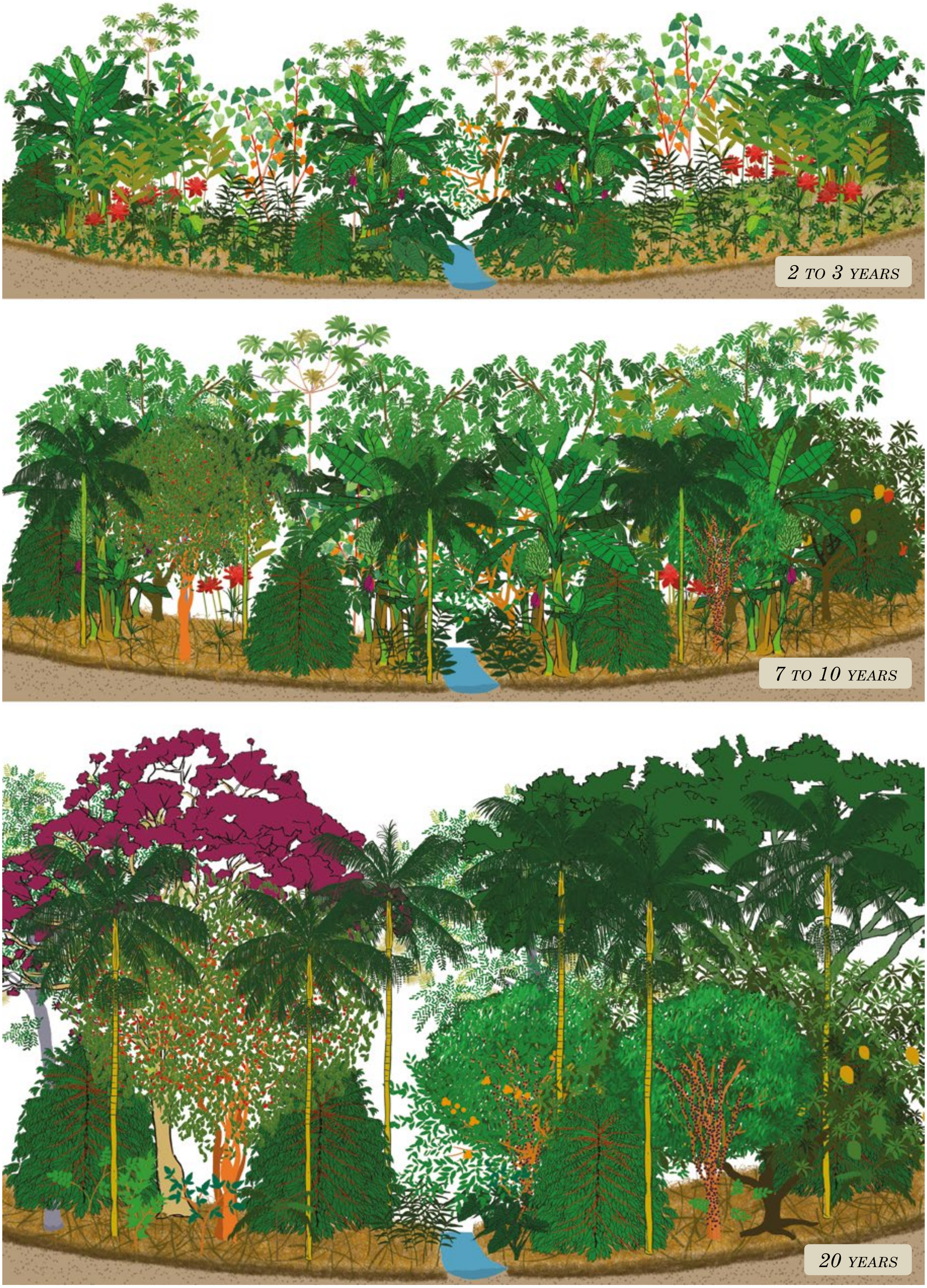
build up the forest and enrich native biodiversity, use *pinha do brejo, landim*, pink trumpet, stinkingtoe, *gomeira, mirindiba, copaíba, puçá, bacupari da mata* and *jenipapo*. For fruit production recommended species are banana, mango, jackfruit, avocado, yellow mombin*, buriti, juçara, jabuticaba* and lychee.

Implementation: In areas with prevalence of grass in large clumps, first cut and separate out the biomass, dig out the clumps with roots. The roots can be buried beneath the banana holes. Otherwise, shake off the dirt and lay them out to dry in the sun. If the grass is not very tall, it can simply be weeded out. The rows of trees are planted with seedlings, depending on the availability of material and labor, and with seeds, interspersed with bananas. The seeds are planted in the same hole as the maize and hearty greens, or else with cassava as explained in section 4.4.2. Fertilize with manure or compost in the holes where trees, bananas, rhizomes, maize and greens will be planted. The grass biomass is placed near the planted rows, spread over all the soil. Between the rows of trees, the ornamental, food or medicinal species are planted with rhizomes at the recommended spacing.

Management: Selective weeding and periodic pruning. After harvesting the maize, the maize stalks should be cut



Sketch of Option 2: Biodiverse agroforest for restoring Permanent Preservation Area



OPTION 2: BIODIVERSE AGROFORESTRY FOR PPA RESTORATION

Photo: Marcelino Barberato

and spread to cover the soil. Clumps from the tropical flowers and bananas are periodically pruned when the flowers and fruit are picked, and their biomass cut up and spread on the soil. Half to two thirds of the medicinal and food crops are harvested and the rest of the rhizomes are left in the soil to resprout. Biomass-producing trees are periodically pruned to cover the soil with organic matter, organized to allow people to walk easily through the area (branches in contact with the soil, covered by leaves). Trees with other functions should be managed with thinning, formative and stratification pruning operations (see section 4.5.4), as needed to achieve their objectives.

Long-term management/system configuration: Forest with a closed canopy after about seven to ten years, even using selective pruning. Management should enhance the establishment of natural regeneration, with room for native tree saplings to allow the progress of ecological succession.

Observations: Exotic species can and must be selectively pruned and thinned in the first years, in order to select individuals good at producing fruit and others for biomass, which will leave the system in the medium to long term. Exotic species should not occupy over 50% of the area to comply with Brazilian legislation for permanent preservation areas.

OPTION 3: AGROFORESTRY INTERCROPPED IN STRIPS WITH ENRICHMENT OF THE CERRADO

Context: Medium soil fertility; high regeneration; predominance of shrubs and small plants with some trees; good drainage; LR; Cerrado; variable (medium or low) availability of labor; variable access to inputs (high, medium or low); market access.

Main objective: Production for market, consumption.

Secondary objectives: Enrichment of areas with native vegetation in natural regeneration.

Overview: In highly resilient areas, i.e. with a high number of regenerating plant species, agricultural crops can be introduced in strips interspersed with native vegetation. The choice of crops should prioritize species that the farmer wants to plant in that context. Food species may include sweet potatoes, cassava, banana, taro and maize. These crop strips can also be used to grow fruit and wood-producing trees. The strips with native vegetation can be enriched with native or exotic fruit species.

System design components: Where only short-cycle crops are to be planted in the cultivated strips, these should be no more than 6 m wide (to facilitate mechanization), and the native vegetation strips should be wider (at least 15 m). Farmers with an easily available labor pool can intercrop different combinations in the crop strip including fertilizer and fruit trees such as bananas and palm trees. In this case, with the introduction of perennials in the crop strips (including native species), they can be widened to as much as 18 m, with the native-vegetation strips at least that wide, or wider. The width of the crop strips should never be more than that of the native strips, i.e. never more than 50% of the total area to comply with Brazilian norms for legal reserves. In the natural regeneration strips, fertility islands with seedlings of native trees can be planted to enrich the soil (see Section 4.4.2).

Criteria for species selection: Economically valuable, high-yielding, easy-to-manage species.

Key crop species (in contexts with low access to inputs): cassava, sweet potatoes, pineapples, cowpeas or black-eyed peas. Where more inputs are available, species that demand more fertility can be planted, such as maize, 2 TO 3 YEARS

7 TO 10 YEARS

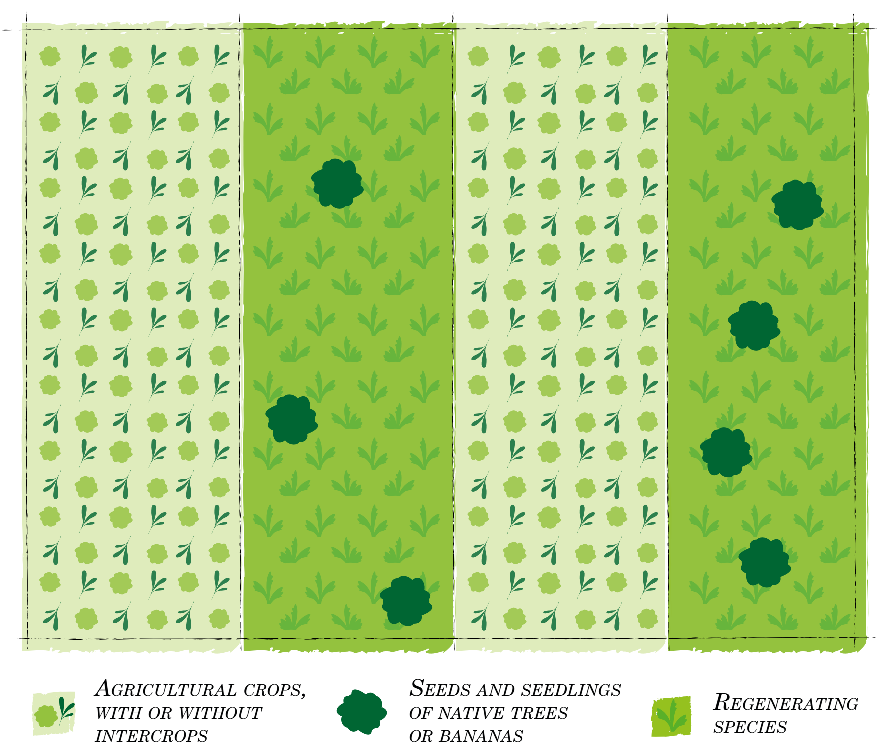
OPTION 3: AGROFORESTRY INTERCROPPED IN STRIPS WITH ENRICHMENT OF THE CERRADO

pinto beans, squash or sesame, bananas and taro.

Key tree species (in contexts with low access to inputs): *murici*, *mangabeira*, *baru*, souari nut, stinkingtoe, *copaíba*, *aroeira*, *xixá*, *amburana*, pink trumpet, yellow trumpet, *indaiá*, *gueroba*, *macaúba*, West Indian elm, nettle tree, Surinam cherry, Brazilian grapetree, *araçá*, *ingá mirim*, yellow mombin, tree cotton, *angico*, *copaíba*, *carvoeiro*.

Implementation: Preparation of the area can be mechanized or done manually. First coppice the trees and shrubs in the strip to be cultivated, organizing the biomass along the side. When using machinery, cut the trees and then incorporate the fertilizer, e.g. rock dust, lime or manure for demanding species, or with no fertilizer for less demanding species. The strips can be prepared with green manure species (jack beans, crotolaria, etc.) sown by hand or with the seeder, before planting the agricultural crops. When using manual labor, the first step is a selective weeding, followed by selectively cutting down plants in the crop strip. Leave any species with economic potential, which should be coppiced or pollarded. The crops can be spaced as farmers usually do. Trees and bananas should be planted in islands or rows. Larger trees should be planted in the strips with crops whose management will be less intensive. It is also very important to include fertilizer species on the edges of the strips with native

LAYOUT OF OPTION 3: Agroforestry intercropped in strips with enrichment of the Cerrado



vegetation, which will be pruned to fertilize the crops. The regeneration strips should be enriched by planting native tree seedlings or seeds in small islands in openings in the midst of the plant cover or in areas with grass or other herbaceous species, which should be weeded out in advance. As needed, some trees located in the native strip may be pruned to make way for these islands.

Management: Intensive management of the cultivated strips and selective weeding and pruning in the natural regeneration strips to promote succession. The resulting organic matter should be piled around the native plants considered most valuable by the farmer, or else carried over to the cultivated strips. This management approach will also help reduce the presence of grass and shrubs present during initial phases of succession, as well as fuel for forest fires and the prevalence of less desirable species in the understory. The edges of the native rows adjacent to the crop rows must be pruned to keep the trees nearest to the crops shorter than those behind them, leaving a diagonal cut in the native vegetation. The pruned material is carried to the crop strip or laid around the seedlings in the row of native vegetation.

Long-term management/system configuration: Once the trees have grown, in seven to ten years, the canopy may have closed, especially if it has not been renovated with pruning. If timber species have been planted, take care not to damage other plants when they are harvested. Biomass from the tree tops must be well-shredded and spread out evenly to cover the soil.

OPTION 4: AGROFORESTRY TO ENRICH AND MANAGE NATURALLY REGENERATED SECONDARY GROWTH (*CAPOEIRAS*)

Context: Medium fertility soil; high regeneration; predominance of shrubs and saplings, with some adult trees; good drainage; PPA or LR; Cerrado biome; variable labor pool (high, medium or low); market is accessible.

Main objective: Restoration

Secondary objectives: Food security and production for marketing

Overview: In this context, natural regeneration can be managed with the objective of enriching the secondary growth (*capoeira*) to increase plant diversity and introduce multi-purpose plants farmers find useful, especially by seeds and cuttings, but also with seedlings, when labor is available. Although the main objective is restoration, this option is highly compatible with food production (potentially for sale) using species such as bananas, medicinal trees and shrubs and fruits prized by both animals and people. In this case, instead of planting in strips, the approach is to enrich small islands with native and exotic tree species (for fruit and timber), interspersed in small openings in the midst of regenerative species. As a productive strategy, shade-tolerant agricultural crops (as in Option 2) are recommended. Beekeeping is also a very interesting alternative in this context.

System design components: Regeneration area enriched with small islands with bananas, tree seedlings or seeds and agricultural crops.

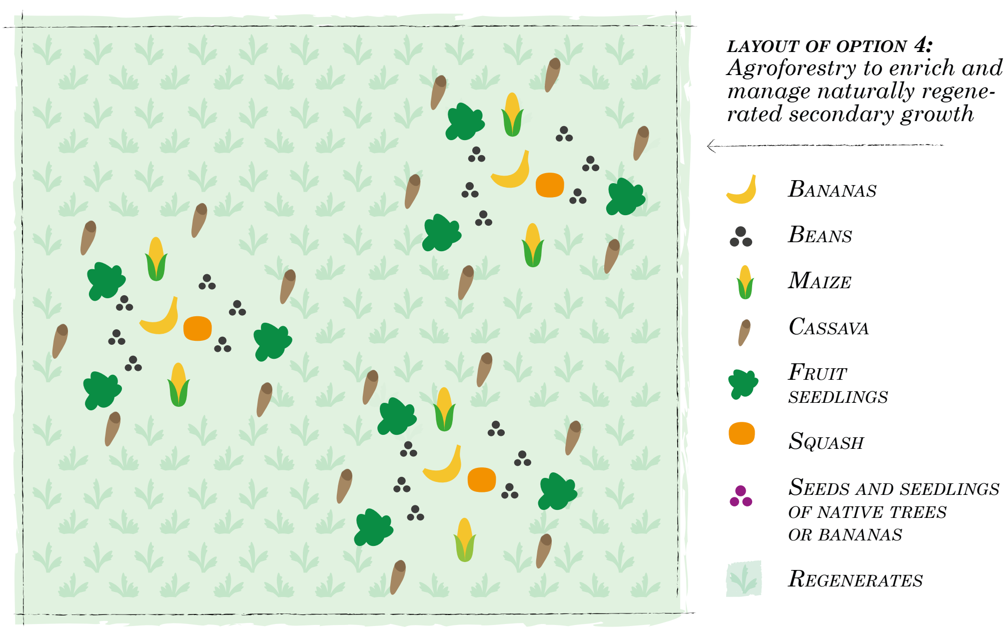
Criteria for species selection: Native and exotic species for multiple uses, along with less demanding crops, especially shade-tolerant understory species. If there is no animal manure available on the farm or nearby, food crops can include rustic species and varieties adapted to low-fertility soil.

Key tree species: *mandiocão*, *sangra d´água*, achiote, *juçara*, *pau pombo, gomeira, pimenta de macaco*, ice-cream bean and other *ingás*, yellow mombin, *bacupari da mata* (*Cheiloclinium cognatum*), *puçá* (*Mouriri* sp.), *mirindiba* (*Buchenavia tomentosa*), mulberry (*Morus nigra*), *buriti* (*Mauritia flexuosa*), stinkingtoe (*Hymenaea courbaril*), pink trumpet

(*Tabebuia impetiginosa*), *copaíba* (*Copaifera langsdorfii*), mango (*Mangifera indica*), avocado (*Persea americana*), jackfruit (*Artocarpus heterophyllus*) and coffee (*Coffea* spp.).

Key agricultural species: banana, taro, heliconia, *Zingiberaceae* species (ginger, turmeric, cardamom). When soil fertility is limited, or fertilizer is not available, the recommendation is cowpeas or black-eyed peas, bur cucumbers, sorghum or cassava. In fertile soils or with abundant fertilizer available, options include maize, beans, squash or passion fruit (*Passiflora edulis*).

Implementation: Identify strategic points (small clearings) to enrich. Place stakes to mark existing saplings, clear any grass or old shrubs and thin/prune short-cycle shrubs and trees that are close to the end of their life cycles. Prepare seed holes (soften, fertilize, cover with organic matter) and plant the trees and crops, with seeds, cuttings, rhizomes (bananas and other food and cash crops). For banana plants (see Section 4.4.2), plant the rhizome before covering it with organic matter. Leave a stake to show where it was planted. Deciding whether to plant in islands depends on the size of the clearing or opening amid the



LAYOUT OF OPTION 4: Agroforestry to enrich and manage naturally regenerated secondary growth

***AERIAL VIEW:** 3 TO 4 MONTHS*

***AERIAL VIEW:** 2 TO 3 YEARS*

OPTION 4: AGROFORESTRY TO ENRICH AND MANAGE NATURALLY REGENERATED SECONDARY GROWTH (AERIAL VIEW)

secondary regeneration. When planting in islands in small areas opened in between regenerating plants, the planting circles should be about 60 cm to 1 m in diameter and contain a tree seedling, cutting or seeds (or else a banana rhizome) in the center, surrounded with cassava (whose cutting should be positioned with the root end pointing out of the circle, when planting trees) (see Section 4.4.2) and/or annual species (maize or beans) or green manure (jack beans, pigeon peas or crotalaria). The islands are a little more complex and can cover a larger area (approximately 2 m diameter). If a banana plant is planted in the middle of an island, the root-end of the cassava cuttings should point into the circle (spaced about 80 cm from the center) in order to develop in the soft soil removed to dig the banana hole. Since cassava is very helpful for tree growth, tree seeds can be planted in front of each cassava cutting. In this situation, recall that more trees and annual species are to be planted, as explained in Section 4.4.2).

