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PERSPECTIVE

A classification of cultivated pastures in the Brazilian Cerrado for sustainable intensification and savanna restoration

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Abstract The Brazilian Cerrado, with over 200 million hectares, has approximately 28% of its area occupied by cultivated pasturelands and 39% of them are degraded. In this study, we propose a new classification of the Cerrado pastures and recommendations for sustainable intensification and savanna restoration. We propose seven classes of pastures based on the ground cover proportions of exotic grass, bare soil, and native vegetation. These lands need to be acknowledged for their biodiversity conservation and potential for sustainable intensification and restoration. In order to make ecological intensification available for the ranchers, research and technology transfer have to embrace native tree species-based silviculture, native-grass-based forage management and enhancement, and value chain of biodiversity-friendly products. The pasture management proposals of this paper are based on a concept of biodiversity as an ecosystem service, promoting local productivity and global ecosystem services.

Keywords Ecological intensification · LULC · Pasture degradation · Savannas · Secondary savannas · Silvopastoral systems

INTRODUCTION

The Brazilian Cerrado biome is the most biodiverse tropical savanna in the world. It covers over 2 million km^2 (24%) of Brazilian territory and has the highest rate of habitat loss in the country (Sano et al. 2019). Currently, 28% of this biome is occupied by cultivated pasturelands, mostly for cattle beef production (Fig. 1; Parente et al. 2017). However, 39% of the pastures are degraded, as verified by a significant decrease in productivity from 2011 to 2014 (Pereira et al. 2018). If pasture productivity in Brazil is increased to 50%, it can meet the demand for the national meat consumption and save lands for other uses or for biodiversity conservation for the next two decades (Strassburg et al. 2014). Therefore, degraded pastures in the Cerrado are considered as an opportunity for land use changes toward more sustainable land uses. Recent studies suggest livestock and agriculture intensification as the best option for food production and biodiversity conservation in this biome (Strassburg et al. 2014; Gil et al. 2015; Silva et al. 2017).

Pasture degradation in the Cerrado encompasses biological degradation, which is related to increasing bare soil and agronomic degradation, which is related to infestation of non-pasture species (Dias-Filho 2007). However, agronomically degraded pastures of the Brazilian Cerrado can be seen as savannas in the process of regeneration. While the importance of secondary forests in the tropics for biodiversity conservation and carbon sequestration is highly recognized (Bongers et al. 2015), secondary savannas are often overlooked and undervalued (Nerlekar and Veldman 2020). Differentiating the pasture types and estimating the costs and opportunities for intensification is rather important to make appropriated choices among the options of sustainable intensification or savanna restoration.

In this paper, we support that sustainable intensification of degraded pastures in the Brazilian Cerrado should be considered in terms of both agricultural intensification, *i.e.*, increasing land productivity, ecological intensification, *i.e.*, increased land productivity by integrating the management of ecosystem services delivered by biodiversity (sensu Bommarco et al. 2013) and ecosystem restoration. Sustainable intensification includes land sharing, i.e., agricultural practices that integrate biodiversity conservation and other ecosystem services for sustained food and energy production (Garnett et al. 2013). However, this concept is

