doi: https://doi.org/10.36812/pag.202228115-35

REVIEW

Alternatives for the recovery and renewal of degraded pastures

Natan Teles Cruz[1]*, Daniel Lucas Santos Dias[2], Daniela Deitos Fries[3], Renata Rodrigues Jardim[4], Braulio Maia de Lana Sousa[5], Aureliano José Vieira Pires[6], Bárbara Louise Pacheco Ramos[1]

Abstract - This review aimed to approach the dynamics of pasture degradation, relating its causes and forms of recovery and/or renewal. Despite being based on extensive systems, Brazilian agriculture faces serious problems related to pasture degradation. The reduction in forage productivity directly affects the production system, having negative impacts on the economy and the ecosystem. Factors such as the choice of forage species, grazing management and the use of fire are the main factors responsible for the degradation of pastures in Brazil, causing an environmental and productive imbalance. However, it is possible to stop the progress of degradation and resume system productivity using pre-defined techniques in accordance with the objective of the production system. Furthermore, pasture recovery techniques are efficient for the resumption of productivity, and environmental protection, by helping to reduce greenhouse gases. Nevertheless, more research is needed to prove and consolidate pasture recovery techniques in the environmental, economic, and social scope.

Keywords: Degradation. Greenhouse Gases. Integrated Systems. Tropical Forage.

Alternativas para recuperação e renovação de pastagens degradadas

Resumo - Objetivou-se com essa revisão abordar sobre a dinâmica de degradação de pastagens, os fatores que ocasionam essa degradação, bem como as formas de recuperação e renovação de áreas degradadas e seus efeitos na agropecuária. Apesar de ser baseada em sistemas extensivos, a agropecuária brasileira enfrenta sérios problemas relacionados à degradação de pastagens, pois a redução da produtividade forrageira afeta diretamente o sistema produtivo causando impactos negativos na economia e no ecossistema. Fatores como escolha da espécie forrageira, manejo do pastejo e utilização de fogo são os principais responsáveis pela degradação de pastagens no Brasil, causando desequilíbrio ambiental e produtivo. No entanto, é possível barrar o avanço da degradação e retomar a produtividade dos sistemas utilizando técnicas pré-definidas de acordo com o objetivo do sistema produtivo. Ademais, as técnicas de recuperação de pastagens mostram-se eficientes para a retomada de produtividade e proteção ambiental, através do auxílio na redução de gases de efeito estufa. No entanto, são necessárias mais pesquisas que comprovem e consolidem as técnicas de recuperação de pastagens no âmbito ambiental, econômico e social.

Palavras-chave: Degradação. Forragem Tropical. Gases de Efeito Estufa. Sistemas Integrados.

[1] Universidade Estadual do Sudoeste da Bahia (UESB), Brazil. *Correspondence author. E-mail: teles.nc@gmail.com
[2] Departamento de Ciências Biológicas, Universidade Estadual de Feira de Santana (UEFS), Brazil.
[3] Departamento de Ciências Exatas e Naturais, Universidade Estadual do Sudoeste da Bahia (UESB), Brazil.
[4] Universidade Estadual do Sudoeste da Bahia (UESB), Brazil.
[5] Departamento de Zootecnia, Universidade Federal de Sergipe (UFS), Brazil.
[6] Departamento de Tecnologia Rural e Animal, Universidade Estadual do Sudoeste da Bahia (UESB), Brazil.

ISSN: 0104-907. ISSN ONLINE: 2595-7686.
Received in 31 Aug. 2021. Accepted in 1 Dec. 2021.

Introduction

The territorial extension of Brazil offers conditions to meet the productive demand for products of animal origin in grazing systems. However, the extensive system of animal husbandry has some limitations, such as the formation of pastures through monocultures, problems of forage seasonality (especially in times of low water availability), and lack of strategic management seeking to balance the pasture ecosystem (soil-plant-animal-product) (SILVA; SBRISSIA; PEREIRA, 2015).

The lack of proper management in the production system helps in pasture degradation process, resulting in low economic efficiency of the activity and increased negative impacts on the environment (BORGHI *et al* ., 2018). According to Macedo and Araújo (2019), traditional agricultural production systems, with excessive soil preparation and no crop rotation, affect the physical and chemical quality of the soil, which can lead to infestations of pests, diseases and spontaneous plants.

According to data from LAPIG (2018), Brazil has about 170 million hectares (about 20% of the country's territory) destined for pasture areas, of which it is estimated that approximately 60% are in some processes of degradation. In this sense, when there is some level of degradation, it is possible to observe a reduction in forage productivity, which can achieve greater reductions in productivity if there is no interruption in this process.

The pasture degradation process is observed in the long term, where the system does not have the capacity to fully recover due to the depletion of nutrients and organic matter present in the soil. According to Andrade *et al.* (2016), the consequences of the lack of proper management, causing the degradation of pastures, directly affects the economy of the livestock chain, in addition to contributing to the increase in the emission of greenhouse gases. Finally, the condition of degraded pastures is the factor that most hinders the advancement of agricultural activities dependent on forage plants, directly affecting the sustainability of the production system (BORGHI *et al.,* 2018).

The occurrence of degradation of pastures is the main bottleneck that compromises the sustainability of animal production, and it is necessary to find a balance between food production and with minimal impact on the agroecosystem (MACEDO; ARAÚJO, 2019). In this sense, it is possible to recover or renew a degraded pasture, however, Dias-Filho (2015) states that the strategy for recovering or renewing a pasture depends on the stage of development of the degradation, since the more advanced, the greater the investments necessary. Thus, the management of the ecosystem present in the forage system is of fundamental importance for the persistence of pasture and the prevention of degradation processes in the forage canopy and the soil.

The techniques for recovering and renovating degraded pastures aim at making better use of the area, through chemical, physical and biological soil recovery. Thus, these techniques can increase the feasibility of livestock activities, by increasing the support capacity of the pasture area, in addition to preventing new deforestation, preserving fauna and flora (CARVALHO *et al.*, 2017). Additionally, degraded pasture recovery techniques can reduce greenhouse gases, contributing to the mitigation of the emission of these gases by agricultural activities, making the activity economically and environmentally sustainable.

According to Gosch *et al.* (2020), technologies for recovering or renovating degraded pastures can enable environmentally adequate production systems, with productive efficiency, economically viable and socially fair. Thus, the national animal production will be able to expand even more with the capacity to meet the demands of a globalized market, where quantity, quality and origin of the product are recommended.

Thus, the objective of this review was to address the dynamics of pasture degradation, the factors that cause the degradation of pastures, as well as the forms of recovery and renovation of degraded areas and their effects on agriculture.

