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Agroforestry systems and their link with regenerative agriculture in Guatemala. A topic of analysis in the face of a changing world

Sistemas agroforestales y su vinculación con agricultura regenerativa en Guatemala. Un tema de análisis frente a un mundo cambiante

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Article Data

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Abstract

A literature review on agroforestry systems and their importance within regenerative agriculture was carried out using Google Scholar and Google as search tools. The keywords used were agroforestry systems, regenerative agriculture, and environmental and ecosystem services of agroforestry systems. The information collected is solely interpretative, and the data presented are not subject to statistical validation. The main contributions of agroforestry systems to regenerative agriculture include soil restoration, biodiversity conservation, and water management. Their role in supporting reforestation programs in Guatemala is also emphasized, as these programs promote the sustainable management of natural resources and the environment. In addition, species that can be incorporated into the main cover crops of agroforestry systems in Guatemala were identified. Elements are also presented that encourage a conscious internalization of the environmental dimension in the recovery of degraded lands through these systems. At the territorial level, the potential for implementing agroforestry systems in Guatemala is estimated at 27%, with grasslands currently used for livestock production showing the greatest potential.

Resumen

Se realizó una revisión de literatura sobre los sistemas agroforestales y su importancia dentro de la agricultura regenerativa, utilizando como fuentes de búsqueda Google Scholar y Google. Las palabras clave empleadas fueron: sistemas agroforestales, agricultura regenerativa y servicios ambientales y ecosistémicos de los sistemas agroforestales. La información recopilada tiene únicamente un carácter interpretativo, por lo que los datos presentados no están sujetos a validación estadística. Entre los principales aportes de los sistemas agroforestales a la agricultura regenerativa se destacan la recuperación de suelos, conservación de la biodiversidad y manejo del agua. Asimismo, se resalta su contribución a la promoción de programas de reforestación en Guatemala; favoreciendo la gestión sostenible de los recursos naturales y del ambiente. Se identificaron también especies que pueden incorporarse en los cultivos de mayor cobertura dentro de los sistemas agroforestales en Guatemala. Además, se presentan elementos que permiten fomentar una internalización consciente de la dimensión ambiental en los procesos de recuperación de tierras degradadas mediante estos sistemas. A nivel territorial, se señala un potencial de implementación de sistemas agroforestales equivalente al 27 % del país, con las áreas actualmente cubiertas por pastos para la producción ganadera como las que presentan el mayor potencial.

Introduction

Agroforestry systems (AFS) are forms of use, management of natural resources, and that woody species (trees, shrubs, palms) are used in deliberate association in agricultural crops or with animals on the same land, simultaneously, or in a temporal sequence[1]. Derived from its implementation, multiple benefits are obtained for farmers in the areas where they reside. These systems can be implemented on your plot (open field), or within the backyard boundaries of your homes. Therefore, there is a profuse and varied literature that classifies AFS based on different characteristics, so they have been classified according to their structure in space, their design over time, the relative importance and function of the different components, the objectives of production and the prevailing ecological, social and economic characteristics[2].

If the crop is agricultural, and it is the reason for a farmer's commercial activity, it will allow them to occupy a greater amount of area that allows them to obtain the best conditions for the absorption of nutrients, water and sunlight. This conditions the density, both of the agricultural crops and of the trees within the plantation system, the arrangement in which the planting will be carried out, the management that will be given to the plantation and the inputs to be used within it.

Regenerative agriculture (RA) consists of agricultural and grazing practices that, among other benefits, reverse climate change, by rebuilding soil organic matter and restoring degraded soil biodiversity, resulting in carbon reduction and improved water cycling[3].

A literature review was carried out to point out the points of convergence between AFS and RA and their application in the recovery of degraded soils, regulation of the hydrological cycle and the conservation of biodiversity, which lead to the promotion of sustainable agriculture in Guatemala.

The purpose of the literature review was to substantiate the application of AFS in Guatemala and to identify its relationship with the principles of RA. The applicability of both concepts is also identified according to the characteristics of land use in Guatemala.

Development

The territory of the Republic of Guatemala has a high aptitude for the development of AFS, according to the study of land use capacity prepared by the Institute for Research in Natural Sciences and Technology (Iarna), 25 % of its territory has a vocation for cultivation ventures under AFS[4].

For its development, in Guatemala, AFS is promoted through the forestry law, Decree 101-96, which in its "Article 53. License exemptions. The following are exempt from a forest harvesting licence: ... e) The pruning and thinning of AFS". This with the aim of promoting correct management of the established systems and their renewal when their management plan deems it appropriate[5].

The promotion for the establishment of AFS, through the Law for the Promotion of the Establishment, Recovery, Restoration, Management, Production and Protection of Forests in Guatemala (PROBOSQUES), is encouraged through monetary transfers to the owners of agroforestry land for 6 years (1 for establishment and 5 years for maintenance). This law is valid for 30 years from its publication in (year 2015)[6].

In the case of land holders, there is another legal instrument, the PINPEP, Law on Forestry Incentives for Holders of Small Extensions of Forestry or Agroforestry Land, which incentivizes AFS for 6 years (1 year of establishment and 5 years of maintenance)[7].

Agroforestry. When addressing the topic of AFS, it is necessary to first define the concept that best fits our research objective, there are many definitions in the literature, one of them defines it as a sustainable system of crop and land management that seeks to increase yields continuously, combining the production of wooded forest crops (which include fruit trees and other tree crops) with field or arable crops and/or animals of simultaneously or sequentially on the same unit of land, also applying management practices that are compatible with the cultural practices of the local population[8].

Another definition of agroforestry points out the form of land use, where there are at least 2 classes of plant species, and one of these is perennial woody and one of the 2 is managed for agricultural purposes[9], there are 3 essential characteristics in this definition, *the first* is that the crops occupy the same portion of land area, *the second* is that more than one of the tree species must be woody and a *third* is that one of the species in the arrangement must be cultivated for agricultural purposes.