Management: Selective weeding and periodic pruning to enhance succession. Flowering species of herbs, shrubs and trees should be managed to promote honey production. Overall, the main form of management is to do selective weeding and to prune the natural regeneration and the small islands.

Long-term management/system configuration: Forest with a closed canopy after about five years, even using selective pruning.

Observation: Exotic species should never cover more than 50% of the total managed area to comply with the Brazilian norms governing Permanent Preservation Areas and Legal Reserves. Plants that grow from cuttings can be particularly strategic in this context.

OPTION 5: AGROFORESTRY TO RESTORE DEGRADED AREAS WITH FERTILIZER SPECIES

This option is based on the AFS established by Fabiana Peneireiro at the *Ecovila Aldeia do Altiplano*, in Altiplano Leste, Brasília. Her experience was inspired by the teaching and guidance of Ernst Götsch.

Context: Low fertility soil; low regeneration; predominance of grass and shrubs in initial stages of succession like cogon grass, *capim gordura* grass (*Melinis minutiflora*), brachiaria and white *cambará (Vernonanthura discolor)*; well-drained soil; riparian forest PPA and LR; Cerrado biome; variable labor pool (high, medium or low); market is accessible.

Main objective: Restoration

Secondary objectives: Food security and market

Overview: Recovery of a degraded area with a biodiverse AFS planted in strips or islands (Section 4.4.2) with species that produce large volumes of biomass and grow well in

Photo: Fabiana Peneireiro

Agroforest with "fertilizer" species in strips.
Location: Aldeia do Altiplano, Brasília

Photo: Fabiana Peneireiro

low-fertility Cerrado soils. The system requires low-intensity management and can produce enough to make restoration feasible. The priority is for perennial species such as bananas and other fruit trees, with annual crops planted only during the initial stage of this AFS.

System design components: Planted 3-5 m wide strips with species that produce large volumes of biomass, such as grass and Mexican sunflowers, and which grow well in low--fertility Cerrado soils. Between the strips 1 m wide beds produce short-cycle agricultural crops, as well as native and fruit trees. As an option, the trees can be planted in islands.

Criteria for key species selection: Crop and tree species should be well adapted to low-fertility soil (not demanding) and the fertilizer species should be efficient in producing biomass. If fertilizer is used when setting the system up, more demanding crops can be planted.

Key species of agricultural crops: maize, taro, cassava, papaya, bananas

Key species of trees: *mandiocão*, achiote, *juçara* (introduce after the

3rd or 4th year), *pimenta de macaco*, ice-cream bean and *ingá feijão*, West Indian Elm, nettletree, yellow mombin, *puçá*, *mirindiba*, stinkingtoe, pink trumpet, *copaíba*, mango, avocado, jackfruit, Surinam cherry, *jabuticaba*, guava, *araçá*, *jenipapo*. In LRs, include *angico* and *carvoeiro*.

Key fertilizing species: leguminous plants (crotolaria, pigeon peas, velvet beans, Stylosanthes, jack beans), elephant grass, guinea grass, gamba grass, Mexican sunflower, Gliricidia.

Implementation: In areas mostly covered with grass in large clumps, mow and separate the biomass, then weed to remove all the rhizomes, which can be buried under the banana seed holes, or else shaken out to remove the dirt and left to dry in the sun. If the grass is not very tall, skip the mowing and just weed. The strips of fertilizer plants should be from 3 to 5 m wide, interspersed with 1 m wide beds or rows of short-cycle agricultural crops adapted to this kind of soil (more rustic species), together with native and fruit trees. When setting up the system, first stake out the spaces for strips and beds. Prepare the soil, apply fertilizer, plant the seedlings and cover the soil with local organic matter. Bananas and other

Photo: Fabiana Peneireiro

Photo: Fabiana Peneireiro

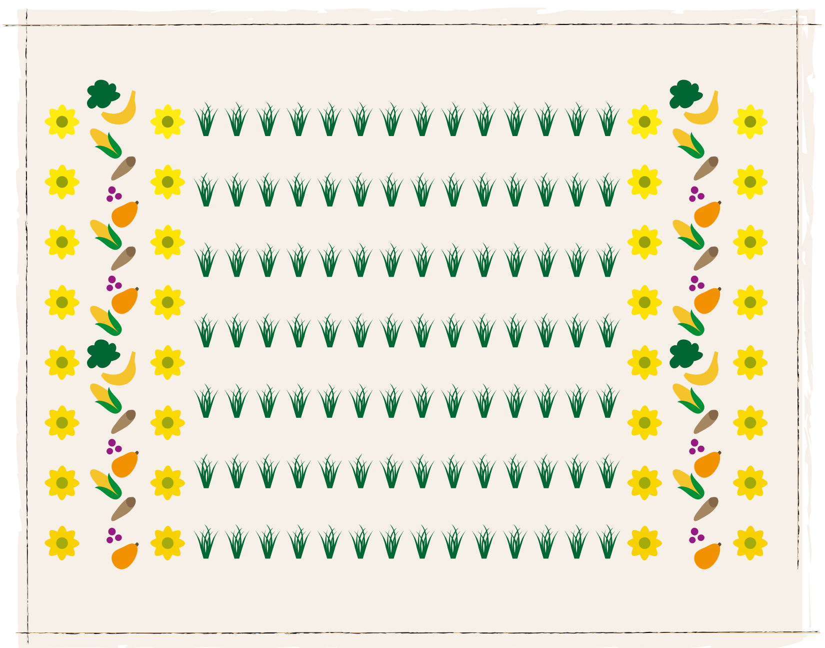
fruit trees are planted in the center of the bed, with normal spacing recommended for each species. For example, if bananas and citrus trees take the lead, they are to be planted alternating with each other, with 3 m spacing between them. Plant two cassava cuttings with the root tips pointing to the sides of the bed, and plant the tree seeds together with the papaya, cotton and castor bean seeds, in front of the cassava cutting (see Section 4.4.2). Crops such as maize, okra and greens (if the bed is fertilized) should be sown in the central row of the bed using normally recommended spacing. The Mexican sunflowers are planted along the edge of the beds, using 20 cm cuttings (diagonally and totally underground), with 0.5 m between each cutting. In the fertilizer-plant strips, plant the elephant, guinea or gamba grass with 0.5 m between the clumps. Other fertilizer plants can also be planted, such as hand-sown legumes. Pigeon pea seeds and Gliricidia cuttings can be planted in a row in the middle of the strip of fertilizer species, so as to avoid being cut by mistake, and then pruned for biomass to spread on the beds.

Where the labor pool is limited, the same species are recommended, but planted in islands spread around the area, instead of in beds and strips. In this situation, the pruned biomass and any fertilizer available on the farm or nearby (like animal manure, ashes, leaves in the yard, sawdust, etc.) should be concentrated in the islands of trees in guilds with crops. The trees should be planted densely with seedlings, cuttings and seeds to allow for later selecting the most resistant and well-developed individuals, along with the crops and fruit species like bananas. This system of planting in islands can be done by preparing a well fertilized hole to plant the banana rhizome (sucker), circled by a mixture of tree seeds, cassava and legumes (see Section 4.4.2). The biomass piled around these islands enhances fertility and inhibits the growth of unwanted plants, also known as "weeds." This also favors the development of cultivated species and the future trees that will emerge from the mixture of seeds.

Management: Once established, the fertilizer species should be cut back systematically, generally three or four times a year for Mexican sunflowers and grasses, and the organic matter should cover the bed (or islands) with the agricultural crops and

Foto: Fabiana Peneireiro

Foto: Fabiana Peneireiro



***Layout of option 5:** Agroforestry to restore degraded areas with fertilizer species*

cultivated trees. This management is generally done at the beginning of the rainy season, in the middle of the rainy season and again at the beginning of the dry season, and may even be repeated once again during the rainy season, depending on plant growth. The beds with crops and trees can be managed with selective weeding and pruning. When there is little labor available, simple machinery like a backpack brush cutter can be used to cut the strip of fertilizer species. The cut material should be piled in the beds near the plants in the central row. Bananas are managed after the bunch is harvested or when the old trunks need to be cut down. The trees can be pruned when there is a need for thinning, formation or synchronization (Section 4.5.2).

Long-term management/system configuration: After about five to seven years of management, the initial fertilizer plants (grasses, legumes, etc.) will be in the shade and the source of biomass will be trees with an aptitude for this function. The strips of fertilizer species can then be enriched with understory species.

OPTION 5: AGROFORESTRY TO RESTORE DEGRADED AREAS WITH FERTILIZER SPECIES

OPTION 6: AGROFORESTRY TO RESTORE HILLSIDES IN THE CERRADO

This option is based on the AFS established by Andrew Miccolis, at Sálvia Institute, in the Núcleo Rural Córrego do Urubu, Brasília.

Context: Hillside PPA or LR; low-fertility soil, with prevalence of rocks and gravel; low to medium regeneration; predominance of grass and shrubs; Cerrado biome; low availability of labor; low to medium market access.

Main objective: Restoration.

Secondary objectives: Production of food, medicinal and ornamental species.

Overview: On hillsides, swales and small terraces are important to control erosion, accumulate nutrients and enhance water infiltration into the soil. Native and fruit trees are planted with seedlings in small islands, and seeded throughout the entire area together with maize, annual crops and hearty legumes, between rows of sisal, mulberries and Mexican sunflowers.

Foto: Andrew Miccolis

Photo: Andrew Miccolis

Hillsides in the Cerrado (or restricted-use areas) with agroforest terraces. Sálvia Institute, Brasília

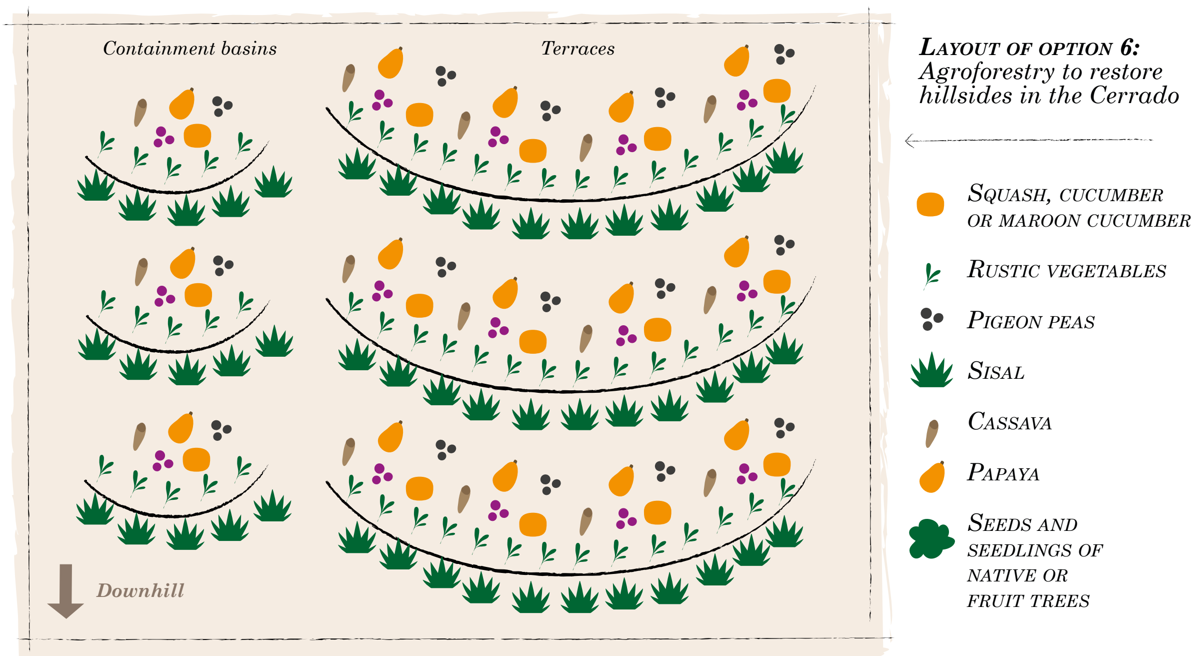
System design components: Swales, contour terraces or beds to control erosion and establish the trees.

Criteria for species selection: Resistant annual crops and fruit and native trees, especially hearty species that grow easily from cuttings or seeds.

Key species: pigeon peas, *carvoeiro*, *tingui*, *baru*, stinkingtoe, trumpet trees, *copaíba*, *angico*, *mangaba*, mulberries, yellow mombin, sisal (*Agave* spp.).

Implementation: Where there is a limited labor pool or the hillside is very steep, prepare small semi-circle basins (0.5 m to 1.5 m diameter) or small contour terraces (2 to 3 m between rows). The terraces should be located in strategic points in the terrain, for example where there is more accumulation and the soil is a little deeper, where there is room between the rocks to facilitate the preparation of terraces and increase the infiltration of water and the accumulation of organic matter and soil. On terrains that are not very steep, the terraces can be built with farm machinery. When building the swales and terraces, ditches and mounds are formed. It is vital to cover the swales/terraces with organic matter, both the ditches and the mounds. Then selective weeding can be done.

Trees, shrubs, legumes and fast-growing grasses are planted directly with seeds or cuttings in the lower part of the mounds or inside the lower part of the ditches or seed holes for species that need moister soil. Large terraces are also effective for concentrating water and nutrients, in addition to controlling erosion, but they require more labor. Another option is



Layout of option 6: *Agroforestry to restore hillsides in the Cerrado*

to plant legumes and sisal (*Angustifolia* or agave) to use the organic matter from pruning as soil cover.

The cut material and prunings from the native trees can also be piled on the small terraces after planting tree seeds and covering them with fertilizer available on the farm or nearby, such as manure, ashes or compost. Along with the tree seeds, in small holes with manure, plant maize and some hearty greens like bur cucumbers, scarlet eggplants, grape tomatoes, heirloom cucumbers and squash. When they are available, lime and rock dust also help reduce acidity and attract nutrients in the soil. In the soft earth mounds, plant cassava at 80 cm intervals, with the roots pointing into the mound. Then insert the tree seeds in front of the cutting tips (Section 4.4.2). Rustic greens can also be planted in the small terraces, once fertilized, along with tree seeds and seedlings. The sisal is planted at 50 cm intervals in the lower part of the mounds or above the ditches and should be pruned. Plant the Mexican sunflower and mulberry cuttings below the mounds as well. To help establish the trees, it is best to plant both the tree and maize seeds in small holes fertilized with manure or compost (Section 4.4.2) covering the entire area, but particularly in strategic places where organic matter and soil have accumulated. Legume species such as crotalaria, velvet beans, stylosanthes and pigeon peas are sown by hand (or with a manual sower). The final step is to prune the trees found in the area. The pruned material is duly organized for the woody branches to reinforce the terraces and help contain other parts of the terrain. The leaves are shredded and piled around the seed holes and wherever the soil is exposed.

Management: Selective weeding and pruning of the legumes and Mexican sunflower during the first three years. Accumulate biomass in the terraces and around the newly planted trees. To avoid dispersion of the velvet beans, it is important to prune the plants before pods ripen. In the third year, begin pruning the sisal and mulberry bushes. The resulting mulch is then laid around the most valuable trees.

Long-term management/system configuration: AFS whose structure and function are similar to those of a hillside forest, but with greater density of fruit-bearing species. Trees whose presence becomes too dense are thinned out, and the other trees are selectively pruned to maintain production of the fruit-bearing species.

OPTION 6: AGROFORESTRY TO RESTORE HILLSIDES IN THE CERRADO | PERSPECTIVE VIEW

OPTION 7: AGROFORESTRY TO RESTORE HILLSIDES OR LEGAL RESERVES IN THE CAATINGA

This option is based on the AFS developed by Gilberto dos Santos, in the Pau Ferro Community, Curaçá, Bahia.

Context: Low to medium fertility soil; low to medium regeneration; predominance of shrubs, cactus and small trees; good drainage; LR; Caatinga biome; low availability of labor; medium market access.

Main objective: Co-existing with the semi-arid region, production of food and other products.

Secondary objectives: Restoration

Overview: In the Caatinga, the major difference between this system and Option 6 is the presence of livestock, including the use of goat and sheep droppings to plant native tree species and forage shrubs. In addition, the species selected must be adapted to a longer dry season given the drier conditions of the Caatinga. Even in terrains with small basins or terraces must be used to establish trees and achieve some production, to make better use of the few available resources (water, labor, manure).

System design components: Small basins or small contour terraces or swales to control erosion and establish trees. Enrichment with manure rich in Caatinga forage species seeds, together with seeds for fruit and lumber trees, both native and exotic.

Criteria for species selection: Resistant annual crops and fruit trees, especially those that reproduce easily with cuttings and seeds.

Key crop species: pigeon peas, sesame, bur cucumber, black-eyed peas.

Key tree species: *umbu, seriguela,* yellow mombin, cashew, *juazeiro*, *favela* (*Cnidoscolus quercifolius*), *mulungu* (*Erythrina mulungu*), soursop, tamarind (*Tamarindus indica*), sweetsop (*Annona squamosa*).

Implementation: Trees, shrubs, legumes and fast-growing grasses can be planted directly with seeds or cuttings at the bottom of the mounds left from digging out the swales, or else in the terraces, mini-terraces or holes used to plant seedlings. The dug-out part of these structures must be covered with animal manure and organic matter to increase infiltration, avoid erosion, enhance fertility and promote regeneration through seeds introduced with the manure. Sisal (angustifolia or agave) should be spaced at 50 cm intervals below the mound left from digging holes to plant the seedlings known to be more valuable and demanding in terms of moisture and nutrients. They can also be planted in contour lines throughout the terrain. Organic matter from the mowed material and pruned from the native trees can also be concentrated in these small terraces, after planting the tree seeds and covering them with fertilizer available on the farm or nearby, such as manure, ashes or compost. Together with the tree seeds, plant pigeon peas and some more rustic vegetables such as bur cucumber, scarlet eggplant, grape tomato, *caipira* cucumber and *menina* squash in these seed holes the first year.