Development

Pasture degradation

The Brazilian livestock activity is conducted, mainly, in extensive systems, which depend on the area of pasture formed for grazing. As the forage plant is the main food source for the animals, it is necessary that the forage canopy is in adequate conditions for grazing. In this sense, pasture degradation acts as a negative factor for the livestock production system, as it reduces forage plant productivity, affecting animal performance (CÂNDIDO *et al.*, 2018).

According to Macedo and Araújo (2019), the pasture degradation process is defined as: “an evolutionary process of loss of vigor, productivity, and regenerative capacity naturally capable of sustaining production levels and food quality (in this case, forage plants) required by animals, in addition, it reduces the plant's resistance to pests and spontaneous plants, resulting in an advanced degradation of pasture and soil in adequate management”. A representative scheme of pasture degradation is shown in figure 1.

In light degradations, there is the possibility of containing the drop in forage production and maintaining the productivity of the forage plant with actions that demand lower operating costs. However, the greater the level of degradation of the area, it is necessary to carry out actions that demand higher operational costs and specific techniques so that there is containment in the advance of the degraded area (ZIMMER *et al*., 2012). Despite being presented in a rational sequence, the processes are not so simple and may not occur in that order, resulting in different sequences and degrees depending on the ecosystem in which the production system is inserted (MACEDO; ARAÚJO, 2019). Thus, research that seeks to understand the boundary between the maintenance phase and pasture degradation processes is encouraged, so that management strategies suitable for the specific pasture ecosystem can be developed.

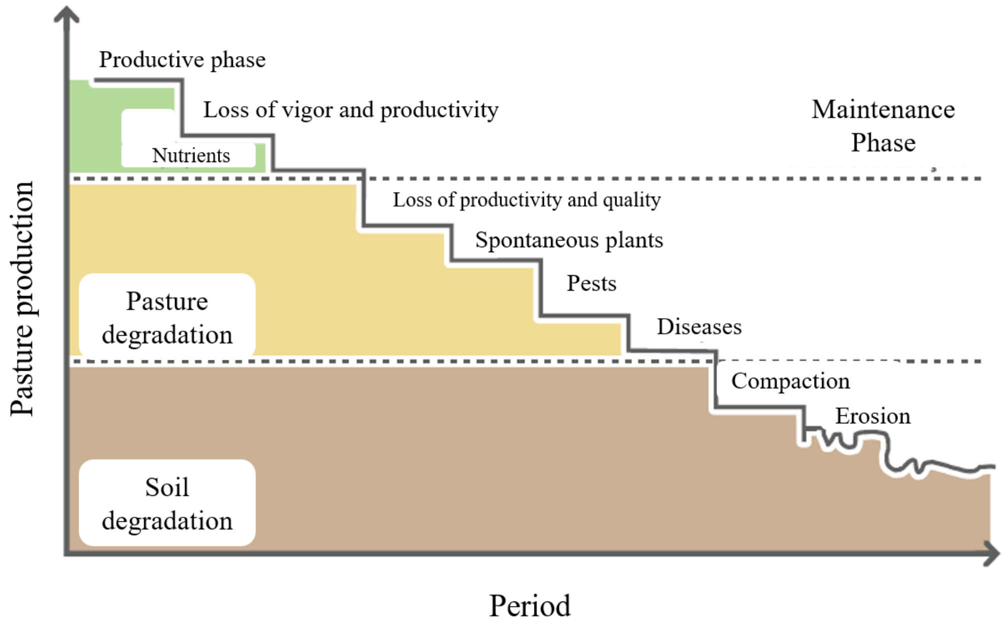

Figure 1. Simplified representation of the pasture degradation process over time. At the top, during the production phase, the highest forage productivity values are located. However, as the steps decrease, the pasture degradation process advances. Source: Adapted from Zimmer *et al*., (2012); Macedo and Araújo (2019).

The main causes of pasture degradation

Pasture degradation processes are the result of imbalance in the soil-plant-animal ecosystem caused by several factors involved in the management strategy of the forage canopy. According to Carvalho *et al.* (2017), inadequate management of pastures, from the choice of forage species to the management of the forage canopy, associated with the lack of pasture maintenance, are the main factors influencing pasture degradation.

Furthermore, practices such as the use of fire as a way to recover pasture can further damage the ecosystem and accelerate the process of pasture degradation. Additionally, factors such as unwanted grass infestation and soil compaction are considered to cause pasture degradation, however, these factors are consequences of unsustainable forage canopy management practices, resulting in degradation. According to Dias-Filho (2015), the understanding of pasture degradation processes is of fundamental importance to contain the advance of damage and restore forage productivity. However, signs of the degradation process are not always visible, making it difficult to identify the first cause of degradation as it triggers a chain

ISSN: 0104-907. ISSN ONLINE: 2595-7686.
Received in 31 Aug. 2021. Accepted in 1 Dec. 2021.

reaction. In this sense, Andrade *et al.* (2016) suggest that the use of geotechnologies is an important strategy and a great ally for decision-making in the production system.

Factors such as forage species choice, grazing management through stocking rate control, associated with maintenance fertilization are essential and indispensable to avoid pasture degradation process (ZIMMER *et al*., 2012).

Formation of forage canopy

Forage plants have different adaptations to the ecosystem (climate, soil, animal, solar radiation, water availability) in which they are inserted. In this sense, the choice of forage species must consider the desired productivity, as well as the conditions of adaptation of the plant to climate and soil (ZIMMER *et al*., 2012).

The soil correction through liming and fertilization must be considered in the pasture formation process, as the soil can present characteristics that impede the development of the cultivated plant (SANTOS *et al.*, 2016a). In this perspective, fertilization and fertilization practices should be based on soil analysis and the requirement of the species that will be implemented since the inadequate use of the soil provides an increase in the degradation of its physical, chemical and biological properties. The adoption of correction and fertilization techniques is essential to maximize the forage production and strengthen its persistence in the system and consequently prevent damage to the soil (CARVALHO *et al.*, 2017).

The decrease in soil fertility restricts the development of the forage plant, negatively affecting its productive potential. Thus, it is interesting that soil analysis is performed regularly to get an idea of how the physicochemical composition of the soil behaves since liming and fertilization promote an increase in tillering and consequently in the dry mass of forage plants (SANTOS *et al*., 2016a). In this sense, when managed respecting their physiological limits, forage canopies can have a great capacity for persistence and quality dry mass productivity for grazing animals.

Grazing management

The management of forage canopies, currently, finds a productive balance between quality dry mass and animal productivity (SILVA; SBRISSIA and PEREIRA, 2015). In this way, it is possible to avoid under and overgrazing conditions, which can cause damage to the pasture causing its degradation. Undergrazing, although less frequent, can be considered a cause of pasture degradation, especially in regions with high rainfall (BORGHI *et al.*, 2018). This happens because, although there is a greater amount of mass under the soil, there is a limitation in the production of new tillers, causing senescence in the forage canopy, contributing to the appearance of spontaneous native plants.

