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ARTICLE

Biodiverse, Productive, and Socially Just Silvopastures: a Solution for the Brazilian Drylands

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ABSTRACT

Drylands constitute more than 40% of global land and are particularly vulnerable to the impacts of climate change. In many of these drylands, livestock activities are a major form of land-use. In Brazil, the two major dryland biomes, Cerrado and Caatinga, play a key role in the country's livestock activities. While important economically, these activities also contribute to the emission of high amounts of greenhouse gases. One suggested strategy for mitigating the impacts of climate change is the adoption of silvopastoral systems (SPS) which combine trees, pasture, and animals simultaneously on the same unit of land. Farmers in the drylands of Brazil have a long history of practicing SPS. The practice of silvopasture is relevant to both climate change and the economy, but not necessarily to the issues of biodiversity loss and economic inequality. The lack of interdisciplinarity in rural agricultural development projects in the past, such as those related to the "Green Revolution", resulted in the aggravation of economic inequalities and biodiversity loss. The present work, focusing on the Brazilian Drylands, reviews these issues to justify the need for interdisciplinary projects considering multiple variables like soil quality, tree density, biodiversity richness, and farmers' perception.

1. Introduction

The present work intends to justify the need of developing and supporting biodiverse and socially-just silvopastoral systems. Focusing on the Brazilian drylands, scientific information was gathered in order to discuss the role of agriculture in climate change, biodiversity loss and poverty; as well on how an interdisciplinary/agroecological approach is capable of resulting in multiple benefits for a truly sustainable rural development.

2. Climate Change and Agriculture: The Brazilian Role

Climate change is one of the greatest challenges of our time and its adverse impacts undermine the ability of all countries to achieve sustainable development [1]. Climate

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change also exacerbates other challenges that humanity faces such as natural resource depletion, environmental degradation, desertification, drought, freshwater scarcity, and loss of biodiversity. Facing these challenges is relevant considering the expected increase of the world population to 9.1 billion by 2050, pushing up the demand for food production by about 70% [2].

Since the industrial revolution, the main gas associated with climate change is atmospheric carbon dioxide (CO_2), the concentration of which increased by 46% from 1750 to 2019, from 280 ppm to 410 ppm [3]. Agriculture is the economic sector that is most vulnerable to climate change, as well as a major cause of it. Agricultural activities directly account for about 14% of the global greenhouse gases (GHG) emissions, and as the main driver of deforestation and land-use change, are indirectly responsible for another 17% of global emissions [4]. The Intergovernmental Panel for Climate Change (IPCC) states that the economic sector of agriculture, forestry and other land-use (Figure 1) directly emits per year 24% of the total GHG emissions, or 11.76 $GtCO_2$ equivalent (eq) (IPCC 2014).

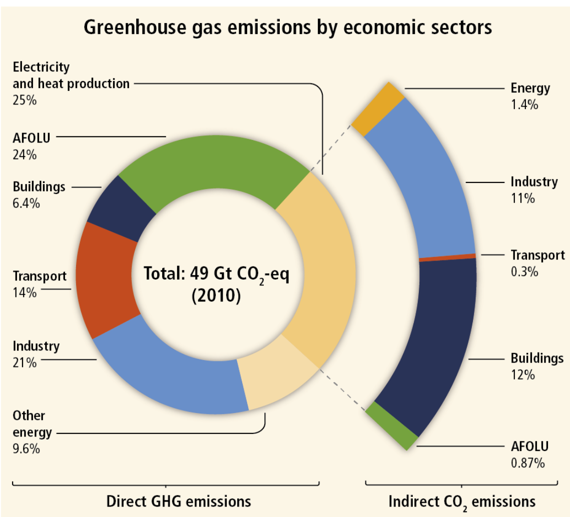

Figure 1. Agriculture, Forestry and Other Land-use (AFOLU) and other economic sectors contributions to total worldwide greenhouse gas emissions in 2010

Source: IPCC (2014).

A key sub-sector of agriculture that plays a significant role in GHG emissions worldwide is livestock supply chains. Beef and dairy cattle contribute 41% and 20%, respectively, of the sector's GHG emissions. For 2005, the sub-sector was estimated to have emitted 7.1 of $GtCO_2$ equivalent, representing 14.5% of all human-induced emissions in the year [5]. In Brazil, agriculture accounts for about 37% of the jobs in the country, and 25% of its gross domestic product (GDP) [6]. Brazil has the second largest herd of livestock on the planet, more than 238 million head of cattle, and is the world's leading beef exporter [7]. The agriculture sector, especially the livestock sub-sector, plays a significant role in GHG emissions.