The basin can be from 1 to 2 m in diameter with in a semi-circle shape to store water. Inside the basin, the plants can go in as recommended in islands. For example, plant an adapted tree seedling (of a key species), and also a tree cutting, together with three cuttings of pear cactus or *mandacaru* distributed around the area, as well as at least five or six pigeon pea seeds, spaced at 0.5 m. Annual species, such as black-eyed peas, sesame or bur cucumbers, can be

Photo: Daniel Vieira

Contour basins to control erosion and establish trees.

planted in the same spacing the farmer is used to. Lastly, the trees in the area are pruned and the material is duly organized so the woody branches can reinforce the terraces and help contain other parts of the terrain. The leaves are shredded and piled on the seed holes and wherever the soil is exposed.

Management: Selective weeding. Accumulate biomass on the terraces and around the trees that are introduced. Prune the sisal beginning in the third year. The material pruned from the pigeon peas and sisal is spread over the soil around the most valuable trees.

Long-term management/system configuration: AFS whose structure and function are similar to those of the native Caatinga, but with a greater density of fruit-bearing and other useful species.

In the Caatinga, PPAs are commonly used for production, as the best place for agricultural crops to grow. It is fundamental to reconcile production with conservation in these cases, something agroforestry systems can do. The next three options refer to the Caatinga biome.

In the approach called "co-existing with the semiarid," recommended for the Caatinga, agroforestry systems should be associated with water harvesting, storage and re-use systems, including social technologies such as cisterns, mini-dams, Amazon wells and others, which provide water for human consumption, livestock and irrigation.

Pear cactus as a source of water for tree seedlings

Photo: Cinara Del'Arco Sanches

PRACTICAL TIPS

GOAT DROPPINGS TO SOW PLANTS IN THE CAATINGA

Goat droppings are very useful for restoring the Caatinga. In addition to the organic matter, they contain all sorts of seeds, from herbs to trees. "The manure does the seeding for us! *Umari, imbu, juazeiro*, all coming up! The manure from each season has a different combination of seeds, depending on which species is flowering. To recover degraded areas with bare soil it is important to work with plants that will cover the ground and hold the soil in place to avoid runoff. This manure is rich in plant seeds that germinate well."

José Moacir dos Santos *– IRPAA – Juazeiro, Bahia*

LAYOUT OF OPTION 7: *Agroforestry to restore hillsides in the Caatinga*

PRACTICAL TIPS

ISOLATION AND RESTORATION OF DEGRADED AREAS IN THE CAATINGA

Fencing in the "clearing" (*"limpo"*) was the first step to begin recovering the area. We're not sure, but it seems that various factors contribute to the emergence of the "clearings," like the concentration of goat herds in these shaded areas, long-lasting droughts and weak soil.

Gilberto digs holes in the middle of semicircle micro-basins. The water can flow into the holes but cannot run off. The curves are about 20 cm high and 1 m in diameter. They cover the entire terrain, like a stairway of basins. In the holes, he plants *umbu* trees every 10m to make his investment in manual labor bear fruit in food and sales.

Gilberto fenced off the area and spread shovels of manure in thin layers. Grass and other plants grow out of the manure. The plants dry out with no water but leave straw that holds in water and the soil, until new plants sprout out of the straw when it gets wet. The fence keeps the goats from coming in to eat the grass. Not only in the basins but all around the terrain plants and trees are growing, brought in with the manure. They germinate and grow because the goats are kept away from the basins that conserve water and because of the manure that both conserves water and provides nutrients. The manure is spread frequently, in areas where the soil is still "clear."

Gilberto dos Santos *– Pau Ferro Community, Curaçá, Bahia*

OPTION 8: FORAGE PRODUCTION IN AGROFORESTRY SYSTEMS FOR THE CAATINGA

This option is based on an experience at the EFASE – the Sertão Family Farming School, in Monte Santo, Bahia.

Context: Medium fertility soil; low to medium regeneration; predominance of shrubs, cactus and small trees; good drainage; LR or PPA; Caatinga biome; low availability of labor; market accessible.

Main objective: Co-existing with the semi-arid region (production of food and income generation, prioritizing livestock).

Secondary objectives: Restoration

Overview: regenerating Caatinga vegetation, pruned and managed for goat and sheep pastures, while maintaining biodiversity and other environmental services.

Given the essential role of livestock in this context, especially goats and sheep, forage-producing agroforestry

Photo: Daniel Vieira

Forage agroforest

systems play a key role in maintaining the livelihoods of family farmers in the Caatinga. They feed the animals through the second half of the dry season, and during the peak of the rainy season. The presence of trees creates a microclimate more favorable for the animals' well-being and, as a result, for their productivity during critical periods. This agrosilvopastoral system has been widely adopted in the Caatinga, since it allows other crops to be planted while feeding the animals[7, 108] with the material pruned from the Caatinga forage trees.[8]

System design components: Establish trees from cuttings, seeds and seedlings, with alternating rows of pear cactus, sisal and food and forage crops in islands. Approximately a dozen native forage species are planted together with some exotic forage species, such as Gliricidia and white leadtree.

Key crop species: maize, sesame, pigeon peas, bur cucumber, black-eyed peas.

Key trees and other species: Gliricidia, white leadtree, pear cactus, sisal, *umbu*, yellow mombin, cashew, *emburana*, Brazilian ironwood, *juazeiro*, *catingueira*, *sabiá*.

PRACTICAL TIPS

HAY AND SILAGE PRODUCTION TO FEED ANIMALS DURING THE DROUGHT

Hay is produced using sorghum and Brazilian ironwood, which is native. Other native species can also include *catingueira*, yellow cotton tree, cassava leaves and bitter cassava. These are gathered and stored until summer, and then mixed with sorghum. They cut the buffelgrass, store everything and make hay to feed the livestock during the drought.

The hay is stored on a bench and closed with sisal above the ground, to avoid mold from contact with the ground moisture.

To build a silo, four or five people from a family dig a hole in the ground and stomp it until it is compact. They cover it with canvas and remove the air.

Caldeirão do Almeida Regional Association – *Uauá, Bahia*

PRACTICAL TIPS

SILVOPASTORAL SYSTEM TO RAISE GOATS AND SHEEP

Antônio has 7 hectares for his livestock. Today those 7 hectares are covered with native Caatinga vegetation and the animals are free to roam. There is a shed where he feeds them fresh or dried grass and maize. He intends to close in the entire area with 12-volt, 3-wire electric fences, divided into five paddocks. Each paddock will be grazed for 2.5 months. Free-range grazing in the Caatinga ensures the livestock is fed for most of the year.

Antônio intends to leave a natural area where the goats will come in for only 2.5 months per year. In the other paddocks, he will prune the *catingueira*, the *mororó* (*Bauhinia cheilantha*), and the *cantanduva* (*Ptyricarpa moniliformis*) for them to grow out again at a height where the goats can eat them. Other tree species from which the goats only eat the leaves need no pruning. This is the principle of the Caatinga silvopastoral system. He also intends to leave some tree species which will be cut down for lumber in the future.

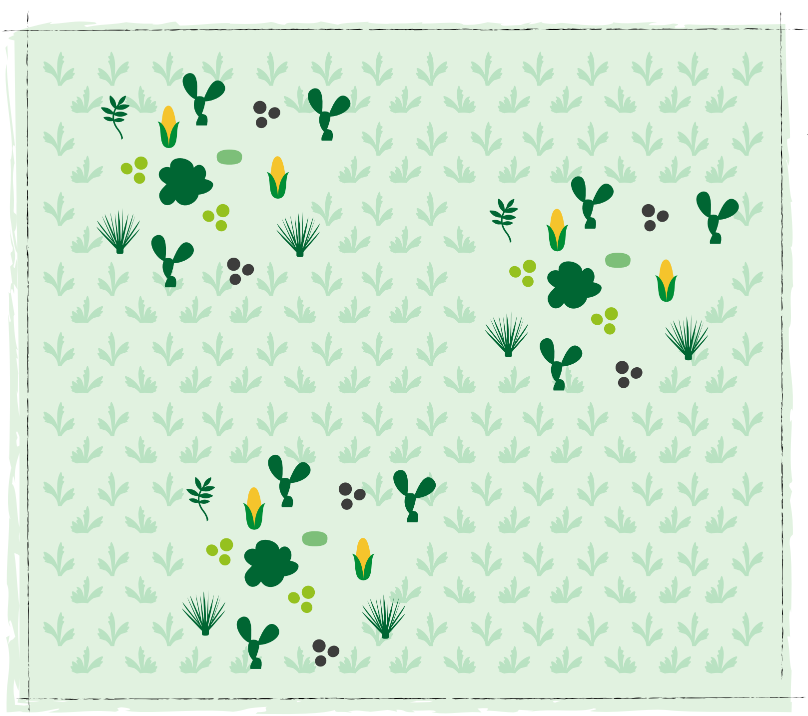
Antônio José de Morais *– Jasmin Flower Farm, Juá dos Vieiras Community, Viçosa do Ceará, Ceará.*

Photo: Daniel Vieira

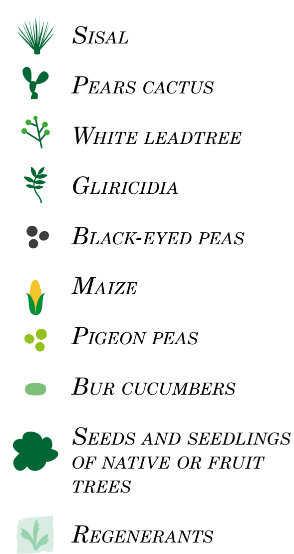
Photo: Daniel Vieira

Implementation: The enrichment is done by planting islands in small clearings that naturally occur in the middle of regenerating vegetation, using mostly forage species. Identify strategic points (small clearings) for enrichment. Mark existing seedlings of saplings that are the trees of the future with stakes and cut any grass or aging herbaceous plants. Prepare holes for seeds (loosen, fertilize, cover with organic matter) and plant trees (including white leadtree, Gliricidia and mesquite, together with seeds of native species such as *sabiá*, for example). The Gliricidia can also be planted with cuttings, as can yellow mombins, *seriguela* and *umbu*, when available. Other species can also be planted, such as *mandacaru*, pear cactus and sisal, with 0.5 m spacing between them, along with agricultural crops at the spacing preferred by the farmer.

In order to increase biodiversity, more multi-purpose species such as fruit and timber trees can be added to this mixture of seeds. Pear cactus helps protect the soil and maintain moisture, as a "protection" for tree seedlings that will grow next to it, in addition to supplying water and nutrients for the livestock. The livestock's manure is brought in and used as fertilizer in these systems, which also increases the volume and diversity of tree and shrub seeds that will become soil cover and expand the diversity of their ecological and social functions. Finally, thin and prune the shrubs and trees in



LAYOUT OF OPTION 8: Forage production in agroforestry systems for the caatinga



PRACTICAL TIPS

SILVOPASTORAL SYSTEM WITH GOATS AND CASHEW TREES

I raise goats under cashew trees for weeding. There are *mororó* and *sabiá* plants that grow back as soon as a goat eats them; there are white *juremas* and black *juremas*, as well as the *catingueira*. They don't like to eat the *catingueira* green, but only dried out, so I cut it down and make hay for them. I have two paddocks, and they spend half the year in each one. In the area with no cashew trees, they can graze until May, as long as the pasture grows back fast enough for them to eat it dry after the cashew harvest. Then they move into the cashew grove to start weeding the area and save us the work. That's when the *catingueira* is tall, so we cut it down and make hay for them. I started with five does and a buck, and now I have ten. And they're all pregnant. Since I built a protein bank nearby, I want to increase the herd to twenty, I want to stock up on food. I already have a stock of food, and last year they didn't even eat all the *catingueira* hay.

The fodder bank has maize intercropped with gliricídia, white lea-dtree and other plants. In the area I cleared, which had *sabiá* and *jurema*, it's all pasture land. Now I'm picking the maize and there are a lot of clumps to remove, so I use two-year-old Gliricidia to make hay, because it's only good for pruning after two years.

The goats eat the cashew apples and leave the nuts on the ground, so you just gather the nuts. And since the area is clean because you let the goats loose there for a long time, it's easy to gather the nuts. In the area where they don't graze, I pick the cashew, take out the nut and let the fruit dry. When they're dry enough, I shred them and mix with the ground corn for extra feed, and they eat a lot. This silvopastoral system works on two hectares, divided in the middle.

Ernaldo Expedito de Sá – *Tianguá, in the Ibiapaba EPA, Ceará* the area and use the cut material to cover the ground. To harmonize the livestock with the plant restoration and agroforest production objectives, during the system's early years, they should be kept out of the newly established areas, to allow for regeneration from seeds, roots and new buds on the branches.

Criteria for selecting species: Engineer species that accumulate water, with food and forage species adapted to these climate and soil conditions. Rustic goats and plant species that are highly efficient in producing biomass, and tolerant to drought. Food crops and fruit trees adapted to the semiarid climate.

Management: Prune the trees to gather soil cover and produce fodder (hay) for the livestock. Introduce useful species (fruit, honey plants, timber) from cuttings and seeds, including seeds that come in the manure. The trees are managed with regular pruning to gather leaves and twigs to feed the animals. The pear cactus are pruned and fed to the animals in the trough.

Long-term management/system configuration: Prune the trees and cactus species to produce forage and biomass, and to let enough sunlight through for the grass and shrub species to flourish in the understory.

Photo: Daniel Vieira

PRACTICAL TIPS

MAIZE AND GRASS FOR LIVESTOCK TOGETHER WITH FRUIT TREES

The corn is intercropped with grass to feed the livestock along with new fruit trees. The land is being recovered with material pruned from the trees that were already there and are growing out again, and organic matter that the farmer finds easily off the farm, mainly sugarcane and carnauba palm bagasse, as well as goat and sheep manure. Antônio cuts the grass every three months when it rains, to cover the ground and make hay for the livestock to eat during the drought. Early-bearing dwarf cashew trees were planted, as well as sweetsops. In the future, the plan is to let the forest grow along the creek.

"I planted sweetsop and cashew, and I left some trees that were already there. Some of them are shaped and pruned to produce organic matter and develop their trunks. Pruning works fine and smaller plants do very well. I got a Swedish billhook with a long handle that reaches way up there, and has a sharp saw."

The trees are pruned to let more sunlight in for the grass, the maize and the new seedlings. The grass is cut every year when they plant the maize so it will grow faster and flourish. The grass can be pulled out with the roots and laid out on the ground, allowing it to take root again. This is an interesting approach since the grass takes longer to grow back, while the maize is growing. The grass helps a lot in the restoration process, but now it's about time to leave the maize and the stylosanthes, because the grass is very aggressive.

Antônio José Sousa de Morais *– Flor de Jasmim farm, Juá dos Vieiras community, Viçosa do Ceará, Ceará*

OPTION 9: RESTORING DEGRADED AREAS WITH AGROFORESTRY IN THE CAATINGA

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

Context: Low fertility soil (becoming desertified); low regeneration; good drainage; LR; Caatinga biome; medium to high availability of labor; access to the market.

Main objective: Restore degraded area, reverse process of desertification.

Secondary objectives: Ensure farm family's livelihood and generate income, prioritizing livestock and living with the semiarid region.

Overview: These systems aim to restore areas in advanced stages of degradation, including areas in the process of desertification. The soil is recovered, and agroforests are established initially with "engineer" species that are hearty and drought-resistant, with a significant capacity to store water, and which can also be used for forage. The engineer species are planted very densely in rows, and are regularly pruned or used for forage, depending on the farmer's objectives (livestock, annual crops or fruit production, or soil restoration, establishment of trees and storage of water in the vegetation).

System design components: Engineer species planted very densely in rows and regularly pruned or used for forage. The agroforestry systems are planted in rows of pear cactus (*Opuntia ficus-indica*) 1 m apart (depending on the size of the area and the availability of cuttings), with 1 m between plants, which can also be interspersed, in each row, with sisal. Between the rows, fruit and forage trees are sown, together with legumes and grain crops.

Criteria for species selection: Engineer species that accumulate water and forage, plus honey and food crops adapted to the climate and soil conditions, highly efficient at producing biomass and drought tolerant; agricultural crops and fruit trees adapted to semiarid edaphoclimatic conditions.

Key species of food crops: maize (when manure is available) or sorghum, pigeon peas, sesame, bur cucumbers, black-eyed peas.

Photo: Cinara Del'Arco Sanches

Photo: Cinara Del'Arco Sanches

Initial stage of the high-density intercrop of forage species, food crops and native trees. Cafarnaum Municipality, Bahia

Key trees and other species: Gliricidia, white leadtree, pear cactus, *umbu*, yellow mombin, cashew, *emburana*, Brazilian ironwood, *juazeiro, catingueira, sabiá*, drumstick tree, *maniçoba*, *baraúna*, licuri palm, Brazilian peppertree, mesquite, castor beans.

Implementation: The pear cactus cuttings are planted in a row between the sisal plants, 0.5 m apart, with 1 m between rows. Between the rows, place a mixture of seeds in a furrow, with forage trees, including Gliricidia, white leadtree, *mulungu* and *sabiá*. Together with the forage seeds, also mix in *mamauí* and cashew, along with cuttings of *umbu*, yellow mombin, *juazeiro*[69] and other species adapted to these conditions. To enhance biodiversity, more multi-purpose species, including fruit and timber, can be added to this mixture of seeds. If animal manure is available, it is brought in to fertilize this system, increasing the number and diversity of trees and shrubs that will cover the soil and expand the diversity of the system's ecological and social functions. Along with the tree seeds, also plant maize or sorghum, pigeon peas every 1 m (3 seeds). Azuki beans or black-eyed peas can also be added, as well as squash and bur cucumbers, with the spacing normally used by the farmer. Another possibility is to plant trees with cuttings and seeds together with

PRACTICAL TIPS

PLANTING ANNUAL CROPS WITH SISAL AND PRICKLY PEAR IN THE BACKLANDS (*SERTÃO*)

Ernst, with much experience in the sdsemiarid, recommends planting sisal very densely (20 cm apart). After a year, cut ¾ (every other row). This can be done with a trimmer. Sisal, after seven years, accumulates 10 cm of biomass over the ground. This species takes water from the air (dew) during the dry season. As soon as the sisal is cut, plant both maize and beans, and even with little water the harvest will be good. The maize can also be planted together with sorghum. If the environment is unfavorable for the maize, the sorghum will still produce. Interspersed with the sisal, after a year, plant pear cactus. There are other species in the sisal (*Agavaceae*) family that can also be used if that species is not available.