A broader concept than the previous one defines agroforestry as a system of ecological management of natural resources through the introduction of agricultural crops into forests or the incorporation of trees into land intended for agriculture. Its purpose is to generate environmental, economic and social benefits simultaneously[9]. It considers more than the agricultural part and defines it as a management system, aimed at generating environmental, economic and social benefits, not only for producers, but for society as a whole.

Agroforestry incorporates four basic characteristics: i) *Structure:* Unlike modern agriculture and forestry, agroforestry combines trees, crops, and animals. ii) *Sustainability:* Agroforestry optimizes the beneficial effects of interactions between forest species and crops or animals. By using natural ecosystems as models and by applying their ecological characteristics to the agricultural system, it is hoped that long-term productivity can be maintained without degrading the land. iii) *Increased productivity:* By improving the complementary relationships between the components of the farm, with improved growing conditions and an efficient use of natural resources (space, soil, water, light). iv) *Cultural/socioeconomic adaptability:* Although agroforestry is appropriate for a wide range of farms of various sizes and socioeconomic conditions, its potential has been particularly recognized for smallholder farmers in marginal and poor areas of tropical and subtropical areas[10.11].

Agroforestry involves a series of techniques that include the combination, simultaneously or sequentially, of trees and food crops, or trees and livestock (trees in pastures or for fodder), or all three elements[12]. Here cattle breeding is added as part of the production techniques within a specific site. A set of agricultural practices that are carried out in the same place and at the same time (simultaneous practices), or those developed in the same place, but at different times (sequential practices) is added within the term. Therefore, emphasis is placed on the development of these practices being simultaneous or sequential.

It should also be considered that agroforestry has been used to meet different needs of the inhabitants of a particular site, they can be extensive production at different scales (open fields) or for self-sufficiency production on a small scale, to satisfy the food needs of a particular family, or small communities, therefore it can be considered as an alternative to land use, with different objectives, one of them can be for the recovery of degraded landscapes of forest cover or for soils in degraded areas[12].

Therefore, agroforestry is not only a way to combine vegetation in space and time, but it can also be a technique for the recovery of ecosystems that are degraded.

Agroforestry is a form of multiple cropping in which the following conditions are met: i) multiple cropping with at least 2 species managed. (ii) at least 1 perennial woody species. (iii) species interact biologically[12]. Therefore, the species that are selected for the establishment of the system must contain one of the aforementioned characteristics.

Approaches have been pronounced, go beyond just the concept of agroforestry, by relating it to the impact that it could have on the conservation of biodiversity, these being: i) an opportunity for the environment and the sustainability of the population, mainly those who live in rural areas, ii) an agricultural livelihood that has a direct influence on the conservation of the environment and the biodiversity of the planet, iii) it provides traditional knowledge and productive functionality, iv) it promotes the conservation of biodiversity and human well-being[13]. This term includes the residence of the beneficiaries that also incorporates traditional knowledge and the benefits it can have for biodiversity and human well-being.

In addition, agroforestry promotes biodiversity, since it integrates different species of plants and animals, fosters a diverse habitat, and is home to a variety of organisms, from pollinating insects to birds and mammals. Biodiversity is essential for the balance of ecosystems and helps prevent the spread of pests and diseases[14].

Agroforestry offers multiple environmental advantages, which are fundamental for the conservation of natural resources. Firstly, this system helps to improve soil quality. Trees contribute to the formation of humus, which increases soil fertility and its ability to retain water. This is especially important in drought-prone regions, where water availability is crucial for crop growth[14]. As for biodiversity, it is more latent when it comes to family gardens[15], in a review of information on biodiversity in family gardens in Mexico, it finds a record of 1400 species of plants used in these systems. Within these, they document 537 species of herbaceous plants, 224 of shrubs and 228 of trees; of which 572 species have medicinal use, 528 are ornamental, 442 are edible and 682 have other uses[15]. This is an indicator of the potential of home gardens for the conservation of biodiversity and the conservation of species that may be endemic in certain territories.

Agroforestry systems. In line with agroforestry are AFS, which are modes of production that combine forest species with agricultural and even livestock species. These species establish and develop within the same space and in the same period (of time), in order to optimize land use, diversify plantations, contribute to biodiversity and increase productivity, which is known as simultaneous AFS[11]. In the design of this type of AFS, care must be taken with the horizontal or vertical stratification that the plants in the system may have, and always privilege the species that is the farmer's commercial objective.

Diversity can be increased over time, through the use of crop rotations or sequential crops, in the same space, through the use of cover crops, intercropping, and mixed crop-livestock production systems, commonly known as sequential AFS[11]. These systems are used to improve soil structure through cover crops, which are plants that are planted in order to protect and improve the soil.

Classification of AFSs. There are different ways to classify AFS. Thus, these have been classified according to their structure in space, their design over time, the relative importance and function of the different components, the objectives of production, as well as the prevailing ecological, social and economic characteristics[2]. This indicates that AFS are multifunctional and complex systems, whose organization depends on how they are organized, and on the prevailing conditions of the ecosystems where they develop.

Other classifications can continue to be considered, such as products and the type of combinations between their components, or by the basis of the products that can be obtained, and the type of combinations between the components. They can also be based on scale and production targets, and establish that they are commercial, subsistence, and intermediate AFS[2]. When we refer to the scale of production, it indicates the very nature by which we establish them.

The three main agroforestry components, perennial woody plants (trees), agricultural crops and animals (pastures), define the following categories: i) *Agroforestry systems:* the use of land for sequential or concurrent production, consisting of alternating trees and seasonal crops (annual or perennial). ii) *Silvopastoral systems:* A combination of trees and grasslands, for the production of wood, food and fodder to sustain animal production. iii) *Agrosilvopastoral systems:* systems in which the land is managed for the concurrent production of forest and agricultural crops, and for the raising of domestic animals, alternating trees, seasonal crops and pastures to sustain animal production[11,16].

One more is added: i) *Multipurpose Forest production systems:* in which forest species are regenerated and managed to produce not only wood, but also leaves and/or fruits that are suitable for food and/or fodder[11].