ISSN: 0104-907. ISSN ONLINE: 2595-7686.
Received in 31 Aug. 2021. Accepted in 1 Dec. 2021.

According to Carvalho *et al.* (2017), overgrazing is when the intensity of grazing by animals is greater than that supported by the forage plant. In this sense, high grazing intensities, despite greater tiller renewal, promote a reduction in tillering and increase in tiller death, having negative impacts during forage plant regrowth (SILVA; SBRISSIA and PEREIRA, 2015). In the condition of overgrazing, the plants are at greater risk of reducing their persistence and regrowth vigor, providing conditions to start the pasture degradation process. Thus, the correct management of pastures can be considered as a low-cost technology, but extremely important for the sustainability of pasture animal production and to avoid pasture degradation processes.

The most notable feature of the pasture degradation process is its reduction in support capacity and forage supply (MACEDO; ARAÚJO, 2019). However, according to Zimmer *et al.* (2012), the observation of the drop in carrying capacity has not been sufficient for adopting maintenance techniques and prevention of pasture degradation. The authors also suggest that if no measures are taken in the initial stage of degradation, forage quantity and quality will decrease and the effects will be noticeable on animal performance, causing damage to the production system (Figure 2).

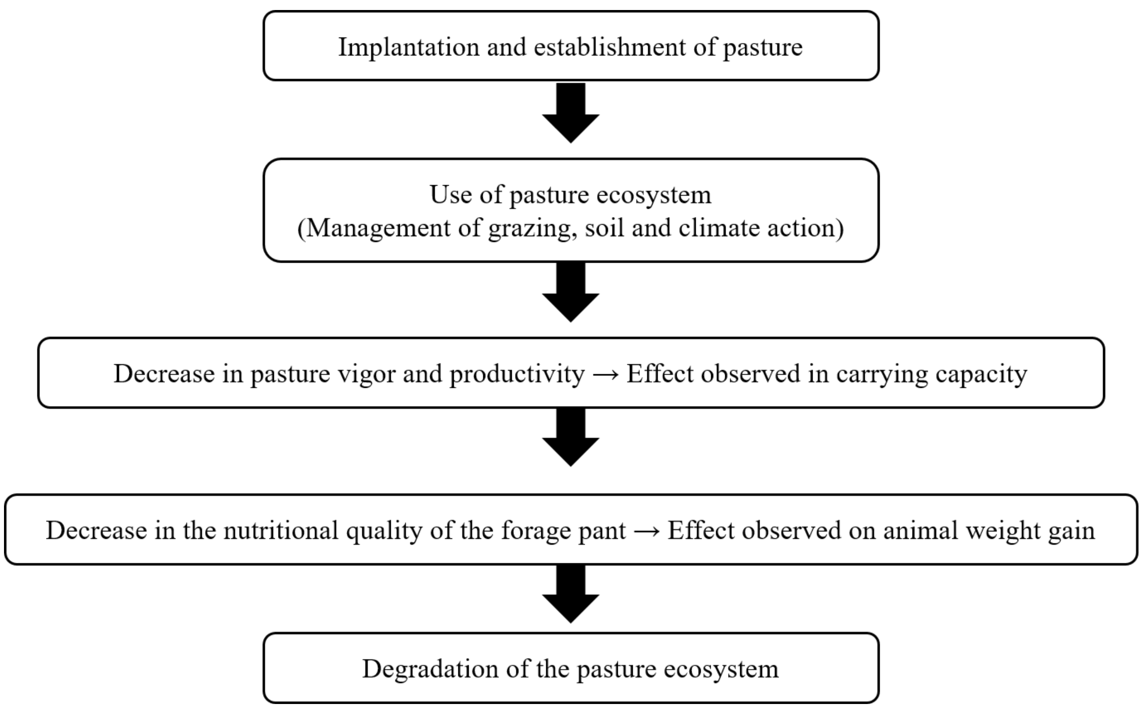

Figure 2. An illustration of the initial stages of pasture degradation, where following the stages allows the degradation process to be interrupted before it becomes more serious. Source: Adapted from Macedo (2001).

ISSN: 0104-907. ISSN ONLINE: 2595-7686.
Received in 31 Aug. 2021. Accepted in 1 Dec. 2021.

Use of fire

The use of fire in pasture areas is still widely used as a way to recover degraded pastures, however, this practice that can cause imbalances and large fires in environmental preservation areas. In this sense, it is common to observe biomes such as Caatinga and Amazon Forest with large fires, especially in the dry period, which was initiated by burning pasture areas. Thus, the use of fire in pasture areas can trigger environmental imbalance and favor the process of degradation of the ecosystem, including pastures (CARVALHO *et al.* 2017).

According to Borghi *et al.* (2018), the use of burning in pasture areas is made to try recovering the regrowth potential of the forage plant and try to control unwanted plants in the area being used. However, according to the authors, frequent fires can deplete the organic reserves of forage plants, compromising their regrowth vigor. Additionally, high temperatures associated with fire intensity can decrease soil microorganisms, in addition to the loss of nutrients from plant biomass through volatilization (CARVALHO *et al*., 2017). Thus, instead of controlling unwanted plants and increasing the regrowth potential of the forage plant, the use of fire can have effects contrary to that intended and cause even more degradation of pastures.

Considering this, Marinho and Miranda (2013) evaluated the effect of using fire to control *Andropogon gayanus* in an area of Cerrado and reported that this technique did not consume the entire structure of the plant, leaving about 20 cm residual of this forage plant. The authors reported a reduction in the seed bank of *A. gayanus* in the soil after burning, however, the remaining seeds of this species have the potential to germinate during the rainy season, being able to establish again in the area that would be controlled with the use of fire. Furthermore, this situation associated with the recovery of residue (approximately 20 cm) remaining after burning suggests that the *Andropogon* seed bank can be replaced in the next reproductive season, indicating that the use of fire is inadequate to control this forage species.

In another study, Simon *et al.* (2016) evaluated the effect of burning on chemical attributes of a soil in the Brazilian Cerrado and reported, in general, that there was no difference in the contents of K, Al, Ca, Mg, and organic matter in the soil. Therefore, the use of fire did not bring benefits to the soil in this area, and other recovery techniques could be used. Furthermore, the deeper layers of the soil were influenced by fires, with a reduction in the chemical composition of the soil, which could affect root development and negatively affect the recovery power of the desired forage plant.