In Brazil, the total GHG emissions (direct and indirect) from the agriculture sector in 2016 were 1,696 $MtCO_2$ eq, about 70% of the country's emissions. An increase of 165% from 1970 to 2016. Currently, the country accounts for 8.4% of the global agriculture sector GHG emissions, the 3rd greatest emitter [8]. This large contribution of agriculture activities to Brazilian GHG emission, also made the country a top-10 world GHG emitter [8], even though a majority of Brazil's energy comes from renewable sources.

The direct GHG emissions of the agricultural sector in Brazil in 2016 were 499 $MtCO_2$ eq, 1.7 % higher than that of the previous year. Beef and dairy were directly responsible with 69%, and 10%, or 342 $MtCO_2$ eq and 50 $MtCO_2$ eq, respectively. The agriculture sector's indirect GHG emissions were 1,197 $MtCO_2$ eq, and from this total, 1,167 $MtCO_2$ eq were related to land-use change associated with agricultural expansion into native vegetation for crop or cattle ranching [9].

The high emissions in the agriculture sector and livestock sub-sector in Brazil can, however, be potentially mitigated. A large area in the country has ruminant systems operating at low productivity, which have the potential to use management practices that can reduce their emissions while also providing economic benefits [5,9]. To support such practices, the Brazilian government passed a Decree in 2010, with the objectives of reducing the GHG emission of the country by 2020. The National Plan for Low Carbon Emission in Agriculture (ABC Plan), a part of the Decree, lays out some targets and plans, however not much was accomplished after its publication in 2010 [9].

In the ABC plan, the main targets of the mitigation of livestock activities were to recover 15 million ha of degraded pasture, by proper vegetation management and fertilization, potentially sequestering annually 8.3-10.4 $MtCO_2$ eq; and convert open pastures to silvopastoral and other agroforestry systems in 4 million hectares (Mha), potentially sequestering annually 1.8- 2.2 $MtCO_2$ eq [6]. The sequestration rates per ha in the ABC program are in line with the literature on carbon sequestration from the restoration of degraded grassland sites [10].

3. Drylands Vulnerability

Several definitions of drylands exist, the Millennium Ecosystem Assessment [11] describes drylands considering the aridity index classification, including hyper-arid, arid,

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semiarid, and dry subhumid categories. These regions are home to 2 billion people and occupy more than 60 million km^2, 41% of the earth's land area. The UN Environment Programme -World Conservation Monitoring Centre [12] included additional areas as drylands for their relevance on biodiversity conservation, e.g. Cerrado biome and other dry subhumid forests (Figure 2).

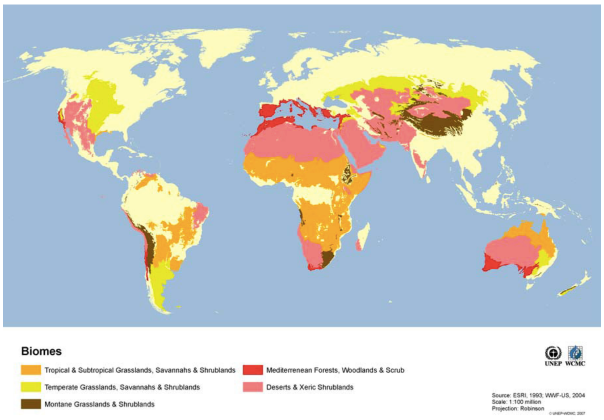

Figure 2. Worldwide drylands delimitation

Source: UNEP-WCMC (2007).

The dryland area affected by desertification is in the range of 6-12 million km^2, reducing their capacity to have enough primary productivity to sustain human livelihoods. The associated socio-environmental crises caused by desertification in these regions are often aggravated by the fact that the local populations are often excluded from policy processes, including lack of political dialogue, and denied appropriate investments from sustainable development projects [11]. In addition to the desertification processes in these regions, drylands are already being impacted by climate change [13] and there is a high probability that the extent of drought-affected areas will increase in coming years. The expected decrease in water resources might affect multiple sectors beyond agriculture, including water supply, energy production and health [4].