Other AFSs can be specified, such as tree beekeeping, aquaculture in mangrove areas, multipurpose tree lots and so on. The components can be arranged temporally or spatially and various terms are used to indicate the various arrangements[11]. This is a broad classification, combining plants, trees and animals, and grouping them depending on the main component of the system.

Due to the complexity of AFS, it is difficult to frame their classification under a single scheme. There are classifications that are based on the structure or function of the system, agroecological zones, the latter are conceived as the geographical space that presents regularity in its edaphic, climatic or orographic variability, with a similar response in its agricultural potential, where the system exists or is adoptable according to the socioeconomic scenario (production scales and level of management of the system)[12,17]. Therefore, AFS cannot have a single classification, since they can vary depending on the agroecological context in which they are developed, and the socioeconomic and social conditions of the producers.

A classification based on structure is as follows:

Agrosilvocultural systems: i) shifting cultivation with fallow management. (ii) cultivation in forest plantations and the "Taungya" system. iii) trees for shade of crops. iv) trees in crop plots (living fences, windbreaks, trees on borders, or scattered trees). (v) woody as living supports. (vi) mixed home gardens. (vii) alley cultivation.

Silvopastoral systems. i) Trees or shrubs scattered in pastures. (ii) grazing on forest or fruit plantations.

iii) forage banks or protein banks. iv) pasture in alleys.

Special systems. i) silvoentomology (trees for beekeeping). (ii) silvoaquaculture (trees for fish farming).

A synthesis of the approaches of Mendieta Lopez & Rocha Molina[12] on the characteristics of AFS is presented in Table 1.

Table 1 Characteristics of agroforestry systems[12]

System	Modality	Feature	Objective	Management recommendations
Agrosilvocultural.	Shifting cultivation with fallow management.	Trees and agricultural crops are arranged sequentially, in time and space.	Subsistence systems aimed at satisfying the basic needs of food, fuel and housing.	Introduction of legumes and trees of fruit or timber species for commercial use.
	Cultivation in forest plantations and Taungya System.	Methods of establishing forest plantations in which annual crops are carried out simultaneously with tree plantations.	Combining trees and crops simultaneously during the plantation establishment period, known as the Taungya system, which is that short-term crops are produced in the first years of planting perennial woody species, in order to use the land, control weeds, reduce establishment costs, generate income and stimulate the development of perennial woody species.	The Taungya system is a means of reducing the costs of forest plantations and at the same time contributing to solving social problems.
	Trees for shade of crops.	Simultaneous combination of trees and perennial crops.	Diversify production, i.e., supply wood, firewood, fruit, etc., or provide insurance against fluctuations in market prices.	These systems represent an alternative when the use of monocultures is not economically feasible due to the high cost of agrochemicals.
	Trees in crop plots (living fences, windbreaks, trees on borders, or scattered trees).	Trees distributed randomly or systematically within or on the edges of agricultural plots.		
	Living fences.	A line of trees or shrubs that delimit a property.	Obtain products of economic value, such as human food, fodder, medicinal products, firewood, and new fence posts.	Selecting the right species is critical. Desirable characteristics include: speed of growth, ease of vegetative reproduction, speed of regrowth after pruning, and provision of benefits such as wood, firewood or fodder.
	Windbreak curtain.	Lines of trees (one to ten) that protect a field of grasses, crops, or trees from the wind.	Reduce wind speed in plots for agricultural purposes.	It is necessary to take into account the height of the crops and their vulnerability to wind in the different stages of growth.
	Trees on borders.	Line of timber trees that delimit a property.	Production of wood or fruit in underutilized areas.	Select a species of high commercial value and with rapid topping growth.
	Woody as living supports.	Trees as supports for climbing plants of economic interest.	Spread by cuttings. Abundant root production and rapid growth. Withstand frequent pruning.	Some stakes provide additional products such as wood, fodder, edible fruits, craft materials, and woodworking wood.
	Mixed home gardens.	Intimate association of multi-use trees and/or shrubs with annual and	Production of animal and plant species to meet the basic needs of families.	Mixed home gardens contribute in large proportion to the family diet, for their planning a balanced nutritious diet should be considered.

		perennial crops and animals in the plots of individual households.		
	Cultivation in alleys.	Association of trees or shrubs (usually nitrogen-fixing) intercropped in strips with annual crops.	Use tree pruning waste as green manure to improve soil fertility, and as high-quality fodder.	The choice of tree species. In addition to providing shade, trees contribute to maintaining the level of organic matter in the soil and leaf litter acts as a protective layer.
	Combination of forest or fruit species and animals, without the presence of crops.	In situations where livestock farming is an inefficient use of land, when tree products (firewood, wood, fruit, fodder) are added, the system can become ecologically and economically more viable.	Income generation, both short-term and long-term, through animal and tree products.	Ecologically, the use of trees (especially legumes) can contribute to improving the productivity and sustainability of existing systems.
Silvopastoriles.	Trees or shrubs scattered in paddocks.	The animals are fed on grass that grows under the trees naturally, or on grass, if planted under the trees.	In these systems, the main objective is livestock; secondarily, the production of wood, firewood or fruits can be achieved.	When cutting down forest plots for cattle ranching, leaving valuable trees standing.
	Grazing in forest or fruit plantations.	The animals graze on a plantation, which can be trees for firewood, timber or fruit trees.	Partnership can be started when the trees are old enough not to be harmed by animals.	Animals can defoliate or damage trees in the plantation if the plantation is not managed carefully.
	Forage banks or protein banks.	Presence of animals and the forage necessary for their food.	Forest plantation to obtain fodder for animal supplementation purposes.	The management techniques of these systems are aimed at conserving the productive capacity of the soils.
	Pasture in alleys.	Establishment of forage fields within rows of trees or shrubs.	Provide good quality forage; improvement of soil fertility, and reduction of nutrient loss.	The species to be considered must have the following characteristics: Adaptation to soil and climate conditions; tolerance to pruning and/or grazing; Good nutritional value.
Special.	Silvoentomology (e.g. trees for beekeeping).	When trees are used to breed useful insects.	Develop a productive activity where insects are under human control.	
	Silvoaquaculture (e.g. trees for fish farming).	Fish can also be supplemented with tree leaves and fish farming can benefit from various products and services provided by trees.	Planting woody species around fish production ponds.	