Pasture recovery and renewal techniques

The pasture degradation process can be avoided with the use of technologies that are capable of achieving the necessary productive objective in balance with the ecosystem. However, when there is any

ISSN: 0104-907. ISSN ONLINE: 2595-7686.
Received in 31 Aug. 2021. Accepted in 1 Dec. 2021.

indication of forage degradation, it will be necessary to use techniques for recovery or renewal of pastures, directly or indirectly (Figure 3).

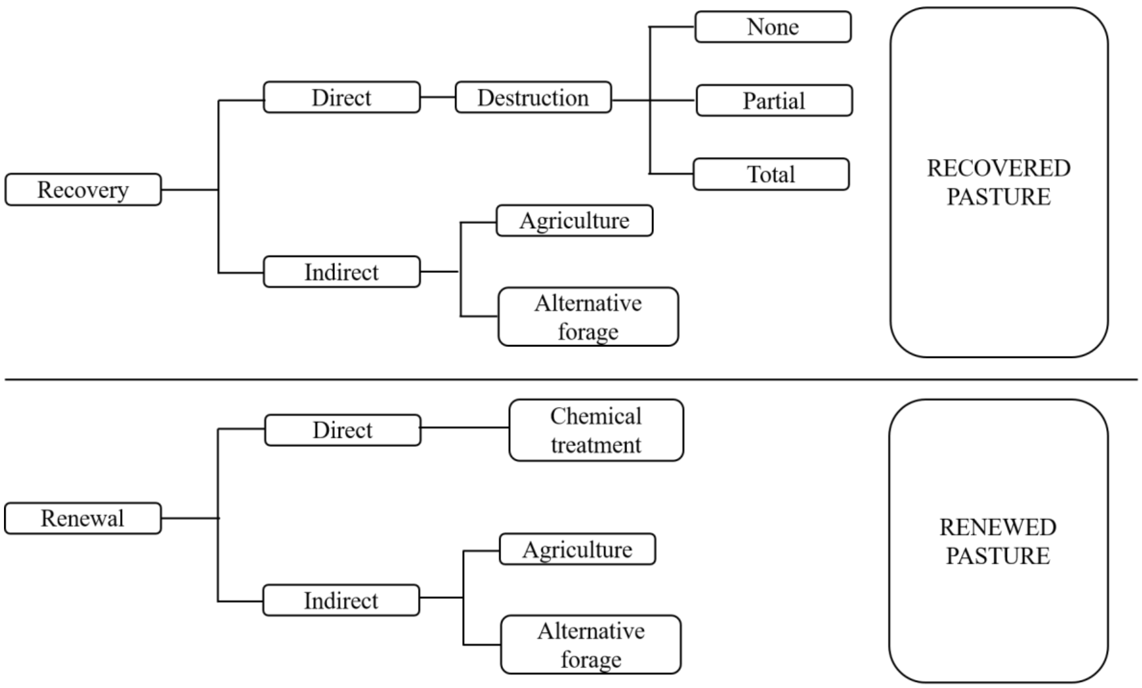

Figure 3. Pasture recovery and renewal alternatives. While *recovery* is defined as the reestablishment of forage productivity, keeping the same species or cultivar present in the area, *renewal* is defined as the reestablishment of forage productivity with the introduction of a new species. These techniques can be direct or indirect. Direct techniques are mainly used when there is a slight degree of pasture degradation and consist of the use of mechanical and chemical practices under the forage canopy. Alternatively, indirect practices are used when there is a high degree of pasture degradation and consist of intercropping pastures with other cultures, with the objective of making economically viable the restoration of forage productivity. Source: Adapted from Macedo (2001); Carvalho *et al.* (2017).

Management techniques to recover or renew a pasture are well defined by Macedo and Araújo (2019) and are listed below:

Direct recovery: These are mechanical and/or chemical practices applied in the pasture area with the objective of recovering forage productivity *without replacing* the existing species. Fertilization and liming are used in pastures that present early stages of degradation. While plowing, harrowing, subsoiling, scarification, among other mechanical methods, they are used when there is a high degree of degradation, since the greater the level of degradation, the greater the need for mechanical action in the degraded area. Thus, the choice of methods will depend on the stage of pasture degradation.

ISSN: 0104-907. ISSN ONLINE: 2595-7686.
Received in 31 Aug. 2021. Accepted in 1 Dec. 2021.

In this sense, Santini *et al.* (2015) evaluated strategies for the recovery of Basilisk grass pastures (*Urochloa decumbens syn. Brachiaria decumbens* cv. Basilisk) in an advanced stage of degradation and reported that fertilization + liming strategy was not sufficient to recover the degraded pasture in a single application. Furthermore, the authors report that overseeding with Marandu grass (*Urochloa brizantha syn. Brachiaria brizantha* cv. Marandu) associated with fertilization was more efficient in producing dry mass and recovering pasture degraded with Basilisk grass.

Fogel *et al.* (2013) suggest that organic fertilization with swine manure or poultry litter can be used to recover degraded pastures. The authors found satisfactory results in the potential of organic fertilization in the recovery of pastures, however, they suggest that research be carried out to elucidate its long-term effects.

Direct renewal: These are agronomic techniques applied on degraded pastures to *replace* the current species, and reverse the degradation with the implantation of another forage species. It is characterized by the attempt to replace degraded forage without the use of an intermediate crop. It presents some practical and economic limitations, as forage species, even in some stage of degradation, have a high seed bank in the soil. Thus, it is used doses of herbicide that, if applied incorrectly, can cause serious environmental damage.

Indirect recovery and renovation: Indirect recovery comprises practices carried out through mechanical and chemical inputs, using a different culture to *recover* the existing forage. For the renewal indirectly, the practices are similar, but aiming to *replace the present species* with another one with different characteristics. Grain crops or annual pastures with minimal cultivation are used, aiming to take advantage of the residual fertilization required by the annual crop to recover or renew the forage species.

Agroforestry systems in pasture recovery

The use of integrated systems is indicated as a strategy for recovering degraded areas. In this sense, the use of these systems allows to improve the components of the pasture ecosystem, integrate culture and animals, diversify agricultural production and help in the maintenance and improvement of the physical and chemical properties of the soil, avoiding or recovering the degradation process (GONÇALO FILHO *et al.*, 2018).

Additionally, the adoption of agroforestry systems has the capacity to assist in the recovery of degraded biomes, stimulating the growth of native species present in the system (SANTOS *et al.*, 2016b). Additionally, Macedo and Araújo (2019) suggest that the integration crop-livestock and crop-livestock-forest are alternatives that fall under both recovery and indirect renewal. However, it is necessary to respect the limits of pasture degradation stages to use these techniques at the right time.

Dias-Filho (2015) reports that agroforestry systems can be made using the livestock farming integration, called the agropastoral system, or the livestock farming/forest integration, the silvopastoral system. Additionally, the author also suggests that for adopting of these systems, it is necessary that the soil of the system is favorable for the production of grain, that there is the necessary infrastructure for the production and storage of grain, as well as the logistics of harvesting, storage and use or sale of the harvest.