As livestock activities help to sustain many communities in drylands, this fact conveys the urgency of the adoption of livestock management practices that are capable of climate change mitigation and adaptation while also increasing productivity. The adoption of these practices becomes even more urgent when considering the expected demand for meat and milk in 2050 compared to 2010 are projected to increase by 73% and 58%, respectively [14]. Considering the drylands fragile nature and inherently low productive capacity, designing and adopting productive resilient land-use systems is a particularly challenge of land management in these regions.

4. Brazilian Drylands and Livestock Activities

The drylands regions in Brazil have a key role in the livestock activities of the country, as well as contributing significantly to GHG emissions. Brazil, the fifth largest country in the world, has approximately 35%, or circa 2.8 million km^2 of drylands [12,15]. These areas are represented mainly by the Cerrado (Brazilian savanna) and the Caatinga (Brazilian semiarid) biomes (Figure 3). These regions are also placed among the most endangered eco-regions on Earth due to high rates of conversion and few protected areas [16].

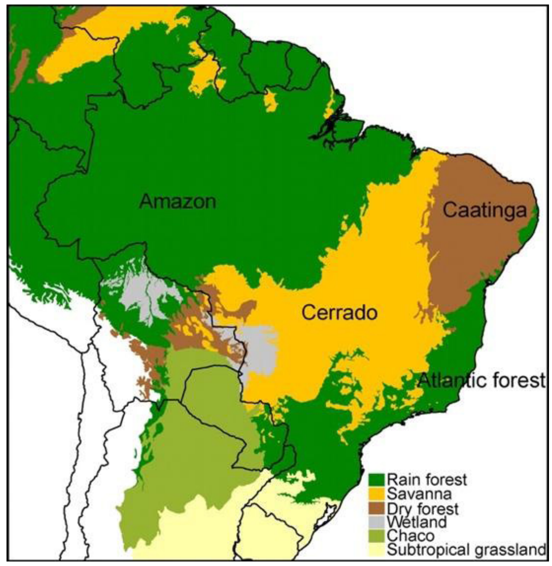

Figure 3. Brazilian biomes

Source: Simon et al. (2009).

4.1 Caatinga Biome

The semiarid Caatinga region is an unique biome of Brazil, located in the Northeast of the country (3° to 17° S, and 35° to 45° W) and occupies 845,000 km^2, about 10% of the country [15]. The annual average rainfall is 750-800 mm, with a rainy season usually lasting 3-5 months . Every three to four decades severe drought periods occur, lasting 3-5 years, with rainfall remaining around 260 mm for several years. High annual average temperatures are another striking feature of the Caatinga, with values between 25 to 29° C [15].

The Caatinga's proximity to three wetter arboreal biomes, the Cerrado savannah, and the tropical forests, Amazon and the Atlantic Forest biomes, contributes to the biome's rich diversity of plants and very unique flora of drought resilient tree species. The Caatinga has 4,320 species of angiosperms, 744 of which were described as endemic [17]. In addition, 620 belong to the Fabaceae family (Leguminous), which contains many nitrogen fixing species, which have special relevance for agricultural systems.

Currently, 45% of the Caatinga has been deforested, from 1985 to 2017 the Caatinga lost a 5 Mha of forest area. Although several experiences exist in the biome integrating animal activities with forest conservation, the predominance of livestock activities using, e.g., slash-and-burn with a fallow period shorter than 50 years, overgrazing, and intense firewood gathering, are the main reasons for deforestation, and desertification processes in many regions in the biome [18,19].

Historically and currently, livestock-related activities were/are the primary occupation of the Caatinga inhabitants, in a drought year, the agricultural production in a major state of the biome declines 84%, while livestock activity drops 20% [20]; which reinforces the value of livestock farming for the local communities. The recognition of the negative impact of some management practices and the recommendations on tree growing in the Caatinga's pastures for improving livestock productivity date back to the 1860s [21]. Today, a substantial body of knowledge on SPS, is available in the form of numerous reports and books describing these practices [20,22-24].

4.2 Cerrado Biome

The Cerrado biome is the largest woodland-savanna in South America and second largest vegetation formation after the Amazon [25]. Stretching over most of east-central Brazil, Cerrado is slightly bigger than Mexico, covering approximately 205 Mha, about 24% of Brazil's land area [26]. The climate in the region is characterized by two well-defined seasons: dry winters and rainy summers, the precipitation ranges from 800 to 1,800 mm [27].