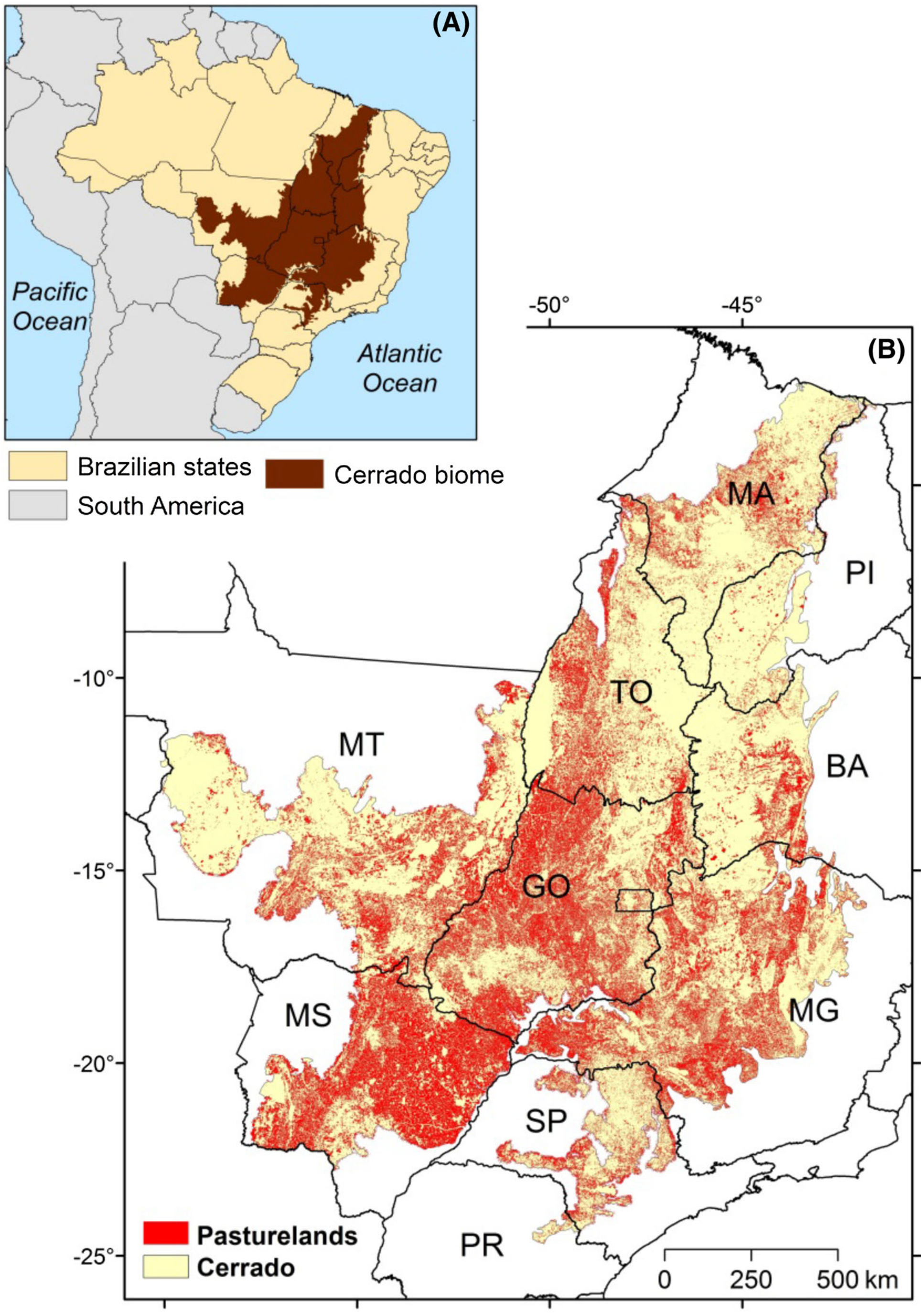

Fig. 1 Location of the Cerrado biome in Brazil (**A**), as well as the cultivated pastures in this biome (**B**)

used strictly for the enhancement of productivity and efficient use of natural resources, ultimately contributing to the reduction of further land clearing. It has not been used for onsite conservation neither for land sharing of the Brazilian pastures (Dias et al. 2016; Garcia et al. 2017; Silva et al. 2017; Cortner et al. 2019; Mandarino et al. 2019). There are opportunities to build sustainable pastures with ecological intensification by adding the role of biodiversity as an ecosystem service for pastures and the role of pastures for biodiversity conservation. For example, silvopastoral systems with native trees and semi-natural savanna pastures should be further investigated and promoted as effective strategies for improving productivity and ecosystem services of pastures.