Ernst Götsch *– Piraí do Norte, Bahia*

Photo: Cinara Del'Arco Sanches

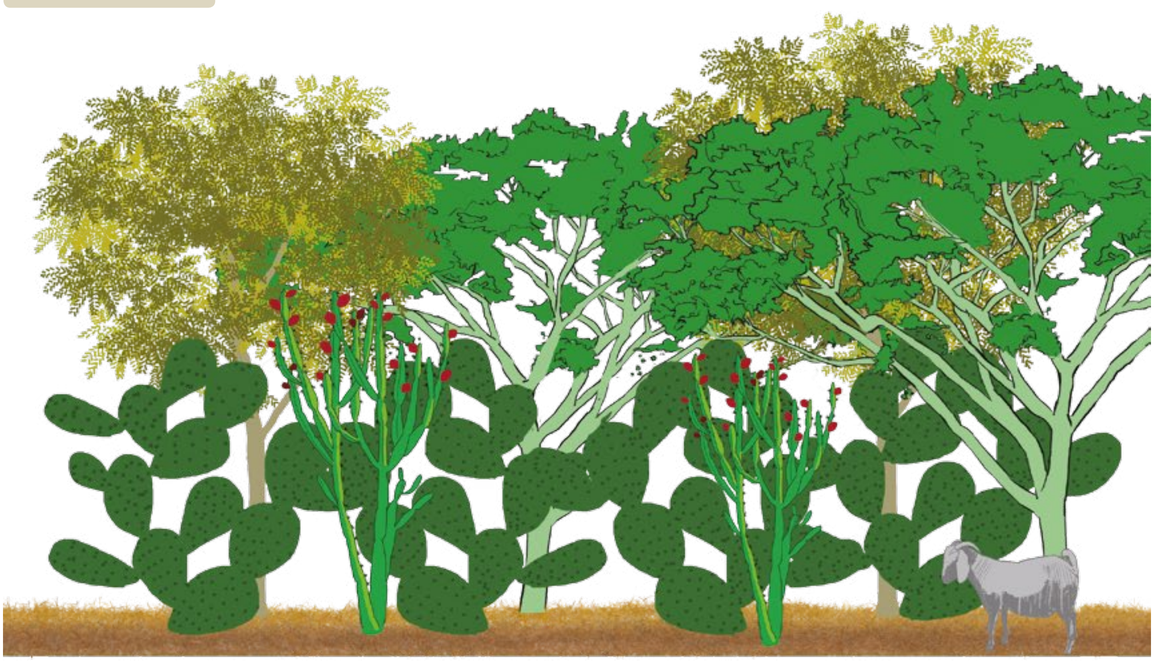
Photo: Cinara Del'Arco Sanches

Agroforest established in a high-density intercrop with forage species, food crops and native trees. Umburanas, Bahia

6 months

2 to 3 years

7 to 10 years



OPTION 9: RESTORING DEGRADED AREAS IN THE CAATINGA

the pear cactus and the sisal, to make better use of the moisture and create a favorable microclimate for the emergence of trees.

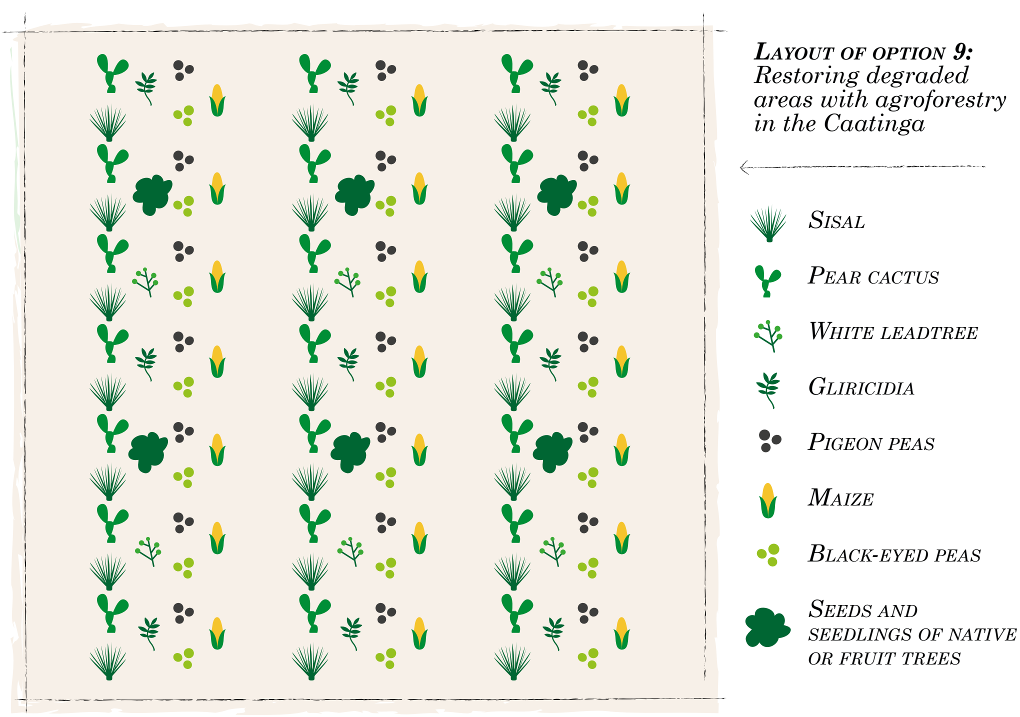
Management: Systematic pruning of the engineer plants to cut and spread the material for covering the soil around trees and annual crops. Prune the forage species to feed the livestock. The livestock is kept outside the area and fed in troughs either with fresh forage or with silage or hay during the first years, and then inside the area, in rotation. The trees are managed with regular pruning to gather the leaves and twigs to feed the livestock. After some time, thin out the trees that were planted very densely.

PEAR CACTUS: WATER IN A PAD

The prickly pear cactus is pruned, and the part cut away is placed near the plants to become fertilizer.

Caldeirão do Almeida District Regional Association

Long-term management/system configuration: Prune the trees and produce forage and biomass, letting in enough sunlight for the ground-level species to grow.



Layout of option 9: Restoring degraded areas with agroforestry in the Caatinga

OPTION 10: PROTECTING AND RESTORING SPRINGS WITH AGROFORESTRY

Context: Spring PPA; Cerrado biome; flooded soil; typically, not very aerated; in some cases very acid and unproductive, while others display medium fertility and may even allow some production

Since spring areas are extremely delicate, any intervention must be carefully studied and assessed. In many cases, spring areas still have regenerant plants and can thus be restored simply by protecting them from outside threats like livestock and fire. Larger animals, especially cattle, can harm spring areas as they trample on and compact the soil, thus reducing infiltration and replenishment, as well as polluting the water with their feces. Like bovine cattle, goats and sheep can also impair the natural restoration of springs, since they eat small tree and shrub saplings that regrow naturally, whether from seed banks, roots in the soil or animal dispersers such as birds, monkeys or others.

The first thing to do in most cases is to fence off the spring area to avoid the entry of livestock, in itself a very important step to enable natural regeneration processes. Fire is another major threat to springs, since it favors the emergence of grass, whose regrowth ability is greater after a fire and which, like animals as well, tend to eliminate the small shrub and tree saplings of typical local species that are essential for the spring's future. In some cultures, where springs have an immense spiritual value, the relationship with local species and care for the area transcend any utilitarian attitude regarding the water.

Main objective: Conserve and increase the quantity and quality of water; ecological restoration.

Secondary objectives: Produce food, medicinal and ornamental species.

Overview: Protect against drivers of degradation (livestock and fire), manage natural regeneration and enrich spring areas, including species of interest to humans.

System design components: Maintenance of natural regeneration species and enrichment with seedlings and seeds of species that grow well in the area's conditions, planting in islands, (see Section 4.4.2) or furrows arranged in concentric circles or contours lines.

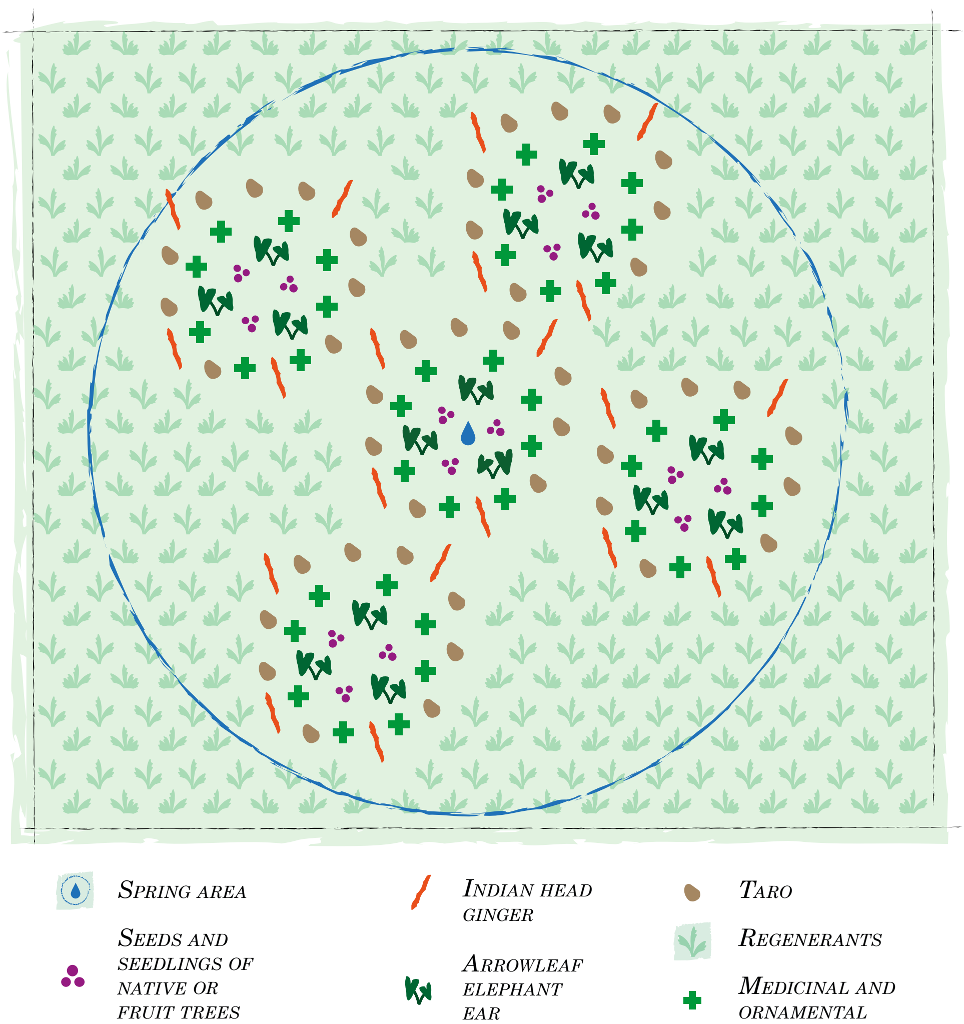
Criteria for species selection: Species adapted to waterlogged environments, species of value to farmers.

Key agricultural species: Taro, arrowleaf elephant ear, ginger, Indian head ginger (*Costus spicatus*).

Key tree species: *ingá (Inga sp.), capororoca (Rapanea gardneriana), pinha do brejo (Talauma ovata), landim (Calophyllum brasiliense), buriti (Mauritia flexuosa), juçara (Euterpe edulis), sangra d´água, quaresmeira (Tibouchina stenocarpa), pau pombo (Tapirira guianensis)* and *jenipapo (Genipa americana)*.

Implementation: Fence off the area to protect it from livestock. Identify

Layout of option 10: *Protecting and restoring springs with agroforestry*



species of native shrubs and trees present in the area and protect the plants from being cut or trampled when preparing the area. Whenever possible, introduce more individuals of these same species. If exotic grasses are dominant, they must be managed to allow seedlings to take hold and fire must be avoided, by cutting and organizing piling the dry grass around the tree seedlings and food crops. In situations with low density and diversity of regenerants, introduce native species, whether by seedlings, seeds, cuttings or rhizomes. Around springs with a production potential, vegetable, medicinal and ornamental species may be planted, as long as they are adapted to waterlogged conditions. When labor is available, prepare fertility islands by planting seedlings and banana trees, as well as cuttings and seeds sown together with food crops. If labor is scarce, it is best to plant the trees by seed, along with rhizomes or cuttings of species of interest.

Management: Do selective weeding and cut the grass frequently, especially the more flammable exotic grasses, to avoid the spread of fire. Prune existing trees enough to allow the introduced species to take hold and ensure that natural regenerants present will be able to come back successfully. The organic material cut and gathered from the pruning should be organized in windrows or around the seedlings to avoid the spread of any fire that might come into the area. Firebreaks must also be made to keep fire away and make it easier to fight. If possible, create a living firebreak with species that will not let a fire through.

Long-term management/system configuration: Vegetation with structures and functions similar to the native forest around springs. Selective pruning of the trees to advance succession and enable ongoing production of some food crops.

OPTION 11: AGROFORESTRY HOMEGARDENS

Context: Cerrado or Caatinga biomes; well-drained soils; variable (medium to high) fertility; located near the home; PPA, LR or other areas.

Main objective: production of food and multi-purpose species.

Secondary objectives: restoration, improvement of the microclimate.

Overview: biodiverse, multi-stratified agroforests, with intensive management and use of domestic waste.

System design components: Quite diversified vegetation, with food, medicinal and ornamental species arranged irregularly (no defined pattern), with the presence of small animals, such as poultry and pork.

Photo: Andrew Miccolis

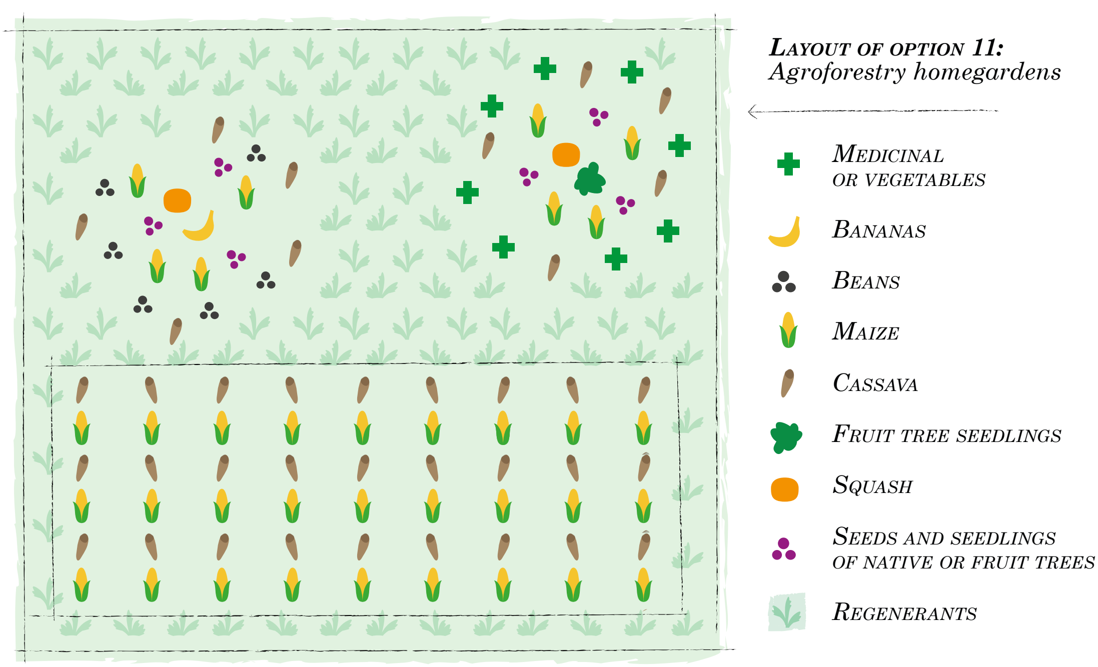
Possibility of using food waste, ashes from firewood stove, animal manure, waste water (sinks, shower) and rainwater (cistern).

Criteria for species selection: Diverse, multi-purpose species for use as food (grains, fruit, condiments), medicine, ornamentals and small-animal feed. The species must be adapted to local conditions.

Key food crops: Cilantro, kale, maroon cucumber, pigeon peas, black-eyed peas, sweet potatoes, cassava, passion fruit, papaya, banana, arrowleaf elephant ear, taro, purple yam, leaf cactus.

Key tree species: Fruit trees in general and native species, including fertilizer trees.

Implementation: Planted near the farm house, with a dynamic approach for constant enriching the area. The location is chosen to meet the needs of the species. Multi-purpose trees are introduced as seedlings, seeds or cuttings, in islands, or beds. Planting the trees together with vegetables makes efficient use of labor and other resources, while facilitating the overall establishment. Fertilize the plants with manure, ashes, compost and leaves. Different compositions are possible, in mosaics



Layout of option 11: Agroforestry homegardens that makeup guilds in small clusters with ornamental, medicinal, fruit and fertilizer plants, small animals and a vegetable garden. Although covering the soil with organic matter may not be a cultural habit, it is fundamental to maintain soil fertility and moisture for a homegarden.

Management: Management is done basically with a machete for selective weeding and pruning. It can be irrigated with rainwater stored in a cistern, especially for species more demanding in water such as vegetables. The animals are fed with produce from the homegarden (green and fruit waste and grains such as pigeon peas for chickens). Trunks, branches and rocks are used to make path edges and help accumulate organic matter. Management can also produce firewood, which is an important raw material used by most farm families.

Long-term management/system configuration: Selective weeding and pruning. The system is a diversified forest, with clearings kept through pruning, thinning and enrichment with seedlings and seeds. Once the trees have grown old, they can be managed indefinitely with the aim of reintroducing species that require sunlight and fertile soil.