Crop-livestock integration

Very in the intercropping of grasses and annual crops there is a balance in the productivity between them, that is, it is necessary that the species are compatible and not establish themselves, causing an intraspecific competition that causes productive losses. In this sense, it is necessary to consider the habit and growth cycle of the forage crop, its architecture in the canopy, as well as the adequate sowing density and timing of system implementation (SANTINI *et al.*, 2015).

Carvalho *et al.* (2017) define livestock crop integration as annual crop rotation systems or in intercropping with forages. In integrated crop-livestock (ILP) systems, the introduction of crops is an integral part of a system of production of grains and animal products, which interact and complement each other biologically and economically by allowing the efficient use of inputs, and diversification of the productivity of food of plant and animal origin (MACEDO; ARAÚJO, 2019). Thus, integration systems have the capacity to recover degraded areas by resuming or increasing the system's production.

In this sense, Silva *et al.* (2018a) evaluated the recovery potential of a degraded pasture composed of Marandu grass, through intercropping with corn. The authors reported that the intercropping with grain crops benefited the recovery of Marandu grass pasture. Furthermore, the intercropping between these species did not harm corn productivity, being a viable alternative for pasture recovery and maintenance of forage productivity.

The integration of livestock farming also alters the physical and chemical characteristics of the soil. Carvalho *et al.*(2016) evaluated 3 integrated systems: an area without grazing, with crop rotation; an area with grazing, crop rotation and adjusted stocking rates; and an area of native grassland with grazing and adjusted stocking rates. The authors reported that integrated systems improve the physical and chemical quality of soil or maintain it at a level similar to that of soil with native vegetation helping to avoid the degradation process. Furthermore, Salton *et al.* (2011) reported that the ILP favors the accumulation of carbon (C) in the superficial layers of the soil, due to the accumulation of residue used on this layer during no-till of the annual crop, helping to improve the physical qualities of the soil.

Silvipastoral system

The inclusion of trees in the agricultural production system is interesting from a productive and ecological viewpoint. In this sense, the silvopastoral system can provide a favorable microclimate for developing of forage plants, in addition to improving the structural qualities of the soil and forage plant (SANT-ANNA *et al.*, 2017). However, the spacing of tree planting must be done so that there is no reduction in the availability of solar radiation, affect the production of the intercropped forage.

The implantation of the silvopastoral system has some limitations, such as the presence of the animal in grazing during the implantation of the seedlings, which can harm their initial development and survival. In this context, Dias-Filho (2015) suggest that the implementation of the silvopastoral system should be carried out when a renovation or total renovation of the pasture is planned. Thus, the implantation of annual agricultural crops, between the first and third year of system implantation (planting of tree seedlings), has conditions to provide more time for the trees to develop, before the implantation of pasture and grazing by the animal. In this sense, Santos *et al.* (2016b) evaluated Piatã grass (*Urochloa brizantha syn. Brachiaria brizantha* cv. Piatã) cultivated with eucalyptus under 2 densities: 417 and 715 eucalyptus trees per hectare. The authors reported that the higher density of trees impaired the development of Piatã grass, suggesting that the minimum spacing between rows of eucalyptus trees is 22 meters, when intercropped with this forage grass.

Grass x legume integration in the recovery of degraded pastures

Forage legumes have the capacity for symbiotic nitrogen fixation in the soil, in addition to higher nutritional value than most forage grasses, thus being able to be an ally in agricultural systems. The use of intercropping between grasses and forage legumes has been used for livestock production on pasture, and is a sustainable alternative for livestock production (FARIA *et al*., 2015). Additionally, the introduction of legumes into the system aims to alleviate or solve the problems of low nitrogen availability in the soil, in addition to increasing the crude protein content of the animal's diet (OLIVEIRA *et al*., 2017). Furthermore, the presence of legumes in the agricultural system is an effective technique for recovering degraded pastures, however there is a need to intensify research with different cultures to ensure the sustainability of this system (TERRA *et al*., 2019).

The introduction of legumes into the system, as an alternative for pasture recovery, is directly related to the replacement of nutrients and organic matter in the soil. In this sense, Zimmer *et al.* (2012) report that legumes of the *Stylosanthes* genus are the main forages used in intercropping with grasses because of their adaptation to soils with low fertility, and high capacity for association with rhizobia. Thus, Fabrice *et al.* (2015) described that the introduction of *Stylosanthes* cv. Campo Grande was essential to recover a degraded pasture composed of Basilisk grass, in the municipality of

Andradina/SP. Furthermore, the use of Campo Grande styling agents in no-tillage contributes to increase the total nitrogen present in the roots of degraded pastures, enabling the regrowth of the pasture and closing the forage canopy (Fabrice *et al*., 2014).

Even despite the work conduced with legumes of the *Stylosanthes* genus, the choice of the forage legume species depends on its adaptation to the ecosystem in which it will be inserted and its objective in the production system. Additionally, it is necessary to understand how forage plants will behave in a consortium so that there is no competition, but complementarity, ensuring the system's productivity.

Souza *et al*. (2016) evaluated the introduction of *Stylosanthes* cv. Campo Grande or *Calopogonium muconoides* associated with the 3 fertilization strategies (liming + phosphate; liming; without correction and fertilization) in the recovery of Marandu grass pastures (*Urochloa brizantha syn. Brachiaria brizantha* cv. Marandu). The authors concluded that the inclusion of both legumes associated with liming and phosphating are efficient alternatives for recovering tropical pastures. Thus, through the intercropping between grasses and legumes, it is possible to increase agricultural productivity through the reestablishment of dry mass production in the forage canopy.

Animal performance and economic viability of recovered/renewed pastures

One of the first signs of pasture degradation is the reduction in its support capacity, that is, a decrease in the supply of food for the animals, causing overgrazing, which will negatively affect the system's productivity. In this sense, the restoration of forage productivity with the availability of quality forage can provide better animal performance (SILVA; SBRISSIA; PEREIRA, 2015).

The pasture degradation process directly affects the sustainability of the system, as in addition to causing environmental damage, it may cause economic damage since the productivity of the activity is affected by degradation. Thus, the interruption of the pasture degradation process is beneficial not only from an environmental viewpoint but also from an economic perspective.

In this sense, Silva *et al.* (2018b) evaluated the performance of steers on restored or renewed Marandu grass pastures. The authors concluded that, given the degradation of the pasture, application of limestone and fertilization with nitrogen, phosphorus and potassium were sufficient to contain the degradation and resume the dry matter productivity of Marandu grass, increasing the support capacity of the forage canopy. Additionally, with the application of this technique there was an increase in the support capacity of pastures and, consequently, greater weight gain by animals, thus restoring the income-generating activity of the system, increasing its economic efficiency.