Cerrado is one of the 34 worldwide *Biodiversity Hotspots* [28] due the its high level of species richness and endemism, and the rapid loss of habitat due the conversion of native vegetation to pasture and cropland. The Cerrado has the highest plant diversity among tropical savannas with ca. 11,384 species of flowering plants (Angiosperms), where 29,7% or 4,151 are endemic to the biome. In addition, 1,158 species in the biome are Fabaceae [17], suggesting great potential for exploiting native nitrogen fixing trees.

The Cerrado region is the main cattle production area of Brazil, with an estimated herd of 75 million animals, or 44% of the Brazil's herd [29]. About 28% of the biome, 60 Mha, is occupied by pastures[30]. Traditionally, beef cattle production is a major source of income for many farmers in the Cerrado region [31,32]. It is estimated that 39% of the Cerrado pastures have some level of degradation, representing about 18 million ha [33].

The land-use change of the Cerrado biome has been significant in past decades, with great areas of forest changing to farming. The biome lost 20.8 Mha of natural forest formation from 1985 to 2017 [34]. This high land-use change of native arboreal vegetations to farmland, is considered a threat to the Cerrado biodiversity. According to the Brazilian Greenhouse Gases Inventory [35], the carbon emissions due to deforestation in the Cerrado increased from 0.05 petagrams (Pg) C yr^{-1} (1988 to 1994) to 0.06 Pg C yr^{-1} (2002 to 2008).

In addition to vulnerability to land degradation, the Cerrado economy and farmer livelihoods might be greatly impacted by climate change [27]. The estimated changes of temperature in the biome for the year 2100 is 4-6 °C in the most severe prediction, and 2-4 °C considering the least severe prediction (IPCC SRES A2 and B2 emissions scenarios)[36]. For precipitation, the most severe scenario predicts a decrease of 20-50% of current levels in the central and southern parts of the Cerrado, and reductions of about 70% in the northeastern part, which is near the Caatinga region; the projections with less severe changes indicate a reduction of 30% in the central and southern parts of the Cerrado, and a reduction of 50% in the northeastern area. These predictions show how great the reduction of water availability could be and call for urgent actions to adopt agricultural alternatives with proven mitigation and adaptation potential to climate change.

5. The Silvopasture Alternative

Solutions are needed and some are already being applied in dryland regions. In Brazil, estimations show how it might be feasible for the country to achieve sustainability and productivity. An increase in the grasslands productivity from ~32% to 50% would satisfy the demand for meat and milk until ~2040, without the need for native forest conversion/deforestation to cultivated grasslands [37]. Adding to the feasibility to achieve better productivity, the growth of trees could also help to achieve mitigation. Tree planting in agricultural lands is indicated as a relatively efficient and cost-effective method compared with other mitigation strategies and provides a range of co-benefits important for improved farm family livelihoods and climate change adaptation[38].

Agroforestry systems (AFS) involve the intentional integration of trees and shrubs into crop and animal farming systems to create environmental, economic, and social benefits and has been practiced around the world for centuries [39]. Trees and shrubs can enrich biodiversity in the landscape, increase ecosystem stability as well

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as diminish the effects of extreme weather events, such as heavy rains, droughts and windstorms. Agroforestry systems can also contribute to preventing erosion, stabilizing soils, raising infiltration rates, and halting land degradation [38].

Considering the need for strategies to fight climate change, AFS has been recognized as having the greatest potential for carbon (C) sequestration of all the land-uses analyzed in the Land-Use, Land-Use Change and Forestry report of the IPCC [40]. Since the Kyoto Protocol, AFS has gained increased attention as a strategy to sequester C for its potential to do it by at least two ways: 1) increasing direct C sequestration through the addition of C into the tree and shrub components and stored as wood, and, 2) increasing C storage in the soil organic carbon (SOC), which has also the added advantage related to soil fertility improvement and moisture retention content [41].