PRACTICAL TIPS

PRODUCTIVE HOMEGARDENS

The management is done with a machete, for selective weeding and pruning. The species found in Chico Antônio's homegarden were: acerola, *amburana*, pepper trees, bananas, sweet potatoes, yellow mombins, cashew, *canafistula*, elephant grass, *catimbira*, *catingueira*, Argentine cedar, crotalaria, eucalyptus, fava beans, beans, jackbeans, sesame, Gliricidia, guava, soursop, pigeon peas, Brazilian ironwood, oranges, white leadtree, cassava, papaya, castor beans, mango, maize, drumstick tree, *pau branco*, brazilwood, *pau jaú*, sisal, sorghum and tamarind.

Sr. Chico Antônio *–Recanto do Beija-flor farm, Viçosa do Ceará, Ceará*

5.3 STEP-BY-STEP IMPLEMENTATION OF THE OPTIONS IN DIFFERENT CONTEXTS

Strategies to implement these AFS options may vary in each situation, depending on the availability of labor and inputs, the stage of succession and the density of regenerating vegetation. All situations, however, require certain steps to prepare the area, implement and manage the systems. It is important the steps be taken in the right order, to optimize the work, cut costs and enhance the likelihood of success. The following steps may be taken in different types of vegetation.

SECONDARY FOREST

Access to labor and inputs: *medium or high.* ***Stage of succession:*** *initial to middle.*

- Measure and delimit;
- Do selective weeding;
- Identify and mark existing saplings;
- Prune vegetation for thinning, renewal and enrichment (extent and height of pruning depends on the system to be established);
- Prepare and plant beds or islands;
- Prune secondary growth for thinning, renewal and enrichment, depending on the area´s stage of succession, then shred and pile the pruned and outside material in the beds or islands.

SECONDARY FOREST

Access to labor and inputs: *low.* ***Stage of succession:*** *initial.*

- Selective weeding (underbrush, including grasses, especially exotic grass, and annual weeds), pruning of shrubs;
- Prepare and plant islands with maize, vegetables, legumes, cassava, trees (described above);
- Prepare simple holes to plant seedlings that the farmer wants to introduce (when there are enough seedlings and labor and, if possible, a little fertilizer) of hearty species
- Prune to clean and thin out vegetation (trees), organizing the pruned material throughout the area;
- Plant and manage the edges and connections with other landscape components.

PASTURES MOSTLY COVERED BY GRASS

Access to labor and inputs: *low.* ***Stage of succession:*** *initial.*

- Measure and delimit the area, using cuttings that root easily around the edges and inside (if this is part of the design);
- Mow the entire area and weed out alternating strips removing the rhizomes or, if enough labor is available, weed out the entire area;
- Prepare the beds or islands in the weeded areas;
- Organize/pile straw in the beds;
- Plant and manage the edges and connections with other landscape components.

DEGRADED AREA WITH SOME REGENERATION

Access to labor and inputs: *low to high****. Stage of succession:*** *initial.*

- Measure and delimit the area;
- Selective weeding (grass, annual weeds), selective pruning and thinning (shrubs), identification, labeling and piling of organic matter from all pruned trees;
- Planting: the technique varies depending on access to labor and inputs, as well as the farmer's own objectives;
- Manage the grass;
- Plant and manage the edges and connections with other landscape components.

Photo: Andrew Miccolis

TABLE 7: SUMMARY OF AFS OPTIONS FOR DIFFERENT CONTEXTS

Option/ Context	Ecological resilience / Natural succession	Biome	Preservation Area	Soil fertility and drainage	Need for inputs	Market access	Labor availability	Farmer's objectives	Type of System
1	low regeneration, predominance of exotic grasses like gamba and brachiaria	Cerrado	Legal Reserve	degraded; well drained	high	High	high	cash crops, food, restoration	Successional agroforestry for the Cerrado with intensive management
2	low regeneration, predominance of exotic grass like brachiaria and Guinea	Cerrado	Riparian PPA	medium to high fertility; fair to medium drainage	medium	High	low to medium	cash crops, food, restoration	Biodiverse agroforestry for PPA restoration
3	high regeneration, predominance of shrubs and tree seedlings	Cerrado	Legal Reserve	medium fertility; good drainage	variable	medium	variable	cash crops, food, restoration	Agroforestry intercropped in rows with enrichment of the Cerrado
4	high regeneration, predominance of shrubs and tree seedlings	Cerrado	PPA and LR	medium fertility; good drainage	low	High	variable	restoration, food security and some marketing	Agroforestry for enrichment and management of naturally regenerated secondary growth
5	low regeneration, predominance of grass and shrubs in initial stages of succession like cogon, molasses grass, brachiaria and white *cambará*	Cerrado	PPA and LR	low fertility, well drained	medium	High	variable	restoration and provide livelihoods	Agroforestry to restore degraded areas with fertilizer species
6	low to medium regeneration, predominance of grass and shrubs	Cerrado	Hillside PPA	low fertility, good drainage	medium or low	low to medium	high	restoration and provide livelihoods	Agroforestry to restore hillsides in the Cerrado
7	low to medium regeneration, predominance of shrubs, cacti and small trees	Caatinga	Legal Reserve	low to medium fertility, good drainage	medium or low	medium	low	restoration and livelihoods, co-existing with the semiarid	Agroforestry to restore hillsides or legal reserves in the Caatinga
8	low to medium regeneration with some shrubs, cacti and small trees	Caatinga	Legal Reserve or PPA	good drainage	low	medium	low	restoration, livelihoods, income, livestock, co-existing with the semiarid	Forage production in agroforestry systems for the Caatinga
9	low regeneration, degraded area	Caatinga	Legal Reserve or degraded area	low fertility (process of desertification), well drained	medium	High	medium	restoration, halt desertification, livelihood and income, livestock, co-existing with the semiarid	Restoring degraded areas in the Caatinga
10	low, medium or high regeneration	Cerrado	Spring PPA	waterlogged, poorly aerated	low	variable	variable	Increase quantity and quality of water; livelihood	Protecting and restoring springs with agroforestry
11	low to high	Cerrado or Caatinga	PPA, LR or other areas	Variable but generally well drained; many nutrients from the household	high	variable	high	produce food, medicine, fuel, shade, leisure	Agroforestry homegardens

5.4 KEY SPECIES TO RECOVER DEGRADED AREAS

Key species to recover degraded areas are those that enable both social and environmental functions in AFS, opening the door for abundance and well-being. They are species that grow and flourish in adverse and degraded environments, favoring the entry of others, particularly those with attributes listed above as criteria for the selection of species (Section 4.2.1), as well as species with similar features identified by farmers and extension agents in their specific agroforest contexts. Here are some of the features that distinguish these species from others:

- Generally, they are more efficient at using resources (water, sunlight and nutrients) and producing biomass, especially in adverse conditions;
- They improve the soil's fertility, structure and microbial life;
- They can store water in inhospitable conditions or take in water from deep underground and make it available to smaller plants through their roots;
- They create fresh, moister microclimates during the dry season, enhancing the development of other species that need more favorable conditions to grow.

In this section, we present some such species identified as strategic in the Cerrado and Caatinga, the context in which they are recommended, special characteristics, centers of origin, uses and functions. We also provide guidance on how to manage them to fulfill their desired roles, without hindering the development of other plants.

MESQUITE *Prosopis juliflora*

Characteristics: Leguminous tree that produces sweet pods, bearing fruit after the second or third year.

Origin: Dryer regions of Mexico, Central America and northern South America (Peru, Ecuador, Colombia and Venezuela).

Favorable environmental conditions: Average annual rainfall: 150-1,200 mm (produces more pods when rainfall is from 300-500 mm) and tolerates up to nine months of drought; Altitude: sea level to 1,500 m; Average annual temperature: above 20ºC; Soils: rocky, sandy or saline.

Uses and functions: Multi-purpose tree: timber (poles, planks, ties, fence posts, firewood, charcoal) and forage (leaves, branches, pods and seeds); protect soil against erosion; shade; conservation and improvement of pastures; for honey pasturing; production of tannin and gum. Its fruit is an important source of carbohydrates and proteins, especially in dry regions. The sweet pulp of its fruit and the seeds contain 34-39% protein and 7-8% oil.

Photo: Daniel Vieira

Mesquite

As forage, the pods have a 13% gross protein content and their digestibility is above 74%. Its leaves, which are less palatable, have 18% protein, digestibility 59% and tannin 1.9%. It improves soil fertility by increasing the content of organic matter, nitrogen and phosphorus, while helping lower the pH of very alkaline soil. It has a symbiotic association capacity with Rhizobium bacteria, which fix nitrogen in the soil.

For all those reasons, mesquite has been recommended for intercropping with other plants, especially in the Caatinga's silvopastoral systems. According to researchers at the federal agricultural research corporation, Embrapa, mesquite is a species that can reestablish fertility and yields in degraded, saline soils, and studies – mainly in India – have shown its capacity to recover unproductive alkaline soils.

Propagation and observations: Can be reproduced by seed or cuttings. The seeds' dormancy can be broken by mechanical or chemical scarification, or else by the most recommended method, namely submerging the seeds in hot water for 3-5 minutes. Animals easily propagate the seeds, since the dormancy is broken by their warm, acid digestive tracts. As an exotic species, mesquite has a major invasive potential, because it grows quickly and can spread many seeds, often occupying the space normally taken by slower, native plants. Its invasive potential, however, can be contained by thinning and pruning the trees, cutting (weeding) the seedlings and manually collecting mature seed pods, isolating invaded areas to avoid direct grazing and processing the pods to feed the animals in troughs. This means that, where the area can be managed, this species is an important ally and can even fight desertification, since it grows well in extremely degraded areas. Water stress is also a natural barrier to its uncontrolled proliferation over large areas of the semiarid. *Sources:* [36, 96]

WHITE LEADTREE *Leucaena leucocephala*

Photo: Andrew Miccolis

White leadtree

Characteristics: A fast-growing leguminous tree of the Mimosaceae family, also known as leucaena, it can reach 20 m in height with a 30 cm diameter at breast-height. It produces a large volume of seeds, which spread widely to cover areas thoroughly. It responds well to pruning and regrows vigorously.

Origin: Central America

Favorable environmental conditions: Average annual rainfall: 650-3,000 mm; grows best in limey soil and does not tolerate acid or soggy soils; tolerates long drought periods; Average annual temperature: 10-40º C; Soils: well drained, deep, average to high fertility with pH between 5.5-7.5. Efficient symbiosis with nitrogen-fixing bacteria.

Uses and functions: Improves soils with its high-quality leaves, making it an excellent green manure. Its symbiosis with nitrogen-fixing bacteria provides up to 400 kg of nitrogen per hectare every year. Its association with *Mycorrhizae* fungi releases phosphorus both for the white leadtree and for other crops. Periodic pruning speeds up nutrient cycling. The plant is also recommended for animal feed, because it is very palatable, nutritious, high-yielding, fast to regrow (even during the dry season) and provides quality fodder. The leaves contain an average of 20% gross protein and, mixed with the new-grown fruit, the fodder can reach up to 35% protein. In protein banks, it is one of the most promising fodder plants for the semiarid region. It can be used for grazing and harvested to produce green fodder, hay and silage, in addition to producing seeds. It is also good poultry feed and can make yolks redder with the beta-carotene from its leaves. Researchers at Embrapa recommend cutting it every 42 days, during the rainy season, "to produce green manure, silage and hay, or as livestock fodder. During the dry season, wait 84 days before cutting. In Sobral, Ceará, farmers recorded the production from 1,539 kg to 5,387 kg of dry matter per hectare per year. With irrigation, white leadtree can be cut every four to five weeks all year long, adding to the stock of high-quality fodder." White leadtree also provides firewood, charcoal and pulp, as well as shade for pastures (in silvopastoral systems) and other crops, wind-breaks, hedges and honey-bee forage.

Propagation and observations: Contains a substance called mimosine, which, when consumed in large amounts by livestock (i.e., more than 50% of the volume of the fodder), can cause hair loss, excessive salivation and weight loss. The problem is easily solved by withdrawing white leadtree from their diets. As fodder for ruminants, this legume should be introduced slowly, up to a maximum of 20% to 30% of their diet.

The seeds have a very hard shell. To help it germinate, soak the seeds for three minutes, stirring well, in boiled (not boiling) water. Then let the seeds dry in a ventilated area. These seeds can be stored, or else planted the next day. Another approach is to soak the seeds overnight at room temperature. These seeds should then be planted immediately. The season for planting is early in the rainy season. Like mesquite, this tree's invasive potential can be contained by periodic thinning and pruning, especially when it is about to seed. *Sources:* [32], [33], [111]

PIGEON PEA *Cajanus cajan*

Characteristics: leguminous shrub from the *Fabaceae* family. Can reach 4m high and its life cycle can last from 1-5 years. Woody stem and a taproot that can penetrate to 2 m deep, helping to loosen compacted soil. It begins to flower and produce pods after 4-5 months, with edible seeds whose color may be white, yellow, brown or black, depending on the variety, and may even be spotted with brown or purple. While it self-pollinates naturally, pigeon peas have 20% cross pollination and are intensely visited by bees.

Origin: India, Pakistan and Indonesia.

Favorable environmental conditions: Average annual rainfall: 400-2,500 mm; tolerates droughts and dry spells; Temperature range: 18-38º C; Soils: drained and deep, medium fertility; symbiosis with nitrogen-fixing bacteria; does not tolerate soggy or saline soil.

Uses and functions: Edible for humans (eaten raw when green or cooked when ripe). High, good-quality protein content, from 18-32%. Its seeds are recommended as a food supplement for free-range chickens. According to IAPAR and Emater (ag research and extension services in the State of Paraná), based on experience in the Ivaiporã region, "in farmers' conditions, egg and meat production for free-range chickens was multiplied by 5 when pure maize feed was replaced by 67% maize and 33% pigeon peas." Yields of peas, depending on the variety and

Photo: Fabiana Peneireiro

Pigeon pea

crop system, varies from 500-1,500 kg/ha. Pigeon pea also provides fodder for livestock, including ruminants, and can be cut for green manure. Pigeon pea fodder contains 14-22% gross protein, depending on the proportion of leaves, pods and stems in the material used. The crop produces about 35 tons/ha of green matter, i.e., some 10 tons/ha of dried matter on the soil, and it can fix from 41-280 kg of nitrogen per hectare, in symbiosis with *Rhizobium* bacteria. Pigeon pea is an excellent companion for young trees, as a natural nursery and source of nutrients that stimulate the growth of trees, when pruned frequently. Despite its short life cycle, it is a useful windbreak, especially around gardens. It also attracts bees. Its branches and twigs can be used to make baskets. Its woody stem is good for firewood and even for pulp to make quality paper. Its leaves have medicinal uses among traditional peoples. It can also be used to prop up other crops, like tomatoes.

Propagation and observations: We recommend planting pigeon peas together with maize. When the maize is harvested, the pigeon peas remain. Well adapted to scarce water conditions, pigeon peas are often the only food found in the semiarid region during extreme droughts. When pruned after the pods are harvested, the pigeon pea grows back and can produce again. *Sources:* [36, 87, 61]

PEAR CACTUS *Opuntia fícus-indica*

Characteristics: As a xerophyte in the *Cactaceae* family, this species stores water in its structure and can perform photosynthesis even when its stomata are closed (CAM type metabolism). The plant is often mentioned as a solution for areas with little rainfall that are hard to irrigate. It stores water in its leaves (also known as cladodes or pads). Its flowers may be yellow, orange or red and both humans and livestock enjoy its red fruit (Indian figs).

Origin: Mexico

Favorable environmental conditions: <u>Soils:</u> Pear cactus is not demanding, has a symbiotic relationship with *Azospirillum* nitrogen-fixing bacteria, is very suitable to the highland caatinga, the *Agreste* region and mountains where rain is scarce. In Brazil's *sertão, seridó* and coastal regions, its yields are lower.

Uses and functions: It can be used for food, since its fruit is edible, and its leaves (or pads) can be stewed. The fruit also has medicinal uses to prevent asthma, coughing, intestinal worms, prostate problems and rheumatic pain. It is widely used to feed livestock, either as forage or as fodder in the trough mixed with other food like hay, silage or stubble from sorghum, maize, beans or even dry grass, along with protein supplements, to increase the animals' consumption of dry material and protein and to avoid diarrhea when it is served alone or with no limits.

Besides nutrients, it also provides water for the livestock. The water content can vary from 10-15% of its dry matter, with 3.5-5% protein,

Photo: Fabiana Peneireiro

Pear cactus

depending on the variety. Its water-storage capacity means it can be used for irrigation, by cutting the pads to cover the soil. We also recommend shredding pads to line the holes where seedlings, seeds or cuttings will be planted, to keep the area moist for the other plant to develop.

Propagation and observations: Plant early in the rainy season in well-drained soil, and late in the rainy season in poorly drained soil to keep the pads from rotting. Bury a third of a pad to plant it. The more you cut the pads, the more it produces. It is an excellent companion for other plants and cuttings. For neighboring plants, its roots release exudates, moistening the soil around the roots. The plant is also a natural host for the cochineal (*Dactylopius coccus*), an insect that causes no harm to the plant and, if well managed, produces a red dye (carmine) that can be sold on the market. *Sources:* [104, 16]

PRACTICAL TIPS

PEAR CACTUS TIPS

The best season to plant pear cactus is in "high summer, when the weather picks up," or "from August on," and into the first showers. This is when the plant has the lowest water content. "If you cut it when it's full of water, it won't take, but from August on, when it's pretty dry, you just cut it and it'll take." Prickly pear management helps it grow and increases yields.

Mosso *– EFASE monitor, Monte Santo, Bahia*

Find recipes for pear cactus in Portuguese at:

https://come-se.blogspot.com/2010/03/palma--ou-nopal-um-jeito-sertanejo-de.html

MANDACARU CACTUS *Cereus jamacaru*

Characteristics: Large arboreal cactus, with a thick ramified trunk and a woody base. Its main trunk may grow to 50 cm in diameter at breast height. It is green year-round, even during prolonged droughts, can grow up to 16 m high when located in a thick forest, producing white flowers that open at night. Its strong violet fruit has a sweet white pulp with tiny black seeds.

Origin: Native to the Brazilian Caatinga.

Favorable environmental conditions: Temperature: from 7-45º C, or even higher; average annual rainfall: from 500 mm (or less) to 2,600 mm; Soils: sandy, rocky, well-drained and limey, with pH from 5.0 to 7.2.