Regenerative Agriculture (RA). It is the productive approach that emphasizes the protection and restoration of natural resources (mainly soil, but also water and biodiversity) to provide multiple benefits to farmers, the environment and society[18]. Emphasis is placed on the protection of natural resources; however, it lacks more recent conceptions such as resilience, sustainability and climate change[19].

RA is an agricultural philosophy and approach that focuses on restoring and improving soil health, biodiversity, and ecosystem integrity as a whole. When applied in multi-layered AFS (AFSM), it seeks the harmonization of crops of different layers in a single space, promoting biodiversity, maximizing resource efficiency and generating long-term benefits[20].

RA consists of paying attention to the main ecological processes that occur in an agricultural or livestock ecosystem, in order to work together with nature to sustain and increase productivity in the medium and long term. Considered in this way, RA is a way to achieve the ecological intensification of agricultural production[21]. Here the ecosystem is added for live stock production and the productivity of the system. The basis of RA lies in the respect and deep understanding of the natural processes that sustain life on earth. It focuses on principles such as minimizing soil disturbance, maximizing biological diversity, incorporating organic matter, promoting natural nutrient cycles, and integrating crops and livestock[21].

With an emphasis on harmonization with natural cycles, RA not only aims at sustainable production, but also addresses the resilience of agricultural systems to climate change and other risks[22].

In short, RA is based on a simple slogan, to increase and improve the production capacity of ecosystems, based on soil regeneration, achieving greater infiltration and water retention, and increasing biodiversity, replicating the process of natural succession[23]. We see how as new concepts are developed, they become more complex in the search for natural regeneration processes.

The implementation of AR must have certain basic characteristics: i) RA is focused on results. It does not establish specific practices, but focuses on achieving specific objectives linked to multiple aspects of sustainability (environmental, economic and social). ii) RA is flexible. Guided by general agronomic and ecological principles and broadly defined practices, this approach can be adapted to both small- and large-scale production, as well as different agro-ecological conditions. iii) RA is based on solid and context-relevant scientific evidence. iv) Adoption implies a transition or "journey". RA requires a high level of knowledge and demands a process of learning and adaptation[18]. It is indicated that the RA is focused on results, without losing environmental, economic and social sustainability. By saying that it is flexible, it indicates that it can be developed at different scales and in different agroecological conditions, however, its installation requires a high level of knowledge about what is going to be done.

Different regenerative practices can be combined or applied gradually to achieve multiple benefits. To foster these innovations, collaboration between farmers, supply chain actors, and researchers is important.

As already mentioned, RA focuses on three fundamental pillars: soil, biodiversity and water. The restoration and sustainable management of these resources require individual interventions at the farm level and collective interventions at the landscape scale. In addition to the three pillars, producers and their families are essential for RA[18,21]. When indicating collective action, community organization at the local level and the institutional support that could be granted to carry out actions at the landscape level are important.

The *first pillar*, soil health, refers to the ability of soil to perform its ecological functions, i.e., sustaining plant productivity and biodiversity, acting as a habitat for soil biota, regulating the cycle and supply of water and nutrients, mitigating pollution, and regulating pest and disease populations[24]. This pillar turns out to be fundamental, since it is the bastion of productivity according to a sustained supply of water and nutrients, and favors the health of the ecosystem.

RA improves soil health (and stimulates soil life) by achieving the following objectives: i) Control soil erosion and runoff. ii) Minimize tillage and soil compaction. (iii)) Maintain permanent ground cover. iv) Recycling organic matter. v) Optimize nutrient management. vi) Limit the use of pesticides[18].

The benefits of these practices were also documented in a systemic review regarding soil conservation and sustainable management in agriculture[25]. RA, therefore, aims at minimum tillage and soil compaction, producing *mulch* by maintaining cover and developing organic production practices for the reduction of synthetic products.

The *second pillar*, biodiversity defined as, the variety of living organisms present in different ecosystems, including marine, aquatic and terrestrial. Different levels of biodiversity can be considered: (i) biological variation between ecosystems, both natural and agricultural, (ii) variation between species and (iii) genetic variation within species (different varieties within the same crop species). Functional biodiversity refers to (groups of) species that support the provision of certain ecosystem services, including those that support the supply of agricultural products; and it also has an important cultural and intrinsic value[18].

In addition, it is indicated that the RA aims to improve and sustainably take advantage of the benefits of biodiversity, contributing to the following objectives: i) To promote the diversification of cropping systems. ii) To limit the use of pesticides and herbicides. (iii) Provide habitats for wild plants, animals and other organisms, both within the crops of interest and in the surrounding landscape. (iv) Strengthening functional biodiversity (through biological pest control and pollination)[18] The objectives of the RA are therefore to produce in the most ecological way possible without the incorporation of synthetic components that are foreign to the production system.

The *third pillar* is water, which is measured according to the availability, quality and management of water resources, for which it is essential that people have safe access to clean water for domestic, agricultural and industrial uses. Excessive water extraction and pollution from agricultural or industrial activities threaten the water security of the inhabitants of the basin[18]. Therefore, it is necessary to consider the production and consumption capacity of the water resources available within the basin so as not to overexploit them and to have a plan for the evacuation of surpluses from production and consumption to reduce the contamination of the cold beds.

The leaching of fertilizers, pesticides and other pollutants can lead to contamination and eutrophication of groundwater and surface water, and harm aquatic ecosystems. Climate change, deforestation and land-use change can also reduce water availability and quality, leading to more frequent and intense droughts and floods, which reduce yields and damage crops and infrastructure[18]. A rational use of inputs from outside the ecosystem must be carried out, to avoid contamination of groundwater and consider what mitigation measures are going to be implemented to reduce deforestation and land use change, as well as to reduce the effects of climate change.