The objectives of this perspective paper are to propose a new classification for Cerrado's pastures and to make recommendations for sustainable intensification of each class. By recognizing the presence of Cerrado´s native species in cultivated pastures, decision-makers can choose a better management of pastures. In "A new classification for Cerrado's pastures" section, we propose a typology for the Cerrado´s pasture based on the differences in the ground covers. Then, we discuss the management options for the Cerrado´s cultivated pastures ("Management options for Cerrado´s pastures" section) and the actual possibility of being adopted by farmers ("Adherence of the proposed options to the reality" section). Although the concepts presented here are directed to Brazilian savannas, it is expected that they are valid for other savanna regions in the world, because of the strong regeneration ability of savanna species, and because cultivated pastures, secondary savannas, and old growth savannas are grazing resources for cattle.

A NEW CLASSIFICATION FOR CERRADO'S PASTURES

Our proposal for the classification of Cerrado´s pastures was based on the predominance of the ground cover type found in native or cultivated pastures (native species, bare soils, and exotic grasses), as well as on the relevance of the proposed classes for choosing a land management. We did not consider weed density criterion (*i.e.*, cosmopolitan short-lived herbs and shrubs with high dispersal ability, and dense seed banks, commonly invading agricultural sites) since it is not frequent in this biome. In a field survey involving 93 pasturelands randomly selected over the Cerrado (Silva et al., in preparation), we found > 20% cover of native grass, shrub, and tree species in 19 pasturelands, and only one pastureland with > 20% cover of weeds. Weeds are found abundantly in highly fertile soils and in high precipitation regions (Dias-Filho 2007).

Figure 2 illustrates our proposal of classifying Cerrado´s pastures into the following denominations: (a) productive pasture, with < 20% cover of native species and < 20% cover of bare soils; (b) pasture with Cerrado regeneration, 20–40% of native species and < 20% of bare soils; (c) regenerating Cerrado, 40–70% of native species and < 20% of bare soils; (d) Cerrado, > 70% native species; (e) pasture with biological degradation and Cerrado regeneration, 20–70% of native species and 20 –40% of bare soils; (f) pasture with biological degradation, < 20% of native species and 20–40% of bare soils; and (g) pasture with severe biological degradation, > 40% of bare soils. These categories can be split or grouped in other classes, depending on the user´s objectives.

The thresholds between degraded and non-degraded pastures need to be defined at the local scale, considering the differences in precipitation, climate seasonality, and soil physical and chemical properties. This is because of the extent of the Cerrado biome. For example, precipitation in this biome varies from 893 mm in the Depressão Cárstica do São Francisco ecoregion (northeastern Cerrado) to 1757 mm in the Chapada dos Parecis ecorregion (westernmost ecoregion of the biome) (Sano et al. 2019).

Figure 3 shows our proposed conceptual model of pasture types, the options for land use improvement in the Cerrado, and the correspondence of our pasture types with the usual denominations. When cattle are raised in native grasslands and shrublands frequently burned to promote regrowth of grasses for forage (Mistry 1998; Eloy et al. 2019), we propose the denomination Extensive cattle raising on savannas and grasslands. Frequent burning increases grass cover and decreases tree cover. This land use type is indistinguishable from unmanaged savannas and grasslands. Tree cover can vary naturally from 0 to 100% in the grassland-woodland gradient, depending on the fire intensity and frequency, soil fertility, and precipitation regime (Schmidt et al. 2019).

For pastures under constant cultivation, with dense grass coverage (Valle Júnior et al. 2019), we propose the denomination Productive pastures. As the biophysical characteristics of each site determine its carrying capacity for biomass productivity, a healthy pasture does not lose much soil moisture, soil organic carbon, nutrients, and microbial biomass (Pereira et al. 2018).