Several factors contribute to the ability of AFS to sequester C more efficiently than monocultures, including the efficient C (and nutrient) cycling within the soil-plant system, increased return of biomass (C) to soil, decreased biomass decomposition and sequestration of soil C in deeper layers of soil [42-47]. In addition, AFS provides a more shaded environment which contributes to the increase of animals' comfort (and productivity) due to microclimate amelioration [48,49], which will be an important adaptation strategy in a climate change scenario of higher temperatures.

The available estimation of C stored annually in AFS in the aboveground biomass varies from 0.29 to 15.21 Mg C ha year^{-1}; the below ground C stock varies from 1.25 to more than 300 Mg ha^{-1} up to 1 m depth [50]. As an example of the potential mitigation of AFS for livestock activities, in Southern Brazil a study estimated that the tree component (*Pinus ellioti*) could mitigate the GHG emitted by at least 3.58 cows ha^{-1} [51]. In addition, Resende et al. (2019) describe a 100 ha of SPS being capable of mitigating a herd of 150 cows.

In drylands, SPS is one of main types of AFS, and it is characterized by the integration of trees (either for wood, oils, fruits, etc.) with animals being managed in the same area [53]. Silvopastoral systems are traditional land-use systems in many subhumid [54], semiarid and arid regions [55]. In the drylands, SPS plays an important role in the sustainability of many communities as a more resilient activity in comparison with crop production or tree-less pastures.

Several management practices are related to SPS, which include the use of fodder banks, an assemblage of tree and shrub species that are predominantly fodder species. These trees may also provide several products (e.g. fruits) and services (e.g. soil fertility improvement). The fodder trees can be planted as live fences, wind breaks, woodlots, soil conservation barriers, etc. Usually, the fodder is cut and carried to stall-feed the animals, but in some systems the animals are allowed to graze on the fodder bank in a controlled manner for defined periods of time [23].

As deficiency of nitrogen (N) is common in dryland pastures and can significantly affect the growth of grass and trees, a general solution is the use of chemical fertilizers in pasture lands, however the cost is high and the application would have to be repeated indefinitely. Another resilient alternative and low-cost solution is rhizobium inoculation with nitrogen fixing plants, mainly trees species, which would help fertilize soils over the years and, in addition, these plants could be used to feed livestock and produce timber, honey, etc. Dubeux et al. (2017) reviewed the importance of nitrogen fixing trees/tree legumes for the tropics and argued that tree legumes are an underexploited resource in warm-climate grasslands.

The mitigation potential of SPS for drylands was described in a global meta-analysis study [56], in which SPS, compared to pastures, showed 89% higher SOC stock at the topsoil (0-20 cm) and 27% higher at the 0-100 cm depth. In the semiarid region of Brazil, SPS has been shown as the most efficient land-management system in the Caatinga to minimize losses of carbon [24]. Also in the Caatinga, SPS management, when compared to many other practices commonly applied in the region, such as intensive cropping, slash and burn, firewood collection, and secondary forest in natural stands, was considered one of the systems with higher SOC stock [22]. In addition, studies in the Caatinga described higher SOC stock near trees (*Zyziphus joazeiro, Spondias tuberosa* and *Prosopis juliflora)* than away from trees [24,57].

Silvopastoral systems are also of great relevance for optimization of land-use systems, meeting productive and conservation goals. To meet the demand of 500 Brazilians for grains, meat, and energy, the Cerrado's conventional systems (i.e. monocultures) would required 420 ha, while the SPS with Eucalyptus trees would only require 70 ha [58]. In addition, compared to conventional systems, the SPS decreased the climate change potential by 55%, improved the quality of employment, and decreased the total production costs by 54% [58].

In Brazil, the most common tree species used in SPS are exotic Eucalyptus hybrids. This land-use system is practiced over about 2 million ha, an area that has increased due to governmental incentives [59]. On the other hand, many SPS experiences exist in the Caatinga region using native trees feeding animals [55], although many of these examples have not been properly studied. In the Caatinga, new designs are also being developed. For example, some innovative small holder farmers are growing native trees in a cactus (*i.e. Opuntia ficus-indica)* plantation, increasing the plantation's biodiversity and soil resilience; a system maintaining a high yield of > 250 Mg ha^{-1} $year^{-1}$ of green/fresh biomass after 17 years of use [60].