Martins *et al.* (2020) evaluated the performance of heifers in Piatã grass pastures in two integrated systems after five years of implementation: Integrated crop-livestock-forest, with 227 eucalyptus trees per hectare, and the integrated crop-livestock, with five native trees per hectare. The authors reported greater accumulation of dry mass of Piatã grass when managed with five native trees per hectare, that is, in the crop-livestock system. However, there was no difference in stocking rate, average daily gain and weight gain per area, between the two managements. This fact was related to the higher nutritional value associated with the forage canopy managed in the crop-livestock-forest system, which, even with lower mass accumulation, presented animal performance similar to the crop-livestock system.

Thus, in view of these results, it is possible to suggest that the integrated crop-livestock-forest intensifies the system's productivity and becomes a source of extra income through the sale of wood. In this way, it is possible to amortize the investment costs for pasture recovery since the initial costs for the implementation of these systems are higher compared to monoculture systems (ZIMMER *et al*., 2012).
Faria *et al*. (2015) economically evaluated 3 systems for the recovery and maintenance of pastures of MG-5 grass (*Urochloa brizantha syn. Brachiaria brizantha* cv. MG-5) in the dairy farming activity in the municipality of Bambuí/MG, Brazil: Integrated crop-livestock-forest (eucalyptus + corn + MG-5 grass); integrated crop-livestock (corn + MG-5 grass); MG-5 grass in rotational grazing with pre and post grazing height of 25 and 15 cm, respectively. After 2 years of evaluation, the authors estimated the economic situation of the systems, following some pre-established market and management criteria. Thus, the authors concluded that among the systems evaluated, only the integrated crop-livestock-forest was economically viable after 12 years of activity. This was attributed to the revenue generated from sales of wood products, which corresponded to 39.02% of total revenue.

However, the economic viability of an agricultural activity depends on several factors, and it is necessary to consider the time of the year and input prices before preparing forage management planning. Additionally, the market survey of the region is extremely important for the sustainability of the production system, having environmental, social and economic balance. Finally, although interspecific consortium techniques seem promising from an economic and environmental viewpoint, it is encouraged that their economic and productive efficiencies are widely studied so that they can be applied sustainably.

Hohnwald, Kato and Walentowski (2019) suggest an innovative technique for cheapening pasture recovery. The authors evaluated the introduction of swine into degraded pastures in northern Amazonia and concluded that soil disturbance by the animals, due to their natural behavior, contributed to the control of weeds and recovery of degraded pastures. An efficient alternative from an economic perspective because at the same time that swine help with turning the soil, they can gain weight and can contribute to the productivity of animal protein in the production system. However, research with this type of management must be encouraged so that the viability of the systems when adopting it can be proven.

Reduction in the emission of greenhouse gases (GHG) with the recovery of pastures

Greenhouse gases are present in our planet's atmosphere and are capable of blocking infrared radiation that the Earth radiates by receiving solar energy, increasing in Earth's temperature. In this sense, through human activities the level of concentration of these gases, specifically carbon dioxide (CO_2), methane gas (CH_4) and nitrogen dioxide (NO_2) have been increasing in the Earth's atmosphere (ASSAD *et al*., 2019). In this context, the Brazilian agricultural activity is the one that contributes the most to GHG emissions in the country, however, conservation practices in this sector are being adopted and can reduce the emission of these gases (SILVA *et al.*, 2020).

According to Assad *et al.* (2019), strategies such as avoiding deforestation and burning, adequate soil management and maximizing carbon sequestration are essential to reduce the emission of greenhouse gases. In this segment, carbon sequestration is done mainly through the photosynthesis, where plants fix atmospheric carbon and transform them into organic compounds necessary for the plant's survival (SILVA; SBRISSIA and PEREIRA, 2015). Thus, the well-formed forage canopy has a high capacity for carbon fixation caused by greater root development of the forage plant, providing greater carbon sequestration in the system (FERREIRA *et al*., 2018).

Dechen *et al.* (2015) evaluated the effect of 4 vegetative cover rates on the properties of an Oxisol: 0, 24, 40, and 90% of vegetation cover. The authors concluded that land cover with 90% reduced water, land and organic matter losses by approximately 52, 54, and 55%, respectively. In this sense, in the long term, vegetation cover can increase soil carbon levels, due to increased root mass, as well as shoot dry matter deposition (BESEN *et al*., 2018).

The integrated systems used to recover degraded pastures are also efficient in mitigating the emission of greenhouse gases. No-till systems are an alternative for providing physical protection to the soil, preventing the process of degradation and reducing CO_2 emissions, through the carbon stock in the soil (BRIEDIS *et al.*, 2018; FERREIRA *et al*., 2018). In short, systems of integrated crop-livestock-forest and crop-livestock also act as litigators of the emission of greenhouse gases, by increasing the capacity for carbon sequestration through the increase of soil organic matter (SANT-ANNA *et al*., 2017; PONTES *et al.,* 2018).

Thus, these systems have a large capacity for storing carbon in the soil, helping to reduce the emission of harmful gases into the atmosphere. In this sense, systems integrated with adequate soil preparation change from being a source of CO_2 to being a drain, as they assimilate carbon into the soil (FERREIRA *et al*., 2018). Additionally, integrated crop-livestock-forest systems are effective in reducing NO_2 emissions, serving as an alternative for reducing this gas, helping to reduce the impacts of agricultural systems on the environment (NOGUEIRA *et al*., 2016).

Through the replacement of nutrients in the soil, through fertilization, it is possible to achieve

PESQ. AGROP. GAÚCHA, V.28, N.1, P. 15-35, 2022.
ISSN: 0104-907. ISSN ONLINE: 2595-7686.
Received in 31 Aug. 2021. Accepted in 1 Dec. 2021.

greater production of dry mass of forage plants. In this sense, according to Nogueira *et al.* (2015) nitrogen fertilization is a practice used to increase the productivity of forage plants, however, it is necessary to follow proper fertilizer management practices to achieve a reduction in nitrogen losses in the form of NO_2. Thus, according to the authors, correct soil management and application of fertilizers in adequate amounts contribute to the reduction of nitrogen dioxide per kilogram of animal live weight.

In addition, the release of NO_2 it can be alleviated by including legumes in the system. The adoption of this technique can significantly reduce NO_2 emission, by reducing the need for nitrogen fertilization (NOGUEIRA *et al.*, 2016), in addition to providing better animal performance, reducing methane emission by ruminants (OLIVEIRA *et al*., 2017).