We propose the denomination Pasture with Cerrado Regeneration for the commonly found cultivated pastures with African grasses but with infestation of shrubs and treelets, also identified as bushy savanna (Garcia and Ballester 2016). When native species cover > 40% of a pasture field, we denominate Regenerating Cerrado. Although shrub and tree species found in such pastures are called invasive species or weeds by technicians and ranchers, these invaders are essentially plants that survived during the deforestation process and can resprout after deforestation, and pasture establishment and reform (Durigan and Ratter 2006; Vieira et al. 2006; Sampaio et al. 2007). Such ability can be an adaptation to the fire-prone ecosystem of savannas (Simon and Pennington 2012). Pasture with Cerrado Regeneration and Regenerating Cerrado provide less forage, but they can have similar net primary productivity of well-managed pastures because Cerrado vegetation maintains photosynthetic activities during the rainy season and after the onset of the dry season.

For the exotic pastures, with or without Cerrado regeneration, with > 20% bare soil exposition, we propose the denomination Biologically degraded pastures, and with > 40% bare soil, the denomination Severe biological degradation. These pastures are results of overgrazing and

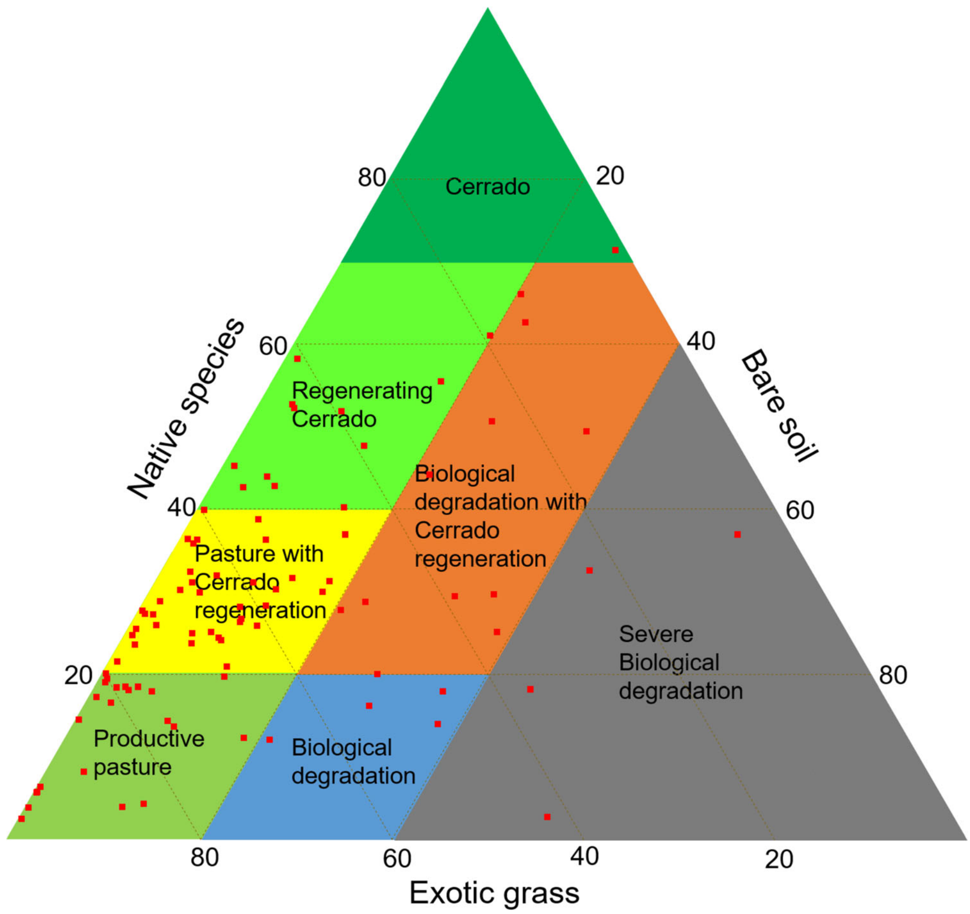

Fig. 2 Ternary plot with the axis exotic grass, bare soil, and native species as the main components of ground cover of pastures in the Cerrado. We did not include the weeds category in the scheme because it is not relevant in cultivated pastures in the Cerrado. With the proportions of those ground cover categories, seven types of pastures for the Cerrado are presented. Red dots are 93 samples of cultivated pastures in the Cerrado. They were positioned according to their ground cover (sampled with line-point intercept sampling; recalculating the proportions after removing “weeds”)