Uses and functions: Ornamental plant with fruit edible for humans and several typical bird species, such as the *gralha-cancã* and the *periquito-da-caatinga*. The fruit is eaten raw, after removing the shell. The stem can be used to make candy or to extract its starch. It can be used for animal fodder, especially during prolonged droughts, because it accumulates much water in its branches, which can both feed the cattle and quench their thirst. When there are thorns on the branches (cladodes), these must not only be cut into pieces, but their thorns cut or burned off as well, before being fed to the livestock. The presence of *mandacaru* in the semiarid region's

Photo: Daniel Vieira

Mandacaru cactus

plant cover means water storage for the system, which is helpful for all the surrounding plants.

Propagation and observations: *Mandacaru* reproduces with pieces of the cladodes, which should be cut between the internodes to help them take root. The cuttings should be planted in semi-shaded beds, vertically, with the base on the ground. As soon as the roots take, they can be planted in the final place where they will bear fruit after the third year. Seeds should be sown as soon as they are gathered, in a substrate with 50% sand and 50% dried, shredded leaves, and will germinate within 25-45 days. Plants grown from seeds begin to bear fruit after 6-7 years. *Sources:* [4]

SISAL *Agave sisalana*

Characteristics: Also known as agave, this perennial species is extremely well adapted to northeastern Brazil's semiarid climate. Its sword-shaped leaves are arranged around an axis. At the end of its 5-10 year life cycle, the plant grows an inflorescence or flower stalk, with flowers, fruit and seeds, or only bulbs (reproductive structure), and then it dies.

Origin: Mexico

Favorable environmental conditions: Sisal can tolerate prolonged droughts and high temperatures. The most appropriate soil types to cultivate it are sandy, permeable, deep and with good average fertility.

Uses and functions: Production of natural fibers from its leaves which are processed into rope, twine, carpets, materials for automobile, furniture and appliance industries, as well as

Photo: Henrique Marques

Sisal

civil construction. The chemical industry extracts fats, wax, glycoside, alcohol, acids and fertilizers. The waste (or bagasse) from the production of sisal fibers contains plant juice or sap, particles and pieces of the leaves and various sized fibers, which can be used for animal feed and as fertilizer. It is also useful for ecological restoration in semiarid regions because, growing in high temperatures with little rainfall, it accumulates water in its leaves (80% of the content of the leaves is water) which, when pruned, can be used to cover the soil and provide nutrients and moisture for other species, while also enriching the soil's biology and structure.

Propagation and observations: Sisal can be reproduced from bulbils (seedlings from the tassel) or buds (from the rhizome at the base of the mother plant), which are vegetative propagation structures. While the bulbils need to be planted in nurseries if they are small, the buds do not, and can be planted directly in the field. The best season for planting is when the plants produce the bulbils or buds, normally shortly before or early in the rainy season. *Sources:* [3, 43]

SABIÁ

Mimosa caesalpiniaefolia Benth

Characteristics: A perennial legume of the *Mimosaceae (Fabaceae)* family, which grows as high as 7-8 m. It grows rapidly in the semiarid region (about 1 m/year) and regrows quickly when pruned.

Origin: Northeastern Brazil, specifically the States of Rio Grande do Norte, Piauí and Ceará.

Favorable environmental conditions: Average annual rainfall: 600-1,000 mm, but it also grows in dryer areas as well as moister areas of the Cerrado; Average annual temperature: 20-28º C; Soils: fertile and deep, with pH from 5.5-8.5, but it also grows in less fertile soil. It's symbiotic relationship with *Rhizobium* nitrogen-fixing bacteria, according to Embrapa researchers, makes it very important for forest regeneration and, above all, for reforestation.

Uses and functions: This multi-purpose species provides wood for posts and fences, as well as hedges (at the end of the third or fourth year); energy (firewood and charcoal); as tutoring plants, especially for grape plantations in the northeast or

Photo: Fabiana Peneireiro

Sabiá

passionfruit elsewhere; industrial uses such as pulp and plywood; fodder for large and small ruminants (leaves and pods, both green and dried) especially in the dry season. Its leaves contain about 17% protein. The flowers attract bees and the shell has medicinal uses. It is also useful as a wind-break or hedge and is an efficient physical barrier because of the thorns on its young branches. The variety with thorns is recommended for posts to manage animal feeding areas. The species is also used to enrich and enhance the soil, to shade crops and to control erosion.

Propagation and observations: Very capable of natural regeneration, it grows easily from seeds. It is considered an invasive species in favorable conditions for its growth and reproduction. It can reproduce from either seeds or cuttings. To break the seeds' dormancy, they can be soaked in recently boiled water for one minute. *Sources:* [98]

A FARMER SPEAKS

SABIÁ'S ECONOMIC POTENTIAL

A *sabiá* fencepost can now be sold for R$3.50* to R$ 5.00. Legal wood is sold for R$4.00, when licensed. One young farmer is growing nothing but *sabiá* on 15 hectares. He plans to sell only the wood of the mature trees. The *sabiá* grows a lot after an area is slashed. His father had cut everything down, so only the *sabiá* grew back. He plans to use correct spacing (1.5 x 1.0m), with at most three cuttings in each clump. When you clear cut an area, you'll cut it down again in 6-8 years. Out in the brush, it takes ten years, but if the *sabiá* is managed like we do it in our region, it's ready in 5-6 years, instead of 7-8 years. You get 22,000 stakes per hectare.

The *sabiá* spreads fast after you clear an area. In a shaded system it nearly disappears.

What most discourages people from growing *sabiá* is all the work it takes to get a license. And the market price is the same as if you take it out of the forest.

Ernaldo Expedito de Sá *– Tianguá, farmer and resident in the Ibiapaba Mountains EPA, in Ceará.*

* *1 dollar = roughly 3.5 Reais.*

GLIRICIDIA (OR QUICKSTICK OR KAKAWATE) *Gliricidia sepium*

Characteristics: An arboreal legume of the *Fabaceae* family, gliricidia can grow to 15 m high, with a diameter of up to 30 cm. The tree begins to bear its pink flowers in the first five years, or even earlier if planted from cuttings.

Origin: Central America, now widely disseminated through the tropics.

Favorable environmental conditions: Altitude: from sea level to 1,600 m, in sub-humid and dry regions; Average annual rainfall: 600-3,500 mm, in defined seasons, but tolerant to water stress; Soils: pH from 4.5-5.0, does not grow well in very alkaline or very acid soil, preferring deep, well-drained and fertile soils; Temperature: 15-30º C. Interacts symbiotically with *Rhizobium* nitrogen-fixing bacteria.

Uses and functions: This multi-purpose plant can be used in windbreaks, hedges and shade for silvopastoral and agrosilvopastoral systems, for fodder and to produce wood. It has a great potential for recovering soil fertility,

Photo: Fabiana Peneireiro.

Gliricidia (or Quickstick or kakawate)

as green manure, since it fixes nitrogen, has a deep root system, tolerates pruning well, regrows vigorously with a large volume of biomass (can recompose its crown about four months after pruning). Produces a large amount (~7.7t/ha/yr) of dry matter and its leaves have a high (24%) gross protein content. It can be stored as a protein bank for animal feed by cutting the green branches and leaving the buds to regrow. This material (leaves and small branches) can be fed daily in the trough or else turned into hay or silage to store for the livestock during the dry season. Shaded pastures promote animal welfare, forage plants are more nutritious, and the soil also improves. It is a strategic species as a hedge or a living fence post. Its leaves have a chemical that kills both insects and rodents. As an insecticide, its leaves can be placed in chicken roosts to avoid fleas, and in seed containers to avoid weevils during storage. As a mouse-killer, the Gliricidia's leaves or root skin can be mixed with cooked maize. The plant also attracts bees.

Propagation and observations: It can reproduce either by seeds or cuttings. The seeds have no dormancy and can be sown immediately after harvest. When planted with seeds stored over a year, it is important to soak them in cold water for 24 hours, or else in hot water (90º C) for two or three minutes.

For cuttings to take well, they should be planted as soon as they are cut, in a diagonal to vertical position, with the buds turned upwards. Cuttings take root easily, with diameters of about 4 cm and 2 m long, buried about 30 cm deep. The cuttings should be planted in their definitive location, or else in a nursery. *Sources:* [94, 6, 29]

UMBU *Spondias tuberosa*

Characteristics: Xerophytic plant in the Anacardiaceae family. Umbu, in the Tupi-Guarani indigenous language ("y-mb-u"), means "tree that gives drinking water," and Euclides da Cunha called it the "sacred tree of the backlands." Its root system, with tuberous structures called xylopodiums, can store large amounts of water. The tree is small, at the most 6 m high, its trunk is short and the crown, shaped like an umbrella, loses its leaves in the dry season. It can live more than 100 years and attracts many bees with its white perfumed flowers. The umbu tree's fruit can be picked in the rainy season. Its ecological requirements are like those of *caroá*, sisal, pear cactus and *aveloz*, and it grows in a natural association with other native plants like the *facheiro* cactus, the *mulungu* tree, the

Photo: Daniel Vieira

Umbu

macambira bromeliad, the *canudo* shrub, malva and several cacti.

Origin: Native to the semiarid region in northeastern Brazil.

Favorable environmental conditions:

Soils: deep, well drained, sandy; does not tolerate soggy soil; temperature: from 12-38º C; Average annual rainfall: 400-800 mm, but it can live in places where it rains up to 1,600 mm/yr.

Uses and functions: Improves the environment for other species and provides a variety of products, many of which come from its fruit, roots, fresh green leaves and even the bark. The fruit can be made into juice, ice cream, candy, jam, wine and vinegar. The roasted and ground seed is used to make a drink. The roots can be processed into flour and provide a medicinal water (used against worms and diarrhea). The roots quench the thirst of locals during severe droughts. The bark is used to make a medicine and the trunk provides light, soft wood. The fresh green leaves go into salads or stews and can also be forage for cattle, goats and sheep. They are also a food source for wild deer, turtles and other animals.

Propagation and observations: umbu can be planted by seed after removing the pulp. To germinate faster, make a bevel cut on the seed's far tip opposite the fruit stem. Seedlings can also be grown with cuttings from the crown, which can be drawn from May through August, with 3.5 cm diameters, and about 40 cm long. The cuttings are planted in the definitive location for the new tree, at a slant with about 2/3 of the length buried. They can also reproduce in nurseries with a sandy substratum to grow roots before being planted in the field. *Source:* [63]

Photo: Fabiana Peneireiro

Yellow mombin

YELLOW MOMBIN

Spondias mombin

Characteristics: A fast-growing tree in the Anarcadiaceae family, up to 25 m tall. It tolerates dry seasons well with an adaptive xylopodium structure (root tubers that store water) that is less extensive than the umbu's. It is also well adapted to poorly drained terrains. It bears fruit in the third or fourth year when planted from cuttings. The yellow mombin fruit is light orange, with a thin shell and distinct, tasty pulp. The tree responds well to pruning, is easy to manage, regrows well and produces much biomass, even in unfavorable conditions.

Origin: Tropical Americas.

Favorable environmental conditions: Tolerates most soils and can tolerate 2-3 months of waterlogged soil per year. Average annual rainfall: 1,500 mm.

Uses and functions: The fruit has a pleasant taste. They are picked after falling to the ground. A single tree can produce up to 1,000 kilos of fruit. The juicy pulp can be used to produce jam, juice, ice cream, preserves, liqueur and desserts. Its leaves and roots are also edible. It attracts honeybees. Medicines are produced from its leaves, bark and roots. Its leaves can be fodder for pigs and cattle while the wood can be used for firewood and has favorable traits to produce paper. Cuttings can become living fenceposts, since they root well.

Propagation and observations: The yellow mombin can be reproduced from seeds or from woody cuttings. Cuttings should be about a meter long with a 4-8 cm diameter, can be planted in the field and must be irrigated until fully taking root. *Sources:* [63, 26, 65]

MEXICAN SUNFLOWER *Tithonia diversifolia*

Characteristics: As a shrub or herbaceous plant, it can grow to 1.5-4.0 meters tall. It has strong branches and, during its reproductive phase, displays inflorescences in the form of yellow capitula. It is considered a rustic species and tolerates pruning down to the ground, with intense and vigorous regrowth, even after it has been burned. It is recommended as a key species in the Cerrado and rainier areas of the Caatinga. In other parts of the Caatinga the Mexican sunflower does not develop well because of the long dry season.

Photo: Andrew Miccolis

Mexican sunflower

Origin: Central America.

Favorable environmental conditions: Since it adapts well to a broad range of environmental situations and tolerates acid, unfertile soil, it found favorable conditions for optimal development in the Cerrado's soils and climate.

Uses and functions: This species is used on farms as beekeeping flora and green manure to improve soil due to its great potential for biomass production, fast growth and low input demand as a crop. Studies have found that the Mexican sunflower "restores soil fertility, increasing yields of subsequent crops, due to the high level of nutrients in the phytomass (the plants biomass)," especially phosphorus, potassium and nitrogen and that its dry matter has high protein content, mainly before flowering. This means that the use of its biomass from periodic pruning makes a substantial contribution to soil fertility. Its large root system and symbiosis with soil microorganisms give Mexican sunflowers an exceptional capacity to provide nutrients normally lacking in the Cerrado's acid soil, especially phosphorus and nitrogen. In addition to this fertilization, it also helps improve the soil's physical and biological makeup. Mexican sunflowers also help control erosion, attract bees and complement the feed for livestock. Its medicinal uses include controlling hepatitis and some infections, malaria, inflammations, diarrhea, amoebas and others. The flowers and seeds are an important food source for wild birds during the dry season. During its adult stage, and with no management, it replaces grasses like brachiaria, and provides a favorable nursery environment for the germination and recruitment of many native and exotic tree species, generally those spread by the fauna that the plant attracts. In its full, adult strength, it should be managed by cutting all the branches close to the ground, to allow neighboring tree seedlings to emerge with vigor.

Propagation and observations: When reproduced with 20-30 cm green cuttings (from mature branches), it takes root well. Like some other highly adapted and efficient key species, or engineer species, the Mexican sunflower is an exotic and potentially very invasive species. It produces a large number of seeds which are spread by the wind. When suitably managed, however, with periodic pruning before it flowers, this species can be an excellent ally for farmer's efforts to recover degraded soil. *Sources:* [29, 112]

INGA *Inga spp.*

Characteristics: An arboreal legume in the Mimosaceae family. There are approximately 300 woody species in the *Inga* genus, with variable sizes and life-cycles. The name inga comes from the indigenous Tupi language and means "having enclosed seeds." It commonly occurs along rivers and in wetlands, for example the ice-cream bean (*Inga edulis*), which prefers moist and even waterlogged soil in riparian forests. Other species adapt to dry forests. The fruit is a pod, and the seeds inside are covered with a sweet, white, soft pulp much like by the wild fauna. The ice-cream bean has a 10-12-year life cycle, while other ingas, like the *Inga marginata* bean, live even longer. Ingas have a symbiotic relation with nitrogen-fixing bacteria, produce large amounts of biomass and generally accept intense yearly pruning, which makes them highly recommended for intercropping in agroforestry systems.

Origin: Tropical South America, with natural occurrence from Mexico to Uruguay

Photo: Fabiana Peneireiro

Inga

Favorable environmental conditions: Varies from one species to another. Some grow well in acid, low-fertility, dry soil, like the *Inga laurina*, while others prefer more fertile, moist soil, like the ice-cream bean, which can tolerate waterlogged soil for 2-3 months. All these species, however, also tolerate up to 6 months of drought. The optimal annual rainfall is 1,200 mm. Ingas have an association with the nitrogen-fixing, endophytic *Rhizobium* bacteria, and/or with symbiont endomycorrhiza, a fungus that helps make nutrients available.

Uses and functions: The fruit, whose seeds are covered in a sweet, soft white pulp, are consumed by humans and are also very popular among the wild fauna. It is also used in traditional medicine to treat bronchitis and heal wounds. In agroforestry systems, it is recommended for shade (especially for coffee and cacao) and to provide biomass when pruned, while also helping cycle nutrients, adding calcium and nitrogen into the system, the latter through symbiotic fixation. It tolerates pruning and regrows well. Its leaves can be fed to the cattle. It is resistant to root pathogens such as *Meloidogyne* nematodes. Its lumber is used for firewood and for packaging, boxes and lightweight internal civil construction, because of its low resistance and durability. The inga tree attracts bees and can flower 4-5 times a year, another feature that makes it strategic.

Observations: Its recalcitrant seeds do not germinate after they dry out. Sometimes the seeds have already germinated before the fruit is picked. This means the seeds must be planted soon after they are picked, either directly in the ground where they are to grow, or in seedling bags. *Sources:* [92, 5, 113, 29]

WEST INDIAN ELM *Guazuma ulmifolia*

Characteristics: An evergreen tree in the Sterculiaceae family, common in dense Cerrado and gallery forests. This fast-growing species can reach a height of 30 m, with a dense crown, and a life cycle of over 15 years. Its flowers are pollinated by bees and other small insects. After three or four years, it begins bearing encapsulated, green to black fruit that are dry, hard and 1.5-3.5 cm long, with approximately 50 small seeds covered with a sweet, mucilaginous pulp. The seeds are spread by birds, fish and other animals, including cattle.

Origin: Tropical Americas, common in Brazil's Atlantic Forest, Amazon, Pantanal, Cerrado and even in the Caatinga.

Favorable environmental conditions: It is common in open, secondary-growth areas, in clearings, along creeks and rivers and altered environments. It grows well in areas with average annual rainfall of 600-1,500 mm and where the average annual temperature is 24º C. It is not demanding in terms of soils and adapts both to dry and to humid environments, with a preference for sandy soil.