6. Agriculture and Biodiversity loss, Inequality and Poverty

As described in the previous sections, SPS are an important strategy for climate change mitigation, but their proper development and adoption may also help to solve additional relevant issues. Currently, the whole planet is at a high-risk of biodiversity loss [61], and the decline of biodiversity (including biodiversity for food and agriculture) has been a feature of conventional agricultural intensification, leaving agricultural systems impoverished, vulnerable, and dependent on continuous use of external inputs [11]. If the role of biodiversity is considered in SPS intensification, it could improve the sustainability of land-use systems as well supporting the biodiversity recovery.

The danger of agricultural intensification focusing on only one target, i.e. productivity, can be exemplified by the adoption of "Green Revolution" practices in Bolivian communities that replaced traditional SPS [54]. Silvopastoral systems that had developed and adapted over generations, underwent significant changes after external actors encouraged the use of chemical fertilizers and pesticides for expanding cash crops, resulting in soil erosion and decrease in the local well-being [54].

In addition, while production and productivity of the major food crops continue to increase due to agricultural intensification, the number of people who are food insecure and malnourished remains high at nearly 1 billion and reached a record high in 2009 [38]. If social aspects are given more consideration when discussing/developing SPS projects, it could support a reduction on the rural inequality, as the 2030 Agenda for Sustainable Development [1] says that "This will only be possible if wealth is shared and income inequality is addressed" [1]. For example, 59% of the variation in the Cerrado pastures' degradation are explained by poverty and low income. The more degraded a pasture is, the lower the social and economic indicators will be and the capacity of rural populations to invest on the the recovery of degraded pastures will also be lower [33].

The development of SPS that consider social aspects is of key importance to Brazil, a country ranking second in inequality and worst when measuring the share of national wealth held by the poorest 10% of the population, with most living in the countryside [62]. To discuss the rural inequality in the country it is important to notice that large rural establishments (>1,000 ha) receive 43% of funds (subsidized low-interest credit) and contribute 24% of production value, while small farms (<50 ha) with 23% of funds, produce 41% of agricultural value (Figure 4).

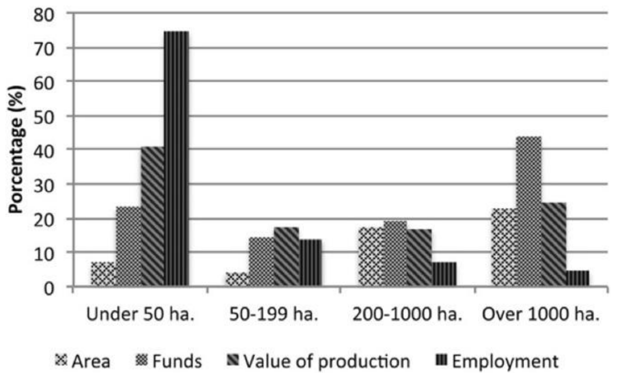

Figure 4. Brazilian agricultural indicators according to establishment size (ha), defined as a percentage of all declared and undeclared arable land [83]

Source: Paulino (2014).

Small-scale agriculture produces nearly double the amount generated by establishments with more than 1,000 ha, even though these large establishments control more than three times the area [63]. In addition, small farmers are responsible for ~70% of Brazil's food consumed by the Brazilian population [64], and have outstanding success with job creation, 74% of the countryside's economically active population[63]. In this way, better financial support and enabling land policies targeting on these successful small farmers, if considering the adoption of SPS, and other AFS, have the potential to both reduce the rural inequality and increase the use of resilient biodiverse rich systems.

Based on the fact that not all small farmers are using sustainable management practices, it is relevant to develop extension projects and funds for the adoption of SPS and other AFS. In the Caatinga region, the lack of interest to adopt sustainable practices was associated with the poor education level of farmers [65], developing accessible learning resources for these is also of great relevance. In addition, in the same Caatinga region 90% of the farmers are male, and as poverty alleviation and rural business development programs were successful when women were involved in the programs [66], gender dynamics should be considered for any future projects.

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7. Considering the Interdisciplinary Agroecological Approach

Agroecology is described as both a science and a set of practices [67], which includes AFS. As a science, agroecology includes ecology, natural, environmental, social and agricultural sciences (e.g. Figure 5). Based on the beneficial biological interactions and synergies among the components of the agroecosystem, agroecological systems can allow the regeneration of soil fertility, enhancement of soil organic matter and soil biological activity, and maintaining food productivity [67,68].