The production of methane gas in the soil is due to the anaerobic decomposition of organic matter associated with the methanogenesis process. Vasconcelos *et al.* (2018) suggest that the deposition of sugarcane straw in the soil, without turning over, contributes to the absorption of methane gas, in addition to preserving the soil cover, preventing the degradation process. Thus, it is possible to see that the fluxes and greenhouse gases in the system depend on variables present in the ecosystem, such as radiation, temperature, presence of animals, physical and chemical characteristics of the soil and type of management adopted.

In general, soil conservation practices, combined with techniques for recovering degraded pastures, are efficient in reducing greenhouse gases, resulting in the mitigation of the emission of these gases by agricultural activities. However, research involving the processes of emissions of greenhouse gases must be deepened, including the variables involved in the productive ecosystem so that it is possible to determine the real mitigation of these gases, associated with the sustainability of the system.

Conclusion

The pasture degradation process can stimulate the opening of new agricultural production areas, increasing in the deforestation of native areas. However, it is possible to restore system productivity through techniques to prevent further degradation, without the need to open up new areas.

The main causes of pasture degradation are related to the lack of adequate management of the pasture ecosystem. Generally, one of the main signs of pasture degradation is the decrease in carrying capacity, with the decrease in dry matter available to the animal. Thus, the pasture degradation process directly interferes in the economic viability of the system, requiring the use of recovery techniques or renovation of degraded areas.

The techniques of recovery and/or renewal of pastures that make it possible to prevent the advance of degradation and resumption of agricultural productivity. The use of each technique will depend on the degree of degradation, as well as the expected objective with the recovery of the system's productivity. Furthermore, it is worth mentioning that after the recovery of the degraded area it is necessary to maintain the implemented system so that there are no new degradation processes.

Pasture recovery techniques are viable in the resumption of production in agricultural systems and their use should be encouraged with the objective of maximizing the chain of animal products sustainably. However, there is a need for more research to consolidate the effects of the recovery of degraded areas on its sustainability, productivity, economy and social function of the recovered system.

Conflict of interest

The authors declare that the research was conducted in the absence of any potential conflicts of interest.

Ethical statements

The authors confirm that the ethical guidelines adopted by the journal were followed by this work, and all authors agree with the submission, content and transfer of the publication rights of the article to the journal. They also declare that the work has not been previously published nor is it being considered for publication in another journal.

The authors assume full responsibility for the originality of the article and may incur on them, any charges arising from claims, by third parties, in relation to the authorship of the article.

Open Access

ORCID

Natan Teles Cruz: https://orcid.org/0000-0001-8164-0429
Daniel Lucas Santos Dias: https://orcid.org/0000-0003-2243-4400
Daniela Deitos Fries: https://orcid.org/0000-0002-3827-6905
Renata Rodrigues Jardim: https://orcid.org/0000-0002-4022-5541
Braulio Maia de Lana Sousa: https://orcid.org/0000-0001-5587-8177
Aureliano José Vieira Pires: https://orcid.org/0000-0002-4015-3445
Bárbara Louise Pacheco Ramos: https://orcid.org/0000-0001-5055-7120

ISSN: 0104-907. ISSN ONLINE: 2595-7686.
Received in 31 Aug. 2021. Accepted in 1 Dec. 2021.

References

ANDRADE, R. G. *et al*. Recuperação de pastagens no cerrado. **Agroanalysis**, v. 36, n. 2, p.30-32, 2016.

ASSAD, E. D. *et al*. **Sequestro de carbono e mitigação de emissões de gases de efeito estufa pela adoção de sistemas integrados**. In: BUNGENSTAB, D. J. *et al.* (Eds.). ILPF: inovação com integração de lavoura, pecuária e floresta. Brasília: Embrapa, 2019. cap. 11, p. 153-167.

BESEN, M. R. *et al*. Práticas conservacionistas do solo e emissão de gases do efeito estufa no Brasil. **Scientia Agropecuaria**, v. 9, n. 3, p. 429-439, 2018. DOI: http://dx.doi.org/10.17268/sci.agropecu.2018.03.15.

BORGHI, E. *et al*. **Recuperação de pastagens degradadas**. In: NOBRE, M. M.; OLIVEIRA, I. R. (Eds.). Agricultura de baixo carbono: tecnologias e estratégias de implantação. Brasília: Embrapa, 2018. cap. 4, p.105-138.

BRIEDIS, C. *et al.* How does no-till deliver carbon stabilization and saturation in highly weathered soils?. **Catena**, v. 163, p. 13-23, 2018. DOI: https://doi.org/10.1016/j.catena.2017.12.003.

CÂNDIDO, M. J. D. *et al*. Potencial e desafios para a produção animal sustentável em pastagens cultivadas do Nordeste. **Revista Cientifica de Produção Animal**, v. 20, n. 1, p. 59-70, 2018.

CARVALHO, W. T. V. *et al*. Pastagens degradadas e técnicas de recuperação: Revisão. **PUBVET**, v. 11, n. 10, p. 0947-1073, 2017. DOI: http://dx.doi.org/10.22256/PUBVET.V11N10.1036-1045.

CARVALHO, J. S. *et al*. Evolução de atributos físicos, químicos e biológicos em solo hidromórfico sob sistemas de integração lavoura-pecuária no bioma Pampa. **Pesquisa Agropecuária Brasileira**, v. 51, n. 9, p. 1131-1139, 2016. DOI: http://dx.doi.org/10.1590/s0100-204x2016000900012.

DECHEN, S. C. F. *et al*. Perdas e custos associados à erosão hídrica em função de taxas de cobertura do solo. **Bragantia**, v. 74, n. 2, p. 224-233, 2015. DOI: http://dx.doi.org/10.1590/1678-4499.0363.

DIAS-FILHO, M. B. **Estratégias de recuperação de pastagens degradadas na Amazônia Brasileira**. Belém: Embrapa Amazônia Oriental, 2015. 25 p. (Embrapa Amazônia Oriental).

ISSN: 0104-907. ISSN ONLINE: 2595-7686.
Received in 31 Aug. 2021. Accepted in 1 Dec. 2021.

FABRICE, C. E. S. *et al.* Atributos químicos do solo, reservas orgânicas e sistema radicular de pastos degradados associada à introdução de leguminosa. **Semina: Ciências Agrárias**, v. 35, n. 4, p. 1721-1730, 2014. DOI: http://dx.doi.org/10.5433/1679-0359.2014v35n4p1721.

FABRICE, C. E. S. *et al*. Recuperação de pastagens de Brachiaria decumbens degradada com introdução de Stylosanthes e adubação fosfatada1. **Revista Brasileira de Saúde e Produção Animal**, v. 16, n. 4, p. 758-771, 2015. DOI: https://doi.org/10.1590/S1519-99402015000400001.