Uses and functions: A multi-purpose plant whose fruit produces a sweet, viscous substance much liked by the fauna, especially monkeys and agoutis, as well as cattle. The tree's wood can be used to make pulp and paper. It is also a good fuel, as firewood or charcoal, and can be used to make furniture. The leaves can be fed to cattle. This species only drops part of its leaves in the dry season, making it important for the integration with animals in the agroforest. Embrapa researchers

West Indian elm Photo: Fabiana Peneireiro.

report that one of this specie's major potential uses is in agrosilvopastoral intercrops, with trees in pastures. The cattle like the West Indian elm's leaves and new fruit, especially during the dry season. Its forage contains 17-28% raw protein. It is also recommended for windbreaks when spaced about 3-5 m apart. It is highly recommended for the recovery of degraded areas, for which it requires frequent pruning, as a fast-growing species, resprouts vigorously and attracts fauna. Its crown, dense in leaves, when pruned produces a large volume of high-quality biomass, which is excellent as forage and to recover the fertility of degraded soil. The fruit is also eaten by humans, either fresh, dried, raw or cooked. Some indigenous peoples use it to make a kind of mush and a drink. The fruit and leaves also have medicinal uses. The cooked bark produces a mucilaginous extract used to make *rapadura* (brick sugar) and to clear the sugarcane syrup while it is boiling. Today there is West Indian elm ice cream on sale in some Brazilian cities. Its melliferous flowers provide abundant nectar, attracting bees that in turn produce a tasty, pleasant and high-quality honey.

Propagation and observations: It responds well to pruning and regrows vigorously. To plant it directly, the seeds' dormancy should be broken by soaking them in boiled water (with the heat turned off) for 15 seconds. Then drain the hot water and place the seeds in cold water. This thermal shock will "wake up" the dormant seeds. *Source:* [25]

BANANA *Musa spp.*

Characteristics: The banana tree belongs to the Musaceae family and is considered a giant herbaceous plant. Its underground rhizome stem produces fasciculate roots and suckers, which make a clump of banana trees. Each banana tree has a succulent pseudostem, made of overlapping leaf sheaths. The leaves, in addition to the sheaths, have a long petiole and a long, wide leaf blade. The bunch of bananas is an infructescence made up of hands, which grow from flowers that emerge from banana "hearts" on stalks at the top of the plant. The plant's height can vary from 1.8-8.0 m.

Origin: Asia

Favorable environmental conditions: The banana tree is a tropical plant that grows best in warm regions. The optimal temperature range is 15-35º C. It does not tolerate frost. Average annual rainfall: over 1,300 mm, well distributed throughout the year, although it tolerates some dry spells. Soils: preferably fertile, deep and well drained.

Uses and functions: The banana tree is most valued for its fruit, which can be eaten raw, baked, fried, processed before fully ripe as chips or flour or else dehydrated. Fibers from the pseudostem and leaves can be used in several kinds of handicraft as rugs, hats, bags, etc., and the banana "heart" (from the blossom) is also edible. The water and nutrients (mainly potassium) stored throughout the plant's

Photo: Fabiana Peneireiro

Banana

tissues help feed other species when recycled. The pseudostem, when cut lengthwise and laid at the foot of other plants, provides water and nutrients for several months, stimulating soil life and avoiding the emergence of unwanted weeds or grass. Its large flowers give the banana tree a high rate of evapotranspiration, helping create a moister microclimate. Its shade is essential for the development of seeds and seedlings of other native and exotic trees, which grow well during their initial stages under the crown of the banana tree.

Propagation: The banana's vegetative reproduction uses rhizome seedlings that tiller from the corm. The smaller bits or suckers should be removed from the larger plant and cleaned, breaking the roots to cut the sucker's connection with the rhizome, near the mother plant. Banana seedlings can also be produced in laboratories, with tissue cultures of the apical meristem, in tubes.

Observations: In agroforestry systems, or to recover degraded areas, banana trees can and must be intensely managed to produce biomass and cover the soil, cutting down most or even all the trunk-like pseudostems. Some banana varieties, like "*prata*" and "*nanicão*," adapt well to the shade and can continue to produce for many years in agroforestry systems managed to let sunlight into the forest floor. *Source:* [146]

Achiote

Photo: Fabiana Peneireiro

ACHIOTE

Bixa orellana

Characteristics: This evergreen tree in the Bixaceae family can grow as high as 3-4 m. It has simple leaves, beautiful pink flowers, and its dry fruit, which grows in bunches, opens up to reveal dozens of red seeds. The native name in Brazil, *urucum*, comes from the Tupi language and means the color red. It begins to bear fruit after three years and generally grows near rivers, from the Amazon region to Bahia, in Brazil.

Origin: Topical Americas

Favorable environmental conditions: Grows well at <u>temperatures</u> from 20-26º C, in regions where temperatures can vary from 15-38º C. It does not tolerate frost. <u>Average annual rainfall:</u> from 1,200-3,000 mm. <u>Soils:</u> Medium fertility, deep, moist and fresh. It tolerates soggy soil and grows well with some shade.

Uses and functions: Its seeds produce a pigment called bixin, which is used in cooking and the food industry as a powdered dye. It is also used in cosmetics and pharmaceuticals. The plant can be pruned to produce biomass and regrows well even when pruned to the ground.

Propagation and observations: To accelerate germination, it is best to soak the seeds in water for 24 hours.

EUCALYPTUS *Eucalyptus spp.*

Characteristics: The eucalyptus genus, in the Myrtaceae family, has more than 700 species. Some of the most common species planted in Brazil are *E. camaldulensis, E. citriodora, E. grandis, E. saligna, E. dunnii* and *E. urophylla*. There is hybridism among the species. Each species or hybrid has different edaphoclimatic needs, sizes, shapes and composition, which affect their potential uses. The most widely used among them are fast-growing species. The leaves are simple, generally lanceolate, and the flowers have a large number of exuberant stamens, which attract many insects. The fruit is woody, slightly conical, with valves that open to release its extremely small seeds. The most common species in Brazil reach heights from 20-60 m.

Eucalyptus Photo: Henrique Marques

Origin: Australia and other islands in Oceania.

Favorable environmental conditions: Occurs naturally at altitudes from 30-600 m, with average annual rainfall from 250-625 mm, and temperatures ranging from 11-35º C. It also grows well in areas with more rainfall like the Cerrado and other Brazilian biomes. Each eucalyptus species responds differently to rainfall, frost, dry spells and soil fertility. Soils: Deep and well drained. Does not tolerate shallow soil. Climate: The species are adapted to long dry seasons, varying from 4-8 months, or even more.

Uses and functions: Eucalyptus has multiple uses and performs many functions, particularly lumber for civil construction, logs for sawmills to make plywood, posts and stakes, energy generated from charcoal, firewood and biofuel, as well as pulp to produce paper. Its flowers attract honey bees and its leaves have medicinal uses and produce an essential oil. Eucalyptus trees can also provide biomass for soil recovery in degraded areas, when managed with frequent, intensive pruning. Finally, it can also be used for shade and as an ornamental plant.

Each of the various eucalyptus species has specific features that make it useful, based on a desired function and environmental conditions, which we have summarized here:

Photo: Henrique Marques

Eucalyptus

EUCALYPTUS SPECIES RECOMMENDED FOR SPECIFIC USES:

- **PULP:** *E. alba, E. dunnii, E. globulus, E. grandis, E. saligna, E. urophylla and E. grandis x E. urophylla* (hybrid).
- **FIREWOOD AND CHARCOAL:** *E. brassiana, E. camaldulensis, E. citriodora, E. cloeziana, E. crebra, E. deglupta, E. exserta, E. globulus, E. grandis, E. maculata, E. paniculata, E. pellita, E. pilularis, E. saligna, E. tereticornis, E. tesselaris and E. urophylla.*
- **SAWMILLS:** *E. camaldulensis, E. citriodora, E. cloeziana, E. dunnii, E. globulus, E. grandis, E. maculata, E. maidenii, E. microcorys, E. paniculata, E. pilularis, E. propinqua, E. punctata, E. resinifera, E. robusta, E. saligna, E. tereticornis and E. urophylla.*
- **FURNITURE:** *E. camaldulensis, E. citriodora, E. deglupta, E. dunnii, E. exserta, E. grandis, E. maculata, E. microcorys, E. paniculata, E. pilularis, E. resinifera, E. saligna and E. tereticornis.*
- **LAMINATES:** *E. botryoides, E. dunnii, E. grandis, E. maculata, E. microcorys, E. pilularis, E. robusta, E. saligna and E. tereticornis.*
- **CRATES:** *E. dunnii, E. grandis, E. pilularis and E. resinifera.*
- **CONSTRUCTION:** *E. alba, E. botryoides, E. camaldulensis, E. citriodora, E. cloeziana, E. deglupta, E. maculata, E. microcorys, E. paniculata, E. pilularis, E. resinifera, E. robusta, E. tereticornis and E. tesselaris.*
- **TIES:** *E. botryoides, E. camaldulensis, E. citriodora, E. cloeziana, E. crebra, E. deglupta, E. exserta, E. maculata, E. maidenii, E. microcorys, E. paniculata, E. pilularis, E. propinqua, E. punctata, E. robusta and E. tereticornis.*
- **POSTS:** *E. camaldulensis, E. citriodora, E. cloeziana, E. maculata, E. maidenii, E. microcorys, E. paniculata, E. pilularis, E. punctata, E. propinqua, E. tereticornis and E. resinifera.*
- **FENCE POSTS:** *E. citriodora, E. maculata and E. paniculata.*
- **ESSENTIAL OIL:** *E. camaldulensis, E. citriodora, E. exserta, E. globulus, E. smithii, E. salicifolia.and E. tereticornis.*
- **TANNINs:** E. camaldulensis, E. citriodora, E. maculata, E. paniculata and E. smithii.

EUCALIPTUS SPECIES RECOMMENDED FOR SPECIFIC CLIMATES:

- **HUMID AND HOT:** *E. camaldulensis, E. deglupta, E. robusta, E. tereticornis and E. urophylla.*
- **HUMID AND COLD:** *E. botryoides, E. deanei, E. dunnii, E. globulus, E. grandis, E. maidenii, E. paniculata, E. pilularis, E. propinqua, E. resinifera, E. robusta, E. saligna and E. viminalis.*
- **SUBHUMID HUMID:** *E. citriodora, E. grandis, E. saligna, E. tereticornis and E. urophylla.*
- **SUBHUMID DRY:** *E. camaldulensis, E. citriodora, E. cloeziana, E. maculata, E. pellita, E. pilularis, E. pyrocarpa, E. tereticornis and E. urophylla.*
- **SEMIARID:** *E. brassiana, E. camaldulensis, E. crebra, E. exserta, E. tereticornis and E. tessalaris.*

EUCALIPTUS SPECIES RECOMMENDED FOR SPECIFIC SOIL TYPES:

- **CLAYEY:** *E. citriodora, E. cloeziana, E. dunnii, E. grandis, E. maculata, E. paniculata E. pellita, E. pilularis, E. pyrocarpa, E. saligna, and E. urophylla.*
- **MEDIUM TEXTURE:** *E. citriodora, E. cloeziana, E. crebra, E. exserta, E. grandis, E. maculata, E. paniculata, E. pellita, E. pilularis, E. pyrocarpa, E. saligna, E. tereticornis and E. urophylla.*
- **SANDY:** *E. brassiana, E. camaldulensis, E. deanei, E. dunnii, E. grandis, E. robusta E. saligna, E. tereticornis and E. urophylla.*
- **HYDROMORPHIC:** *E. robusta.*
- **DYSTROPHIC:** *E. alba, E. camaldulensis, E. grandis, E. maculata, E. paniculata, E. pyrocarpa and E. propinqua.*

Propagation and observations: Eucalyptus trees are generally planted from cuttings (clones) or seeds. When used in a consortium, well-spaced and frequently managed with pruning, eucalyptus can be an excellent ally for farmers, while keeping the environment healthy. When planted as a dense monocrop, however, it can be harmful to the environment. After being cut to the ground, the tree will regrow and can still be cut back again. *Sources:* 50, 147, 148, 149

GRASSES

As members of the Poaceae family, grass species are C4-type plants (with a four-carbon molecule that is the first product of carbon fixation in these plants) capable of making better use of solar energy in photosynthesis, even in very high temperatures, as opposed to C3 plants (all trees and most herbaceous species), whose metabolism shuts down at high temperatures with intense sunlight, conditions frequently encountered in the Cerrado and Caatinga regions. In addition, some species are adapted to soils with different degrees of fertility and can solubilize and provide difficult-to-process nutrients. Its biomass, rich in carbon, helps increase the organic content of soils, protecting it from torrential rain and direct sunlight, while dynamizing life in the soil. Here we describe three key grass species, recommended for conservation with production in the Cerrado region.

GUINEA GRASS *Panicum maximum or Megathyrsus maximus*

Characteristics: A caespitose grass species that grows in bunches. Highly productive and shade tolerant. Its acid root system favors the solubilization of phosphorus and other nutrients, which are absorbed and made available by the grass. This variety produces 130% more biomass than *Colonião* grass and 28% more than cv Tanzania.

Origin: Africa

Favorable environmental conditions: Average annual rainfall: 800-1,000 mm, but adapts well to more rainfall; Average temperature: 15-35º C; Soils: average to high fertility.

Uses and functions: Excellent forage for cattle, goats and sheep, with good nutritional quality and much biomass. The plant's biomass has an average of 11-15% protein. Since it makes phosphorus available both in the soil, when mowed, and in ruminants when eaten, it is an important source of nutrients for the entire system. The high carbon content in its biomass helps the organic matter decompose more slowly, thus protecting the soil for a longer period. That protection keeps the soil moist and full of life, providing favorable conditions for the growth of roots of plant species associated with the accumulated straw. As feed, it can be either forage in the field or fed as fodder in a trough. The powerful roots of Guinea grass also help contain erosion.

Propagation and observations: Can be multiplied with seeds. Use only when it can be managed intensively, either manually or mechanically, to perform its function of providing biomass and improving the soil, without blocking the emergence of native trees and shrubs, especially in PPAs. *Sources:* [124, 120, 118]

Photo: Fabiana Peneireiro

Guinea grass

GAMBA GRASS *Andropogon gayanus*

Characteristics: A caespitose grass species, well adapted to the Brazilian Cerrado. Like other grasses, it can solubilize and offer nutrients for poor soils, especially phosphorus. Its carbon-rich organic matter, which decomposes much more slowly than legumes, also lasts longer, protecting the soil.

Origin: Africa

Favorable environmental conditions: Grows well in full sunlight, in acid soils with lower fertility than required by Guinea and elephant grass; Average annual rainfall: 1,000-2,000 mm.

Uses and functions: Good forage for cattle, goats and sheep in the Cerrado, with medium nutritional quality and much biomass. Since it makes phosphorus available both in the soil, when mowed, and in ruminants when eaten, it is an important source of nutrients for the entire system. The high carbon content in its biomass helps the organic matter decompose more slowly, thus protecting the soil for a longer period. That protection keeps the soil moist and full of life, providing favorable conditions for the growth of roots of plant species associated with the accumulated straw. As feed, it is best consumed as forage in the field.

Gamba grass

Photo: blog.bioseeds.com.br/andropogon-gayanus-secas-prolongadas

Propagation and observations: Can be multiplied with seeds. Use only when it can be managed intensively, either manually or mechanically, to perform its function of providing biomass and improving the soil, without blocking the emergence of native trees and shrubs, especially in PPAs. *Sources:* 124, 120, 109

ELEPHANT GRASS *Pennisetum purpureum cv. Napier*

Characteristics: This Napier grass is a perennial caespitose species, with broad leaves and a thick stalk.

Origin: Africa

Favorable environmental conditions: Grows profusely in tropical conditions; Average annual rainfall: 800-4,000 mm; Temperature range: 18-30º C. It requires medium to highly fertile, well-drained soil, and does not tolerate acid soil with much aluminum. In sandy soil that is less fertile, however, it still produces large amounts of biomass. It is very productive and grows well in full sunlight. Its acidic rhizosphere enhances the solubilization of phosphorus and other nutrients, which are absorbed and made available by the grass.

Uses and functions: Elephant grass, like Guinea grass, is an excellent forage for cattle, goats and sheep, with good nutritional quality and much biomass. Since it makes phosphorus available both in the soil, when mowed, and in ruminants when eaten, it is an important source of nutrients for the entire system. The high carbon content in its biomass helps the organic matter decompose more slowly, thus protecting the soil for a longer period. That protection keeps the soil moist and full of life, providing favorable conditions for the growth of roots of plant species associated with the accumulated straw. As feed, it can be either forage in the field or else planted as a fodder crop and fed to the animals shredded in a trough. Elephant grass is also tall enough to be grown as a

Photo: Fabiana Peneireiro

Elephant grass

windbreak and its powerful roots will help contain erosion, for example on degradable hillsides and river banks. Shredded, it is also an excellent cover for vegetable beds in agroforests.

Propagation and observations: Elephant grass does vegetative reproduction, by planting stem cuttings of the stolons, like sugar cane, along furrows, or else buried in slanted pieces. It is recommended that it be cut close to the ground to allow the basal buds to sprout. Use only when it can be managed intensively, either manually or mechanically, to perform its function of providing biomass and improving the soil, without blocking the emergence of native trees and shrubs, especially in PPAs. Since elephant grass rarely propagates through seeds, there is no risk it will become an invasive species. *Sources:* [124, 120, 77]

To conclude, we present below a **list of multi-purpose species** suggested for the Cerrado and Caatinga regions of Brazil, chosen for the features described in *Section 4.2: Selecting the Species*. This list is by no means exhaustive, but rather a starting point to plan AFS, since there are many other important species.