The objectives of water quality conservation within the RA can be summarized as: i) To control erosion and runoff, while improving water infiltration and retention in the soil. ii) To avoid contamination of water sources with harmful pesticides and fertilizers. iii) Make efficient use of irrigation water. (iv) Reduce water consumption in wet processing. v) For the cultivation of coffee, treat and recycle the wastewater from its processing[18]. In simple words, avoid erosion, pollution and recycle as much as possible.

RA management. For the development of practices within the context of RA, it must be borne in mind that, a key aspect to take into account when entering into RA, is that it is not possible to give universal indications or "recipes" regarding which practices to use, or when or where, for a production system to take advantage of the capacity for natural self-regeneration[20]. What is necessary, if necessary, is to apply the principles and approaches promoted by RA, according to the context in which it is implemented.

At INTA's Mendoza-San Juan Regional Center, the criteria of good practices for RA have been synthesized in 10 general principles that are listed in Table 2:

Table 2 Criteria for the development of good practices in regenerative agriculture [20]

Beginning	Approach
1. Minimize soil tillage. 2. Keep the soil covered with active vegetation. 3. Planned crop diversification. 4. Organic soil nutrition. 5. Prevent water and wind erosion.	They are essentially focused on the soil, which is the main focus of any regenerative agriculture strategy.
6. Avoiding leaching losses. 7. Efficient use of irrigation water.	They revolve around water use efficiency.
8. Minimize the use of agrochemicals. 9. Conserve natural and semi-natural habitats (conservation areas). 10. Promote biodiversity.	They are carried out to influence the conservation and promotion of biodiversity (associated with cultivation, considering both vegetation and fauna and microorganisms).

These principles are not unique or universal, so other recommended management practices for RA can be promoted, including those recommended by Portela et al.[20], such as those proposed by González Sánchez[26], which are summarized in Table 3.

As can be seen in Table 3, the principles of minimum soil tillage are complied with, efficiency is improved to have a greater quantity and quality of water, soil cover is maintained, and grazing is advocated that is more environmentally friendly.

Regenerative Livestock (RL). An agroforestry production system articulated with the dynamics of nature, which, through management practices, increases productivity and reduces production costs, promoting a higher return on investment. It also improves the quality of life for producers and their collaborators and allows healthy and clean food to be obtained for consumers[29]. The RL is placed within the context of agroforestry production that increases productivity per area, reducing production costs to make the system more profitable, and with better economic and healthy benefits for producers.

There are many benefits generated by RL, the following can be mentioned: i) non-use of chemically synthesized products such as fertilizers, insecticides, pesticides, herbicides and other polluting substances that are harmful to the environment and human health. ii) conservation of the natural structure. iii) generation of microclimates that reflect the evolutionary dynamics of the forest and grassland. iv) maintenance of vegetation cover and relative humidity that potentiates photosynthesis in plants to close the carbon cycle. (v) improvement of soil health and fertility by increasing the content of organic matter, as well as the capacity to infiltrate, retain water, recycle and store nutrients and carbon, preventing soil erosion and reversing desertification[29]. In short, to reduce pollution, promote natural succession processes, integrate the forest with the prairie, increase water retention by increasing organic matter and reverse desertification processes.

Table 3 Recommended management practices for regenerative agriculture[20,26-28]

Practice	Description
Minimal tillage or no-tillage.	Tillage is one of the practices that contributes the most to soil organic matter mineralization and soil erosion, so switching to reduced or no-till tillage systems can have a positive impact on soil organisms and soil organic carbon, also allowing savings of up to 70 % of energy and fuel costs and investment in machinery. The idea of "good soil health" lies at the heart of RA. This concept integrates all the components and processes that make up agricultural soil, and is related to a more diffuse set of ideas about the importance of natural cycles, the presence of high levels of biodiversity and their capacity to provide ecosystem services.
Improved water use efficiency. Keyline hydrological design.	It is a technique that allows the runoff water in the plot to be managed efficiently and increase soil fertility. To this end, a design adapted to the topography of the land is carried out that allows rainwater to be mobilized and retained for the use of the crops by means of curves with an appropriate slope that guarantees an adequate distribution of water over the plot, and the performance of tillage practices (essentially, to avoid times of greater risk of storms or strong winds.
Compost application.	Plant remains from crops can also be composted to improve soil health and soil carbon sequestration. Composting is the controlled aerobic decomposition of organic materials such as plants, animals, or manure. The resulting product is an effective soil amendment as it increases soil biodiversity and microbial biomass with a corresponding increase in biological services, such as nutrient cycling, disease suppression and improved soil structure. Various "bioproducts" can be generated from organic waste, which can be recovered as soil amendments or biofertilizers. These include solid and stable ones, such as compost, vermicompost, bokashi, and biochar, and liquid ones, such as compost tea and violins.
Cover crops.	They are established to cover the soil with the aim of improving fertility, soil structure, promoting water infiltration and increasing biodiversity in agricultural production systems. It is common to use a mixture of grasses and legumes to achieve an optimal balance of the carbon/nitrogen ratio of the soil, diversify microorganisms and nutrient availability and improve biomass production.
Retention of plant remains.	It consists of leaving crop residues in the soil instead of eliminating them, as they provide organic matter that is beneficial to soil organisms.
Intercropping or intercropping.	The practice of interspersing one species with another, when the second is already in the final cycle of development. The reason for using this technique is that different crops are unlikely to share the same insect pests and disease-causing pathogens.
Crop and livestock integration.	The integration of different crops, also using different strata and different livestock, to graze pastures, cover crops or stubble, is a measure that allows synergies to be produced between the elements of the production system, improving the resilience and sustainability of the agroecosystem.
Directed rotational grazing.	Also known as holistic management or voisin rational grazing, it is one in which the herds graze on a fairly small plot for a very short period of time (usually half a day to 2-3 days) before being driven to the next plot, to then give the grazed plot a rest time for pasture recovery. It is a planned grazing in which it is anticipated where and how long a certain number of animals will be in a closed plot.