Usual denominations	Degraded pasture Degraded savanna	Productive pasture	Degraded pasture	Degraded pasture	Degraded pasture
Proposed sustainable intensification / restoration	Natural or semi-natural pastures	Silvopastoral systems	Savanna restoration Silvopastoral systems	Savanna restoration Pasture restoration + Silvopastoral systems	Savanna restoration Pasture restoration + Silvopastoral systems
Proposed denominations	Cerrado	Productive pasture	Pasture with Cerrado Regeneration + Regenerating Cerrado	Biological degradation with Cerrado regeneration	Biological degradation + Severe Biological degradation
Vegetation profile					

Fig. 3 A conceptual model of pasture types in the Cerrado biome and conservation options for improving ecosystem services of pastures. Above each vegetation profile are Proposed denominations, Proposed sustainable intensification options, and Usual denominations. Vertical black lines separate different classifications and denominations. Proposed sustainable intensification options do not include replacing pasture by agriculture. Silvopastoral systems can be established in a livestock agriculture integration scheme. Native shrubs and trees are in black, exotic pasture grasses are in red, and native grasses are in green

low pasture management (Oliveira et al. 2004). We separate the Biologically degraded pastures with regeneration (> 20% of native Cerrado species) and without regeneration (< 20% of native Cerrado species), since the savanna restoration, as an option of land use change, is cheaper in the first case.

MANAGEMENT OPTIONS FOR CERRADO´S PASTURES

The types of pastures we describe in this study are quite suitable in the definition of the Cerrado´s pasture vocation, a concept that involves both socio-economic and environmental aspects to reach truly sustainable intensification (Garnett et al. 2013) (Table 1). Besides conventional intensification involving improvement of exotic grass productivity, cultivated pastures with a vocation to agricultural intensification can be converted into silvopastoral systems by planting, managing, or allowing native trees and shrubs to regrow, increasing their ecosystem services (Cubbage et al. 2012; Röhrig et al. 2020). Such systems are mostly found in drier regions of the Cerrado, but they are often unrecognized by the agribusiness sector (Silva et al. 2021). Only in 2020 the Brazilian Agricultural Research Corporation (Embrapa) created a brand concept titled "Native Carbon" to certify the meat produced in pastures with native trees and where carbon has been mitigated through the conservation of existing or introduced trees (Mauro et al. 2020).

Natural or semi-natural pastures with tree thinning and productive grass seeding is still a reality for smallholders and traditional communities that are unable to enhance productivity and promote multiple uses of natural pastures for fruit and timber harvesting (Scariot 2013). We need to identify these ranchers and assist them to improve their livestock productivity and ecosystem services, mostly in terms of biodiversity conservation.

Table 1 Options for sustainable intensification of degraded pastures or resilient Cerrado

	Ecosystem services				
	Water conservation	Carbon stock	Independence of external input	Biodiversity conservation	Productivity
Usual sustainable intensification					
Intensification (crop-livestock integration)	High infiltration, crop rotation frequently exposes soil	High belowground carbon sstock	High fertilizer and defensives input	No biodiversity conservation	High for cattle and crop
Intensification (tree-crop-livestock integration)	Crop rotation frequently exposes soil; evapotranspiration increases with density of trees. Eucalyptus has high evapotranspiration potential	High belowground and aboveground carbon stock	High fertilizer and defensives input	No biodioversity conservation; although tree species are always *Eucalyptus* sp., it can be used native trees to increase biodiversity	High for cattle, crop and wood
Proposed (additional) sustainable intensification					
Silvopastoral system (planting trees or managing natural regeneration)	High infiltration, but evapotranspiration increases with tree density	High belowground and aboveground carbon stock	Low to high fertilizer input	High tree diversity conservation; low herbs and shrubs conservation; high landscape permeability for birds	High for cattle and low for wood/fruit
Semi-natural pastures (tree thinning and African grasses seeding)	High infiltration, but evapotranspiration increases with tree density	High belowground and aboveground carbon stock	Low fertilizer input	High tree, intermediary herbs and shrubs diversity conservation; high landscape permeability for many animal groups	Low for cattle and high for wood, fruit, and subsistence
Savanna restoration	High infiltration, but evapotranspiration increases with tree density	High belowground and aboveground carbon stock	Not external input	High tree, herbs and shrubs diversity conservation; high landscape permeability for many animal groups	No cattle[a], high for wood, fruit, and subsistence