Photo: Andrew Miccolis

TABLE 8: GENERAL TABLE OF SPECIES SUITABLE FOR RESTORATION IN THE CERRADO AND CAATINGA BIOMES

Common name	Scientific name	Fertility requirement	Life cycle	Story/ layer*	Good biomass producer	Food	Attracts fauna and pollinators	Forage	Timber potential	Medicinal potential	Income/ marketing potential	Occurs predominantly (biome)
Achiote	*Bixa orellana*	medium	perennial	medium	yes	yes	yes	no	no	yes	yes	Cerrado
Agave	*Agave spp.*	low	perennial	low	yes	no	yes	yes	no	no	yes	Cerrado/Caatinga
Angico	*Anadenanthera colubrina*	low-medium	perennial	Emergent	yes	no	yes	yes	yes	yes	yes	Cerrado/Caatinga
Angico de bezerro	*Piptadenia obliqua*	low	perennial	High	yes	no	yes	yes	yes	yes	yes	Caatinga
Araruta	*Maranta arundinacea*	high	perennial	Low	No	yes	no	yes	no	yes	yes	Cerrado
Argentine cedar	*Cedrela fissilis*	medium	perennial	High	no	no	yes	yes	yes	yes	yes	Cerrado
Aroeira	*Myracrodruon urundeuva*	high	perennial	High	no	no	yes	no	yes	yes	yes	Cerrado/Caatinga
Avocado	*Persea americana*	high	perennial	High	yes	yes	yes	no	no	yes	yes	Cerrado
Bacaba	*Oenocarpus bacaba*	high	perennial	High	Yes	yes	yes	yes	no	yes	yes	Cerrado
Bacupari da mata	*Cheiloclinium cognatum*	high	perennial	High	no	yes	yes	no	yes	no	no	Cerrado
Banana	*Musa paradisiaca*	high	perennial	medium	yes	yes	yes	yes	no	no	yes	Cerrado
Barú	*Dipteryx alata*	medium	perennial	High	no	yes	yes	no	yes	no	yes	Cerrado
Biribá	*Rollinia mucosa*	medium	perennial	high	yes	yes	yes	yes	yes	yes	yes	Cerrado
Brachiaria grass	*Brachiaria brizantha*	low	perennial	High	yes	no	no	yes	no	no	no	Cerrado
Braúna	*Melanoxylon brauna*	low	perennial	High	no	no	yes	no	yes	yes	no	Cerrado/Caatinga
Braúna do sertão or pau preto	*Schinopsis brasiliensis*	medium	perennial	High	no	no	yes	no	yes	yes	yes	Caatinga
Bur cucumber [maxixe]	*Cucumis anguria*	medium	annual	creeping	no	yes	no	no	no		yes	Cerrado/Caatinga
Canafístula	*Senna spectabilis*	medium	perennial	High	yes	no	yes	no	yes	no	no	Cerrado/Caatinga
Capororoca	*Myrsine (ex-Rapanea) guianensis*	low	perennial	high	no	no	yes	no	no	no	no	Cerrado
Carnaúba	*Copernicia prunifera*	high	perennial	Emergent	no	yes	yes	yes	no	yes	yes	Caatinga
Carvoeiro	*Tachigali vulgaris (ex-Sclerolobium paniculatum)*	low	perennial	High	yes	no	yes	no	yes	no	yes	Cerrado
Cashew	*Anacardium occidentale*	medium	perennial	emergent	no	yes	yes	no	no	yes	yes	Cerrado/Caatinga
Castos beans	*Ricinus communis*	medium	perennial	emergent	yes	no	yes	no	no	yes	yes	Cerrado/Caatinga
Catingueira	*Caesalpinia pyramidalis*	low	perennial	medium	yes	no	yes	yes	yes	yes	yes	Caatinga
Cherry tomato	*Solanum lycopersicum*	medium	annual	medium	no	yes	yes	no	no	no	yes	Cerrado/Caatinga
Chinaberry	*Melia azedarach*	low	perennial	Emergent	yes	no	yes	yes	yes	yes	yes	Cerrado
Climbing bean	*Phaseolus vulgaris*	medium	annual	low	no	yes	yes	yes	no	Yes	yes	Cerrado/Caatinga
Coffee	*Coffea spp*	high	perennial	Low	no	yes	yes	no	no	yes	yes	Cerrado
Copaíba	*Copaifera langsdorfii*	medium	perennial	High	no	no	yes	no	yes	yes	yes	Cerrado/Caatinga
Crotalaria	*Crotalaria sp.*	medium	annual	Emergent	yes	no	yes	no	no	yes	yes	Cerrado/Caatinga
Cucumber	*Cucumis sativus*	medium	annual	low	no	yes	yes	no	no	yes	yes	Cerrado/Caatinga

*__Story/layer__ *refers the necessity of light in the adult phase of the plant*

TABLE 8: GENERAL TABLE OF SPECIES SUITABLE FOR RESTORATION IN THE CERRADO AND CAATINGA BIOMES

Common name	Scientific name	Fertility requirement	Life cycle	Story/ layer*	Good biomass producer	Food	Attracts fauna and pollinators	Forage	Timber potential	Medicinal potential	Income/ marketing potential	Occurs predominantly (biome)
Elephant ear	*Xanthosoma sagittifolium*	medium/high	perennial	low	yes	yes	no	yes	no	no	yes	Cerrado
Embaúba	*Cecropia spp*	low-medium	perennial	emergent	no	no	yes	no	no	yes	no	Cerrado
Embiruçu	*Pseudobombax tomentosum*	medium	perennial	high	no	no	Yes	no	no	yes	no	Cerrado/Caatinga
Emburana-de-cheiro	*Amburana cearensis*	medium	perennial	high	yes	no	yes	no	yes	yes	yes	Cerrado/Caatinga
Erythrina	*Erythrina velutina*	low-medium	perennial	high	yes	no	yes	yes	yes	yes	yes	Caatinga
Espinheiro	*Acacia glomerosa*	medium	perennial	medium	yes	no	yes	no	yes	Yes	no	Cerrado/Caatinga
Eucalyptus	*Eucaliptus sp.*	medium	perennial	Emergent	yes	no	yes	no	yes	Yes	Yes	Cerrado
Faveira	*Parkia platycephala*	medium	perennial	High	yes	no	yes	yes	no	No	no	Caatinga
Faveleira	*Cnidoscolus phyllacanthus*	low	perennial	Medium	yes	yes	yes	yes	no	Yes	yes	Caatinga
Feijão bravo (wild bean)	*Canavalia brasiliensis*	low	biannual	High	no	no	yes	yes	no	No	no	Cerrado/Caatinga
Gamba grass	*Andropogon gayanus*	low	perennial	High	yes	no	no	yes	no	no	no	Cerrado
Ginger	*Zingiber officinale*	medium	perennial	low	no	yes	no	no	no	Yes	yes	Cerrado/Caatinga
Gliricidia	*Gliricidia sepium*	high	perennial	high	yes	no	yes	yes	no	Yes	no	Cerrado/Caatinga
Gomeira	*Vochysia pyramidalis*	medium	Perennial	medium-high	yes	No	Yes	No	Yes	No	No	Cerrado
Gonçalo alves	*Astronium fraxinifolium*	low	perennial	high	no	no	yes	no	yes	Yes	yes	Cerrado
Guava	*Psidium guajava L.*	medium	perennial	high	no	yes	yes	no	yes	Yes	yes	Cerrado
Gueroba palm	*Syagrus oleracea*	low	perennial	high	no	yes	yes	no	no	no	yes	Cerrado
Guinea grass	*Panicum maximum*	medium	perennial	medium	yes	no	no	yes	no			Cerrado
ice cream bean (inga)	*Inga edulis*	medium	perennial	high	yes	yes	yes	yes	no	yes	no	Cerrado
Indaiá	*Attalea apoda*	medium	perennial	high	no	yes	yes	no	no	yes	no	Cerrado
Ingá mirim	*Inga nobilis*	low	perennial	high	yes	yes	yes	yes	yes	yes	no	Cerrado/Caatinga
Jaborandi	*Piper hispidum*	high	biannual	low	yes	Yes	Yes	No	no	yes	yes	Cerrado
Jackfruit	*Artocarpus altilis*	medium	perennial	high	yes	yes	yes	no	yes	no	yes	Cerrado/Caatinga
Jenipap	*Genipa americana*	medium	perennial	high	no	yes	yes	no	yes	yes	yes	Cerrado/Caatinga
Juazeiro	*Zizyphus joazeiro*	low	perennial	high	yes	yes	yes	yes	no	yes	yes	Caatinga
Jucá	*Caesalpinia férrea*	low	perennial	medium	yes	no	yes	yes	yes	yes	yes	Caatinga
Juçara mirim	*Euterpe edulis*	high	perennial	high	no	yes	yes	no	no	no	yes	Cerrado
Jurema branca	*Piptadenia stipulacea*	medium	perennial	high	no	no	yes	no	yes	yes	no	Caatinga
Jurema preta	*Mimosa tenuiflora*	medium	perennial	high	no	no	yes	no	yes	yes	no	Caatinga
Landim	*Calophyllum brasiliense*	medium	perennial	high	no	no	yes	no	yes	Yes	yes	Cerrado
Licuri palm	*Syagrus coronata*	medium	perennial	emergent	no	yes	yes	no	no	yes	yes	Cerrado/Caatinga
Lixeira	*Curatella americana*	low	perennial	medium	no	yes	yes	no	no	yes	no	Cerrado
Lobeira	*Solanum eryanthum*	medium	perennial	medium	no	yes	yes	no	no	yes	no	Cerrado

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Common name	Scientific name	Fertility requirement	Life cycle	Story/ layer*	Good biomass producer	Food	Attracts fauna and pollinators	Forage	Timber potential	Medicinal potential	Income/ marketing potential	Occurs predominantly (biome)
Lychee	*Litchi chinensis*	high	perennial	medium	yes	yes	yes	no	no	no	yes	Cerrado
Macaúba palm	*Acrocomia aculeata*	medium	perennial	high	no	yes	yes	yes	yes	yes	yes	Cerrado
Mahogany	*Swietenia macrophylla*	high	perennial	high	no	no	yes		yes		yes	Cerrado
Mamoninha or *melzinho*	*Mabea fistulifera*	low	perennial	medium	yes	no	yes	yes	no	no	no	Cerrado
Mamoninha-do-mato	*Esenbeckia febrifuga*	medium	perennial	medium	no		yes					Cerrado
Mamuí or *Jaracatiá*	*Jaracatia corumbensis*	high	perennial	high	no	yes	yes	no	no	yes	yes	Cerrado/Caatinga
Mandacaru cactus	*Cereus jamacaru*	medium	perennial	high	yes	yes	yes	yes	no		no	Caatinga
Mandiocão	*Schefflera morototoni*	medium	perennial	emergent	yes	no	yes		yes		yes	Cerrado
Mangaba	*Hancornia speciosa*	low	perennial	high	no	yes	yes	no	no	yes	yes	Cerrado/Caatinga
Mango	*Mangifera indica*	medium	perennial	high	yes	yes	yes	no	no	no	yes	Cerrado/Caatinga
Maniçoba	*Manihot glaziovii*	medium	perennial	high	yes	no	yes	yes	no	no	no	Caatinga
Maracujá do Cerrado (Cerrado passionfruit)	*Passiflora cincinnata*	medium	biannual	high	no	yes	yes	no	No	yes	yes	Cerrado
Marmelada	*Alibertia macrophylla*	low	perennial	medium	no	yes	yes	no	Yes	yes	yes	Cerrado
Marmeleiro	*Croton sonderianus*	low	perennial	medium	yes	yes	yes	yes	yes	yes	yes	Caatinga
Mauritia or *Buriti* palm	*Mauritia flexuosa*	medium-high	perennial	High	no	yes	yes	yes	no	yes	yes	Cerrado
Mesquite	*Prosopis juliflora*	low	perennial	high	yes	yes	yes	yes	no	yes	yes	Caatinga
Mirindiba	*Buchenavia tomentosa*	low	perennial	high	no	yes	yes	yes	yes	yes	yes	Cerrado
Moringa	*Moringa oleífera*	high	perennial	high	yes	yes	yes	yes	no		no	Cerrado/Caatinga
Mulberry	*Morus nigra L.*	medium	perennial	medium	yes	yes	yes	yes	no	yes	yes	Cerrado
Murici	*Byrsonima sp.*		low	perennial	medium	no	yes	yes	no	no	yes	no
Napier or elephant grass	*Pennisetum purpureum*	medium	perennial	High	yes	no	no	yes	no	no	no	Cerrado
Oiticica	*Licania rigida*	medium	perennial	medium	yes	yes		no			no	Caatinga
Pajeú	*Triplaris gardneriana*	medium	perennial	medium	yes	no	yes	no	yes	no	yes	Caatinga
Papaya	*Carica papaya*	high	biannual	emergent	no	yes	yes	no	no	yes	yes	Cerrado
Pau-pombo	*Tapirira obtusa*	high	perennial	high	yes	no	yes	no	no	no	no	Cerrado
Peach palm	*Bactris gasipaes*	medium	perennial	emergent	no	yes	yes	no	no	no	yes	Cerrado
Pear cactus	*Opuntia fícus-indica*	medium	perennial	medium	yes	yes	yes	yes	no	yes	no	Caatinga
Pequi	*Caryocar brasiliense*	medium	perennial	high	no	yes	yes	no	yes	yes	yes	Cerrado
Periquiteira	*Trema micrantha*	low	perennial	high	yes	no	yes	yes	yes		yes	Cerrado
Pidgeon peas	*Cajanus cajan*	medium	biannual	medium	yes	yes	yes	yes	no	Yes	yes	Cerrado/Caatinga
Pigbean	*Canavalia ensiformis*	low	annual	low	yes	no	yes	yes	no	No	yes	Cerrado/Caatinga
Pimenta de macaco	*Xylopia aromatica*	medium	perennial	high	yes	yes	yes	no	no	yes	no	Cerrado
Pineapple	*Ananas spp.*	low-medium	annual	low	no	yes	yes	no	no	yes	yes	Cerrado/Caatinga

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Common name	Scientific name	Fertility requirement	Life cycle	Story/ layer*	Good biomass producer	Food	Attracts fauna and pollinators	Forage	Timber potential	Medicinal potential	Income/ marketing potential	Occurs predominantly (biome)
Pinha do brejo	*Magnolia ovata*	medium	perennial	high	yes	no	yes					Cerrado
Puçá	*Mouriri sp.*	low	perennial	medium	no	yes	yes					Cerrado
Quaresmeira	*Tibouchina candolleana*	medium	perennial	high	yes	no	yes	no	no	yes	no	Cerrado
Sabiá	*Mimosa caesalpiniaefolia*	low	perennial	high	yes	no	yes	yes	yes		yes	Caatinga/Cerrado
Sangra-d'água	*Croton urucurana*	medium	perennial	high	no	no	yes	No	yes	yes	No	Cerrado
Sapoti	*Manilkara zapota*	medium	perennial	medium	no	yes	yes	no	yes		yes	Caatinga
Scarlet eggplant	*Solanum gilo*	medium	annual	high	no	Yes	yes	no	no	yes	yes	Cerrado/Caatinga
Sisal	*Agave sisalana*	low	perennial	low	yes	no	yes	no	no		yes	Caatinga
Sorghum	*Sorghum sp.*	medium	annual	high	yes	no	yes	yes	no	no	no	Cerrado/Caatinga
Soursop	*Annona muricata*	high	perennial	high	no	yes	yes	no	no	yes	yes	Cerrado/caatinga
Squash	*Curcubita pepo*	medium	semestral	low	yes	yes	yes	no	no	no	yes	Cerrado/Caatinga
Stinkingtoe	*Hymenaea courbaril*	low	perennial	emergent	no	yes	yes	no	yes	yes	yes	Cerrado/Caatinga
Stylozanthes	*Stylosantes sp.*	low	perennial	low	yes	no	yes	yes	no	No	yes	Cerrado
Suriname cherry [acerola]	*Malpighia glabra L.*	medium	perennial	High	no	yes	yes	no	no	no	yes	Cerrado/Caatinga
Sweet potato	*Ipomoea batatas*	medium-high	annual	low	no	yes	no	no	no	no	yes	Cerrado/Caatinga
Tamboril	*Enterolobium spp.*	medium	perennial	high	no	no	yes	yes	yes	yes	yes	Cerrado
Taro [inhame]	*Colocasia esculenta*	high	annual	low	No	yes	no	no	no	yes	yes	Cerrado/caatinga
Tingui	*Magonia pubescens*	low	perennial	high	no	no	yes	no	yes	yes	yes	Cerrado
Tithonia or Mexican sunflower	*Tithonia diversifolia*	medium	perennial	high	yes	no	yes	yes	No	yes	no	Cerrado
Trumpet tree [purple ipe]	*Handroanthus impetiginosus*	medium	perennial	emergent	no	no	yes	no	yes	yes	yes	Cerrado/Caatinga
Trumpet tree [yellow ipe]	*Handroanthus serratifolius*	medium	perennial	high	no	no	yes	no	yes	yes	yes	Cerrado
Turco	*Parkinsonia aculeata*	medium	perennial	low to medium	yes	no	yes	yes	yes	yes	yes	Caatinga
Turmeric	*Curcuma longa*	medium	annual	low	no	yes	no	no	no	yes	yes	Cerrado
Umbu	*Spondias tuberosa*	medium	perennial	medium	no	yes	yes	no	no	yes	yes	Caatinga
Velvet bean	*Mucuna sp.*	medium	annual	high	yes	no	yes	yes	no			Cerrado/Caatinga
West Indian elm	*Guazuma ulmifolia*	medium	perennial	high	yes	no	yes	yes	yes	yes		Cerrado
White leadtree	*Leucaena leucocephala*	medium	perennial	high	yes	no	yes	yes	no	yes	no	Cerrado/Caatinga
Xique-xique	*Pilosocereus gounellei*	medium	perennial	low	yes	no	yes	yes	no	yes	no	Caatinga
Xixá	*Sterculia striata*	medium	perennial	emergent	no	yes	yes	no	yes			Cerrado
Yellow mombin	*Spondias mombin*	medium	perennial	medium	no	yes	yes	yes	no	no	yes	Cerrado/Caatinga

Sources: [21, 42, 51, 56, 66, 116, 150, 151, 152, 153, 154, 155, 156, 157]

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AGROFORESTRY SYSTEMS
for Ecological Restoration

Ecological restoration in the context of production areas, or mosaic landscapes, must include farmers and landholders, from planning to establishment and management. Agroforestry systems can harness restoration by re-establishing ecological processes, structures and ecosystem functions to a desired level, while also enabling economic returns, maintenance of livelihoods, local knowledge and culture.

As an integral part of nature, people can actually drive restoration processes. Based on this outlook, we propose principles, systems and practices for enabling restoration through agroforestry.

under the new Brazilian Forest Law (Permanent Preservation Areas and Legal Reserves). For some of the most common contexts, such as degraded pastures and areas with naturally regenerating native vegetation, among others, we present 11 agroforestry options to be adapted to each farm's specific characteristics. Besides the biophysical context, these options also take into account farmers' varying levels of access to resources deemed key to the success of agroforests, such as labor, inputs, knowledge, and markets. We also recommend species, designs, establishment techniques and management practices for each option, and lay out the basic foundations of a social-environmental appraisal methodology at the farm/household level, with the aim of tailoring solutions to that specific context. While this guidebook is geared mainly towards family farmers, the options, techniques and practices, as well as the principles and criteria for systems design and species selection, can be adopted by any farmer or landholder who wishes to produce and conserve natural resources in an integrated fashion.

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