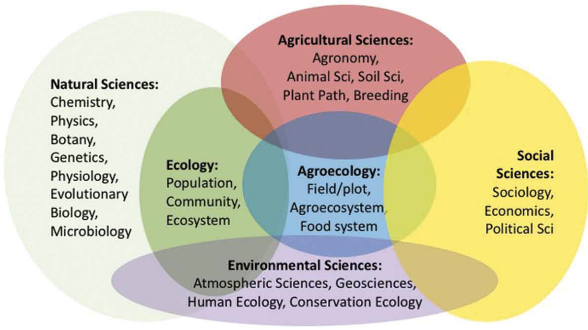

Figure 5. The interdisciplinary science of agroecology

Source: Picasso (2018).

The integration of traditional knowledge and modern technologies has been widely recognized for the development of sustainable land-use systems [69]. The importance of giving value to the farmers' knowledge, perceptions and management practices, is highlighted in agroecology, due to a highly knowledge-intensive system, based on techniques that are not delivered top-down, but developed on the basis of farmers' knowledge and experimentation [70]. In this way, it is described to be important for scientists to recognize farmers' experiences and emphasizes the capability of local communities to experiment, evaluate, and scale-up innovations through farmer-to farmer research and grassroots extension approaches [67,70,71]. Even moreso considering that the most relevant relation between climate change and peasant agriculture is that many small farmers are already mitigating and adapting to climate change by using biodiversity rich systems [72]. This includes farmers that are adopting a variety of sustainable practices, including SPS.

One example of the potential success of such approach in research projects is the recent documentation of an innovative SPS designed by a Caatinga small farmer, who planted cactus with Caatinga native fodder trees [60], both used to feed his animals. In relation to rural extension projects, Cuba probably has the greatest example of how participatory approaches can increase the adoption of sustainable practices by farmers, where, in 10 years of extension projects, the number of families adopting agroecology practices went from 200 to 110,000 families [71].

The Brazilian drylands due to their great plant biodiversity have great potential to explore and develop biodiverse rich systems for livestock activities, which can

Table 1. Common Fodder trees and shrubs of the Caatinga region and their main characteristics.

Common name Species	Height and Succession stage	Growth habits and Coppicing ability	Fodder availability, Animals' preference	Other possible uses
Aroeira *Myracrodruon urundeuva*	Up to 25m; End of secondary succession, near climax	Moderate growth; No coppicing	Leaves consumed either green or dried	Wood for construction; Medicinal; Bees (nectar and pollen)
Catingueira *Poincianella pyramidalis*	Up to 10m; Secondary succession (intermedium)	Slow growth; No coppicing	Leaves highly preferred when dry (dry season - up to 35% of the animal's diet)	Wood for construction; Bees (nectar and pollen)
Juazeiro *Ziziphus joazeiro*	Up to 10m; End of secondary succession, near climax	Slow growth; Inverted phenology, trees grow new leaves in the dry season; No coppicing	Leaves consumed when green in the dry season; Fruits consumed in wet season	Strategic fodder bank for drought periods; Medicinal; Fruit tree (human and animal consumption); Bees (nectar and pollen)
Jurema-preta *Mimosa tenuiflora*	*Up to 8m; Beginning of the secondary succession*	*Fast growth; Leaves remain green during the dry season (even more if coppiced); Coppicing recommended*	*Leaves highly preferred when green (wet season); Fruits avidly consumed in the beginning of dry season*	Strategic fodder bank for drought periods; Nitrogen fixing; Firewood; Medicinal; Bees (nectar and pollen)
Mororó *Bauhinia cheilantha*	*Up to 8m; Pioneer and in secondary succession (intermedium)*	*Slow growth; Coppicing recommended*	*Consumed when green (wet season)*	Firewood; Bees (nectar and pollen); Nitrogen fixing
Sabiá Mimosa caesalpiniifolia	*Up to 9m; Secondary succession (intermedium)*	*Fast growth; Coppicing recommended*	*Highly preferred when green (wet season)*	Firewood; Bees (nectar and pollen); Easy to spread, roots may grow out of branches; Nitrogen fixing

Source: Pinheiro and Nair (2018).