To bring livestock to a RL, practices and strategies must be implemented that allow food production in prolonged times, that do not impact costs, in addition to being friendly and sustainable with the environment. Some recommended practices are described below[30], i) *Living fences:* they provide wood, fodder, fruits, feed for animals, act as windbreaks and nourish the soil for animals that are grazing. ii) *Pasture livestock farming using the PLF model:* Rational voisin grazing (RVG) is the most efficient livestock production system based on pasture. The system allows a high degree of recovery of the pasture, before being intervened by the animals, this is achieved by the rotation given to the cattle[31]. iii) *Improving water use efficiency:* Keyline hydrological design[26]. iv) *Holistic management:* developing an approach to optimize processes in the ecosystem environment, such as water sources, mineral cycles, community dynamics, and livestock grazing. The first step for the development of the holistic practice is the definition of the grazing areas, in the rainy season rapid movements are made in the pastures, the objective is to cover the largest amount of grazing area in a maximum time of three days, in the dry season slow movements are made, evading the return of grazing cattle to the area already intervened. v) *Silage management:* the storage of nutritional forages collected in times of high production, for use in dry seasons or prolonged winters. vi) *Conservation of biodiversity in the pastures:* conserving fauna and flora, increasing the habitat of various species that favor the resilience of these agroecosystems, progressively seeking a natural balance that translates into profitability[29].

As described, the six recommended practices are aimed at: not depleting the soil, improving the quality and quantity of water and conserving biodiversity, which are the fundamental principles of RA.

Dynamics of forest cover in Guatemala. During the last 30 years, studies have been carried out on the behavior of forest cover in Guatemala with similar methodologies, which allow us to visualize the historical behavior of changes in the forest cover of our country. According to the values obtained, the trend, we continue to lose forest. The last of these reports that the annual net loss of forest for the period 2016-2020 was 13184 ha/year, although this seems little, in reality, it does not reflect the problem represented by the gross loss of forest, which is equivalent to 61098 ha/year[32], occurs in geographical areas where the wildlife of our country subsists and that provide environmental goods and services of the ecosystem that are of benefit to the population resident in these localities. Table 4 presents the indicators of forest dynamics for Guatemala for the period 1991-2020.

Table 4 Forest cover dynamics in Guatemala (1991-2020)[33]

Study	Period in years	Forest cover (ha)	Profit (ha)	Period Net Loss (ha)	Gross loss (ha)	Percentage of forest cover	Percentage of deforestation
UVG, INAB, CONAP	1991-2001	4,152,051	19,987	73,148	93,127	38.1	-1.43
UVG, INAB, CONAP, URL-IARNA	2001-2006	3,868,708	53,777	48,084	101,869	35.5	-1.16
INAB, CONAP, UVG, URL	2006-2010	3,722,595	93,432	38,552	131,984	34.2	-1.00
INAB, CONAP, MAGA, MARN, UVG & URL	2010-2016	3,654,303	104,635	18,350	122,985	33.0	-.50
INAB, CONAP	2016-2020	3,601,567	47,914	13,184	61,098	33.3	-.37

The difference between the forest area data of the final year and that of the initial year of the following period is due to the fact that each study determines, independently of the previous period, its initial and final data with the same images. The forest cover for the year 2016 was updated according to the 2016-2020 study, carried out by INAB, CONAP, 2023.

Forest cover indicators indicate that in these 30 years a total of 550484 ha of natural forest have been lost, equivalent to 13.2 % of what was reported for 1991. This has an effect on forest cover that went from 38.1 % in 1991 to 33.3 % by 2020. The gross loss on an annual basis reached its maximum expression during the period 2010 - 2016, 122985 ha/year were reported. Regarding the deforestation rate, it had a downward trend of -1.43 % in the base year (1991) to -0.37 % in 2020.

The potential for the promotion of AFS in Guatemala is reflected in the land-use capacity study prepared by Iarna, 2016 (based on INAB's land-use methodology, who estimated that around 25 % of the land (equivalent to 2,664,098.63 ha)[24] is suitable for agroforestry management (Agroforestry with annual ble 5)[24].

Table 5 Area (ha) of the categories of land use capacity in Guatemala, year 2016

Group	Symbol	Category	Area (ha)	Area (%)
Agriculture.	A	Agriculture without limitations.	1,479,662.38	13.70
	On the	Farming with improvements.	2,509,219.19	23.24
	Subtotal			**36.94**
Agroforestry.	Aa	Agroforestry with annual crops.	961,242.19	8.90
	Ap	Agroforestry with permanent crops.	656,863.06	6.08
	Ff	Silvopastoral systems.	1,045,993.38	9.69
	Subtotal			**24.67**
Forest.	F	Forest land for production.	2,379,110.50	22.03
	Fp	Protected forest lands.	1,675,216.88	15.51
	Subtotal			**37.55**

However, it should be noted that little is reported on agroforestry cover in the study to determine vegetation cover and current land use, in 2020, since it does not consider agroforestry as a category of use[34].

Important crops under AFS in Guatemala. There are a variety of crops grown under AFS in Guatemala such as coffee, cocoa and cardamom. Among the crops developed under AFS characteristics in Guatemala is coffee (*Coffea arabica*), whose cultivation is defined as a set of land use techniques in which the use of forest trees is combined with the planting of coffee[35]. Coffee production in Guatemala was linked to this type of production systems, mainly with shade trees such as Ingas and Gravilleas. It is estimated that 98 % of Guatemala's coffee is grown in AFS. In 2022, this crop represented the largest AFS in Guatemala, covering 305,000 ha, in 204 of the country's 340 municipalities. Coffee cultivation occupies an area of 539,712 ha, which represents 4.96 % of the national territory. It is estimated that 98 % of Guatemala's coffee is grown in AFS. An example of the richness of shade species used in coffee cultivation in the municipality of Olopa, Chiquimula can be found in the characterization of the coffee AFS in the municipality of Olopa, Chiquimula[35].