[a]In savanna restoration, cattle can be inserted in the system, but after vegetation has been restored and under specific legislation and special management. Sources: Batlle-Bayer et al. (2010), Rada (2013), Hunke et al. (2015), and Luz et al. (2019)

Another possibility of the Cerrado's pasture management is the savanna restoration. This is an option to comply with the federal law of native vegetation protection (Rajão et al. 2020), global targets of restoration, and restoration of ecosystem services in sites where agriculture and pasture have no aptitude or lands are degraded (Ferreira et al. 2013; Nunes et al. 2017). Native vegetation restoration is expensive and time demanding. However, sites with high potential for natural regeneration have a vocation for savanna restoration.

ADHERENCE OF THE PROPOSED OPTIONS TO THE REALITY

The management options we recommend for the Cerrado's pastures are supported by the current federal legislation and financial incentives and might be well accepted by cattle ranchers. Rural properties in the Cerrado biome have to preserve 20% of their area with Legal Reserves (30% if the Cerrado area is in the Legal Amazonia). A Legal Reserve should ensure the economical use of the natural resources, assist in the conservation and restoration of ecological processes, and promote the conservation of biodiversity (Brasil 2012). It allows up to 50% of ground cover with exotic perennial species, and do not prohibit grazing, if it does not involve removal of native vegetation. Thus, Legal Reserves in the Cerrado can be ecologically and economically sustainable with natural and seminatural silvopastoral systems.

Legal reserves can also be restored for ecosystem services and native fruit harvesting (Scariot 2013). A large portion of Legal Reserves has been converted into agriculture and illegal deforestation is ongoing fast (Stefanes et al. 2018; Santos et al. 2021); thus, it is urgent to offer options for sustainable use of Legal Reserves in the Cerrado. Native vegetation restoration is also a major strategy of the Brazilian government to reach the nationally determined contributions to the United Nations Framework Convention on Climate Change (UNFCCC), under the Paris Agreement, The Brazilian commitment is to restore 12 Mha of forests by 2030, most of them as Legal Reserves (Bustamante 2019).

For silvopastoral systems, the main government incentive to reduce greenhouse gas emissions from agriculture is the Low-Carbon Agriculture Plan (Plano ABC in portuguese), that finances the adoption of integrated systems, mostly crop-livestock-forestry (Carauta et al. 2021). The plan is being revised for the 2020–2030 decade (Plano ABC + ; Brasil 2021) by incorporating agroforestry (silvopastoral systems included) with native species as a financeable and sustainable production system. The interview of ca. 150 ranchers in the whole Cerrado showed they do acknowledge the value of the trees in the pasture fields. Most of them know the name of the species and their biological functions and will keep and increase the number of trees if they have economic incentives and training (Bruziguessi et al. 2021; Silva et al. 2021).

In order to make the options of ecological intensification more convincing for the ranchers, we should invest in science and technology and in payment for ecosystem services. Technology transfer programs need to embrace native-tree-species-based silviculture, native-grass-based forage management and enhancement, and value chain of biodiversity friendly products. Ultimately, we need to plan the Cerrado´s land occupation for truly sustainable intensification.

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