put the region as a global SPS hot spot and showpiece of the future. The Caatinga biome already has a traditional use of the native vegetation for livestock activities, where many of the native tree species were described as fodder trees (Table 1) and belong to the nitrogen fixing plant group, the Fabaceae family. In addition, there exists a need to intensify the research efforts addressing domestication and utilization of native nitrogen fixing trees in warm-climate grasslands, especially considering the biodiversity rich Brazilian drylands where there are already many native species that could be targets for development. Some studies in Brazil already showed the value of using native nitrogen fixing plants in SPS, which can increase the N accumulation in the system and its pathway cycling, estimated to sustain the forage productivity for several years [49,73]

8. Conclusions

An interdisciplinary approach seems to be necessary for the Brazilian livestock sector and feasible thought the use of biodiverse SPS by the innumerous small/medium holder farmers in the country. In addition, the interdisciplinary approach aligns with several international country agreements.

Brazil as a signatory of the Paris Agreement [74], agreed to reduce its greenhouse gases emissions and as an efforts to limit the temperature increase to 1.5 °C above pre-industrial levels. In 2015, the country pledged to reduce 43% of its 2005 emissions level by 2030 [75]. Since SPS can sequester carbon above and below ground, it has been considered as a main strategy. On the other hand, is important to note that this commitment is currently threatned due to the recent actions (2019-2020) of the central goverment. The current Bolsonaro admistration is receiving the attention of the international academic community for attacking scientists who are reporting the increase in the deforestation rate, for cutting the budget related to science and education, scaling back enforcement of environmental laws, and pushing forward with proposals to shrink the size of protected areas [76-78]; actions that are completely against any intention to in fact reduce its emissions.

When the development of SPS considers vulnerable small farmers, it also aligns with several Sustainable Development Goals of the 2030 Agenda[1] and the associated targets (integrated and indivisible). From the 17 goals, it is mainly connected to these goals:

Goal 1: End poverty in all its forms everywhere. Especially connected to the Target 1.4: highlighting the importance of appropriate new technology for the poor and the vulnerable.

Goal 2. End hunger achieve food security and improved nutrition and promote sustainable agriculture. Especially Target 2.3: expecting to double the agricultural productivity and incomes of small-scale food producers by 2030 through, for example, access to inputs and knowledge.

Goal 8. Promote sustained, inclusive and sustainable economic growth, full and productive employment and decent work for all.

Goal 13. Take urgent action to combat climate change and its impacts.

Goal 15. Protect, restore and promote sustainable use of terrestrial ecosystems, sustainably manage forests, combat desertification, and halt and reverse land degradation and halt biodiversity loss.

The value of the development of SPS using local and native plant species is also reinforced by its connection with international and Brazilian national targets for biological conservation. As a signatory of the United Nations Convention on Biological Diversity [79] and having developed its National Biodiversity Strategies and Action Plan [80] to be accomplished by 2020 (expiring), from the 20 national targets, those related to the use and development of resilient and biodiverse productive land-use systems (i.e. SPS) are:

National Target 1: Brazilian people are aware of the values of biodiversity and the steps they can take to conserve and use it sustainably.

National Target 2: Biodiversity values, geo-diversity values, and sociodiversity values have been integrated into national and local development and poverty reduction and inequality reduction strategies, and are being incorporated into national accounting, as appropriate, and into planning procedures and reporting systems.

National Target 7: The incorporation of sustainable management practices is disseminated and promoted in agriculture, livestock production, aquaculture, silviculture, extractive activities, and forest and fauna management, ensuring conservation of biodiversity.

National Target 15: Ecosystem resilience and the contribution of biodiversity to carbon stocks has been enhanced through conservation and restoration actions, including restoration of at least 15% of degraded ecosystems, prioritizing the most degraded biomes, hydrographic regions and ecoregions, thereby contributing to climate change mitigation and adaptation and to combatting desertification.

National Target 19: The science base and technologies necessary for enhancing knowledge on biodiversity, its values, functioning and trends, and the consequences of its loss, are improved and shared, and the sustainable use

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of biodiversity, as well as the generation of biodiversity-based technology and innovation are supported, duly transferred and applied.

The development of biodiverse and socially just SPS should be considered as a key strategy for the rural development of the Brazilian drylands. Future agricultural projects considering such interdisciplinary approach might contribute to a transition to systems that bring at the same time environmental, economic, and social benefits, resulting in climate change mitigation/adaptation, recovery of biodiversity and sustainable development of neglected rural populations.

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