Another important crop is cocoa (*Theobroma cacao*), which finds optimal agroecological conditions for its production in Guatemala. It is estimated that at least 15 % of the total arable area of the territory (1,594,190 km^2) is suitable for this crop. However, cocoa cultivation is in the hands of small indigenous producers and poor peasants in remote areas, with poor communication routes, which makes it difficult to expand[36].

The study developed by Chavarría Ramírez et al.[37] In his analysis of tree structure and diversity in cocoa agroforestry systems, he pointed out that the species with the highest dominance and importance value index were: Mother cocoa (*Gliricidia sepium* (Jacq.) Kunth), laurel (*Cordia alliodora* (Ruiz & Pav.) Oken) and Cedar (*Cedrela odorata* L.).

The permanent shade of cocoa cultivation should be made up of trees that are taller than the crop; by tradition, legumes such as pito (*Erythrina* spp.), cuje, cushin, chalún (*Inga* spp.), mother cacao (*Gliricidia sepium*) have been chosen[37]. With the possibility of choosing timber species, such as laurel (*Cordia alliodora*), cedar (*Cedrella odorata* L.), flying stick (*Terminalia oblonga*), others, in addition to fruit trees such as avocado (*Persea americana* Miller), orange (*Citrus sinensis*) and paterna (*Inga paterna*)[37].

Among other crops under AFS, cardamom (*Elettaria cardamomum* Maton) is found, which according to the determination of vegetation cover and land use at a scale of 1:50,000 in Guatemala, reports an area of 169,429 ha of this crop, which is equivalent to 1.56 % of the national territory[38].

The importance of cardamom is reflected in the fact that in Guatemala it is the world's leading producer of this crop and number one in export. It is estimated that it reaches almost 1 % of the country's gross domestic product (GDP) and is grown in five departments: Alta Verapaz, Baja Verapaz, Quiché, Huehuetenango and Izabal[38].

The Bank of Guatemala details, through the cultivation of cardamom, more than US$ 450 million were exported in 2022, which has made it possible to boost the economy in the municipalities in which it is planted, which depend on 70 % of the production of this aromatic. The grain brings together more than 350,000 small farmers throughout the production chain[39].

For the promotion of plants to be established within the cultivation of cardamom, the Association of Cardamomeros of Guatemala (Cardegua), produces different types of plants in its nurseries, among which species of the genus *Ingas* stand out for those most accepted by farmers39.

Another interesting practice is what FAO has dubbed the Kurur Rum system, but what is it and how does it contribute to livelihood resilience? A system based on the traditional system and is characterized by being a set of soil, agricultural and forestry management technologies, combined with trees in alleys for the restoration of the forest landscape. It is adapted in the area corresponding to the Dry Corridor of Guatemala, which is a region located at a confluence of three major water sources: the departments of Quiché and Baja Verapaz, for the most part, discharge their surface waters into the Gulf of Mexico slope; the departments of El Progreso, Zacapa and Chiquimula on the Caribbean Sea slope and the departments of Jalapa and Jutiapa on the Pacific slope[40].

This system integrates agricultural production into the family AFS, in such a way that firewood and wood can be obtained from the same plot of land, as well as grain production, reducing the physical and social vulnerability of households[41].

In accordance with the above, from 2003 to 2017, the "Kuxur rum" has been implemented in five departments and 25 municipalities of the Dry Corridor of Eastern Guatemala. With a total of 7629 families benefited[41].

Figure 1 Banana AFS (M. *paradisiacal*), taro (C. *esculenta*) under a pine plantation (*P. maximinoi* H. E. Moore)

One activity that does not appear in the statistics is backyard agriculture, known as family gardens, used for the production of vegetables, fruit trees, woody, ornamental and medicinal plants by rural households in Guatemala. An investigation to analyze the agricultural system of the Mayan orchards in Petén in the municipalities of San Andrés and San José, in the solar orchards or family garden, known as solar in the Yucatan Peninsula, productive strategy of the Maya, vegetables and animals of very diverse utility for the family group and the community in general, are obtained. a total of 57 species in San Andrés, while in San José it reached 124 species. In the plot gardens, the quantities were, San Andrés, 52 species and (San José, 49)[42]. In Figure 1, an association of banana (*Musa paradisiaca*), taro (*Colocasia esculenta*) can be seen under a pine plantation (*Pinus maximinoi* H. E. Moore) in San Pedro Carcha, Alta Verapaz, Guatemala.

Another expression of association of trees with crops under AFS is used in the forestry incentive programs executed by INAB, which is more common within the Incentive Program for Small Holders of Forestry or Agroforestry Land Vocation -PINPEP-, which reports, during the period 2007-2024, has incentivized 64 % of the total plantations under the AFS modality, see the species with the highest demand for PINPEP in order of importance in Table 6. The potential of AFS in northern Guatemala is shown in Figure 2.

Tabla 6 Especies de mayor demanda para el establecimiento de SAF en programa PINPEP [43,44]

No.	Common Name of Species	Technical name
1	Cedro	*Cedrela odorata*
2	Aripín	*Caesalpinia velutina*
3	Madre cacao	*Gliricidia sepium*
4	Pino	*Pinus oocarpa*
5	Gravilea	*Grevillea robusta*
6	Ciprés	*Cupressus lusitanica*
7	Matilisguate	*Tabebuia rosea*
8	Coaba del sur	*Swietenia humilis*
9	Hule	*Inga* spp
10	Indio desnudo	*Bursera simaruba*
11	Pino	*Pinus maximinoi H. E. Moore*
12	Palo blanco	*Tabebuia donnell-smithii*
13	Caoba del Petén	*Swietenia macrophylla*
14	Cuje	*Inga spuria*
15	Alnus	*Alnus* spp.

Regarding natural forest, the forest ecoregion made up of pine and oak species in the northern part of Mesoamerica has an area of 103,842.71 km^2 and includes territorial portions of Chiapas (Mexico), Guatemala, El Salvador, Honduras and Nicaragua[45]. In this ecoregion made up of pine and oak trees, experiments have been carried out on the management of AFS with wood energy, for example in the Sierra de Zongolica, Veracruz, in a mountainous region, which is home to communities of indigenous people of Nahua origin. In these traditional AFSs, oak trees (*Quercus* spp.) are intensively managed to produce charcoal and firewood[45].

Similar experiences are reported in the region of the South Coast of Guatemala in the municipality of San José, La Máquina, Suchitepéquez[46], in an evaluation of four forest species: eucalyptus (*Eucalyptus camaldulensis*), pata mula (*Albizia niopoides*), caulote (*Guazuma ulmifolia*) and laurel (*Cordia alliodora*), from which charcoal can be obtained, found that *E. camaldulensis* it is the one that is most adapted for the conditions of that region, which can be recommended for planting under AFS.

Figure 2 Potential of AFS at the landscape level, northern Guatemala

Another experience on the management of natural oak forest (*Quercus* spp.) took place on the La Viña farm, in the municipality of San Pedro Ayampuc, Guatemala, in the central part of western Guatemala, a silvopastoral system was maintained for a long

time, in which the natural oak forest was harvested for firewood, later cattle were introduced for the regulation of the sprouts of this species. under a controlled grazing system.
In relation to the potential for the establishment of AFS in Guatemala, the Map on Vegetation Cover and Land Use at a scale of 1:50,000 of the (Republic of Guatemala for the year 2020)[34] (reports that approximately 27 % is covered by production systems with potential for AFS, the most important being 17 % percent covered by natural or cultivated pastures (Table 7).

Table 7 Potential for the development of agroforestry systems in Guatemala, 2020[40]

Type of crop	Extension has	% nationwide
Agroforestry systems	18,050	.17
Coffee	539,712	4.96
Cardamom	169,429	1.56
Scattered trees	241,132	2.21
Banana-banana	76,822	.71
Pineapple	12,028	.11
Cultivated grass	341,034	3.13
Natural grass	1,533,570	14.08
Total	2,913,727	26.76

This review has allowed us to point out points of convergence between the production of AFS and RA, since both concepts advocate sustainable production by reducing the use of inputs outside the production systems, improving soil health through the incorporation of organic matter and cover crops, increasing the availability of water (both in quality and quality) and promoting biodiversity according to the context of the ecosystems in which they develop. In addition, according to the conditions of the vocation of Guatemala's soils, we observe that 26.76 % of its territory is feasible for the production of AFS with the integration of RA concepts.

Conclusions

Most definitions of agroforestry refer to land use, combining trees with crops, in which one of these must be a perennial woody plant and the other an agricultural crop. Within the classifications are those that have to do with agricultural crops, that is, AFS, which are the most common, however, there are others, such as the silvopastoral system, there is a combination of trees with the cultivation of pastures for raising livestock. And a third is the combination of trees, crops and livestock (agrosilvopastoral), which is a more complex system.
Now, the terms of temporality mean combinations that can be simultaneous or sequential, incorporating agricultural crops, with trees, or the production of pastures for animal feed.
But what characteristics must we observe within these systems in order to be defined as regenerative, we can point out three main characteristics or pillars: the first pillar is soil health, the second pillar is water conservation and a third pillar is biodiversity, if a combination of AFS meets these requirements we can call it a regenerative system, since it does not degrade the soil, it provides the conditions for the provision of water in acceptable quantity and quality for human consumption and generates a habitat conducive to the conservation of biodiversity. In relation to the latter, the approaches are more related to the conservation of the environment and its contribution to human nutrition.
The latter could be observed in the family gardens,

which are the most biodiverse and have the greatest capacity to meet the food needs of the population.

Among the main functions of agroforestry are the following: reduction of soil erosion and maintenance of fertility; maintenance of water quantity and quality; carbon sequestration and reduction of greenhouse gas emissions; maintenance and management of biodiversity in the agricultural landscape.

The success of agroforestry is emphasized in three aspects, the use of local species, the reduction of greenhouse gases and the identification of specific management options for each agroecological zone. When talking about local species, it is inferred that it is referring to the conservation of the local flora and, therefore, it is deduced that it is as close as possible to conserving the landscape according to its natural condition, the group of native species and the most representative genes of a particular habitat.

AFS can contribute to the reduction of greenhouse gases, thereby enhancing their implementation by virtue of contributing to reducing the adverse effects of climate change, in addition to providing management options according to each agroecological zone with emphasis on adaptation for the conservation of the natural conditions of the site.

Various classifications of AFS were reviewed, however, *roughly* speaking, the main ones are usually those that refer to its structure, these being agroforestry, silvopastoral and agrosilvopastoral (they usually have a broader ramification).

To relate AFS to an RA production, the production system that tends to emphasize the harmonization of natural cycles under a sustainable production of agricultural systems, which encourages the arrangement to acquire resilience to climate change and other risks.

On the other hand, the implementation of RA must contain certain basic characteristics, such as: it must focus on results, it must be flexible, based on scientific evidence, it requires a high level of knowledge and demands a learning and adaptation process.

But what management practices are recommended for RA: i) no-till; ii) application of compost; (iii) cover crops; iv) retention of plant remains; v) directed rotational grazing (which promotes soil health); (vi) Integration of crops and livestock and intercropping crops. As you can see, these parameters are related to the three pillars to consider a production system to be regenerative.

Another of the concepts that we included in this review was RL, which contains four characteristic elements: i) non-use of chemically synthesized products; (ii) conservation of natural infrastructure; iii) microclimates that favor the forest and the prairie; (iv) improvement of soil health and fertility.

Regarding the level of Guatemala's territory, we indicate a AFS potential equivalent to 27 %, with the areas covered with pasture for livestock production containing the greatest potential.

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Conflicts of interest

This research has no conflict of interest.

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Ethical considerations

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Limitations in the research

The research is documentary and did not carry out any field study, which limits the obtaining of its results.

Access to data

The information from this research is present in the article.

Consent for publication

The author, after reviewing the document, I consider it approved for publication.

Use of Artificial Intelligence

I assume that the entire document was written based on ethical and professional criteria, and AI was not used to write the text.

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