FARIA, C. M. F. A. *et al*. Análise econômica de sistemas de recuperação e manutenção de pastagens com gado de leite. **Reflexões Econômicas**, v. 1, n. 1, p. 85-103, 2015.

FERREIRA, A. O. *et al.* Driving factors of soil carbono accumulation in Oxisols in long-term no-till systems of South Brazil. **Science of the Total Environment**, v. 622-623, n.1, p. 735-742, 2018. DOI: https://doi.org/10.1016/j.scitotenv.2017.12.019.

FOGEL, G. F. *et al.* Efeitos da adubação com dejetos suínos, cama de aves e fosfato natural na recuperação de pastagens degradadas. **Revista Verde de Agroecologia e Desenvolvimento Sustentável**, v. 8, n. 5, p. 66-71, 2013.

GONÇALO FILHO, F. *et al.* Efeitos do manejo sustentável da Caatinga sob os atributos físicos do solo. **Pesquisa Florestal Brasileira**, v. 38, p. 1-5, 2018. DOI: https://doi.org/10.4336/2018.pfb.38e201801581.

GOSCH, M. S. *et al.* Pastagens degradadas, uma herança dos imóveis rurais desapropriados para os assentamentos rurais do Cerrado goiano**. Campo-Território: Revista de Geografia Agrária**, v. 15, n. 35, p. 202-229, 2020.

HOHNWALD, S.; KATO, O. R.; WALENTOWSKI, H. Accelerating Capoeira Regeneration on Degraded Pastures in the Northeastern Amazon by the Use of Pigs or Cattle. **Sustainability**, v. 11, n. 6, p. 1729-1745, 2019. DOI: https://doi.org/10.3390/su11061729.

LAPIG. **Atlas digital das pastagens brasileiras**. Universidade Federal de Goiás, 2018. Available at: https://pastagem.org/map. Accessed 23 Nov. 2021.

MACEDO, M. C. M. **Integração lavoura e pecuária: alternativa para sustentabilidade da produção**

animal. In: Simpósio Sobre Manejo Da Pastagem, 18, 2001, Piracicaba. Anais... Piracicaba: FEALQ, 2001. p. 257-283.

MACEDO, M. C. M.; ARAÚJO, A. R. **Sistemas de produção em integração: alternativa para recuperação de pastagens degradadas**. In: BUNGENSTAB, D. J. *et al.* (org.). ILPF: inovação com integração de lavoura, pecuária e floresta. Brasília, DF: Embrapa, 2019. cap. 20, p. 295-317.

MARINHO, M. S.; MIRANDA, H. S. Efeito do fogo anual na mortalidade e no banco de sementes de Andropogon gayanus Kunth. no Parque Nacional de Brasília/DF. **Biodiversidade Brasileira-BioBrasil**, v. 3, n. 2, p. 149-158, mar. 2013.

MARTINS, D. C. *et al*. Animal performance and nutritional characteristics of Piatã-grass in integrated systems. **Arquivo Brasileiro de Medicina Veterinária e Zootecnia**, v. 72, n. 3, p. 1027-1033, 2020. DOI: https://doi.org/10.1590/1678-4162-11065.

NOGUEIRA, A. K. S. *et al*. Emissões de óxido nitroso e metano do solo em áreas de recuperação de pastagens na Amazônia matogrossense. **Química Nova**, v. 38, n. 7, p. 937-943, 2015. DOI: https://doi.org/10.5935/0100-4042.20150109.

NOGUEIRA, A. K. S. *et al*. Fluxos de óxido nitroso em sistema de integração lavoura-pecuária-floresta. **Pesquisa Agropecuária Brasileira**, v. 51, n. 9, p. 1156-1162, 2016. DOI: http://dx.doi.org/10.1590/s0100-204x2016000900015.

OLIVEIRA, V. S. *et al*. Estratégias para mitigar a produção de metano entérico. **Veterinária Notícias**, v. 23, n. 1, p. 39-70, 2017. DOI: http://dx.doi.org/10.14393/VTV-v23n1-2017.4.

PONTES, L.S. *et al*. Performance and methane emissions by beef heifer grazing in temperate pastures and in integrated crop-livestock systems: the effect of shade and nitrogen fertilization. **Agriculture, Ecosystems & Environment**, v. 253, p. 90-97, 2018. DOI: https://doi.org/10.1016/j.agee.2017.11.009.

SALTON, J. C. *et al*. Teor e dinâmica do carbono no solo em sistemas de integração lavoura‑pecuária. **Pesquisa Agropecuária Brasileira**, v. 46, n. 10, p. 1349-1356, 2011. DOI: https://doi.org/10.1590/S0100-204X2011001000031.

ISSN: 0104-907. ISSN ONLINE: 2595-7686.
Received in 31 Aug. 2021. Accepted in 1 Dec. 2021.

SANT-ANNA, S. A. C. *et al*. Changes in soil organic carbon during 22 years of pastures, cropping or integrated crop/livestock systems in the Brazilian Cerrado. **Nutrient Cycling in Agroecosystems**, v. 108, n. 1, p. 101-120, 2017. DOI: https://doi.org/10.1007/s10705-016-9812-z.

SANTINI, J. M. K. *et al.* Técnicas de manejo para recuperação de pastagens degradadas de capim-braquiária (Brachiaria decumbens Stapf cv. Basilisk). **Boletim de Indústria Animal**, v. 72, n. 4, p. 331-340, 2015. DOI: https://doi.org/10.17523/bia.v72n4p331.

SANTOS, M.P. *et al.* Importância da calagem, adubações tradicionais e alternativas na produção de plantas forrageiras: Revisão. **PUBVET**, v. 10, n. 1, p. 01-12, 2016a. DOI: http://dx.doi.org/10.22256/pubvet.v10n1.1-12.

SANTOS, D.C. *et al*. Forage dry mass accumulation and structural characteristics of Piatã grass in silvopastoral systems in the Brazilian savannah. **Agriculture, Ecosystems & Environment**, v.233, p. 16-24, 2016b. DOI: https://doi.org/10.1016/j.agee.2016.08.026.

SILVA, S. C.; SBRISSIA, A. F.; PEREIRA, L. E. T. Ecophysiology of C4 forage grasses—understanding plant growth for optimising their use and management. **Agriculture**, v. 5, n. 3, p. 598-625, 2015. DOI: https://doi.org/10.3390/agriculture5030598.

SILVA, A. A. *et al*. Recuperação de pastagem degradada pelo consórcio de milho, Urochloa brizantha cv. Marandu e guandu. **Journal of Neotropical Agriculture**, v. 5, n. 2, p. 39-47, 2018a.

SILVA, J. A. N. *et al.* Desempenho de novilho nelore em pastagem degradada submetida a diferentes processos de recuperação e renovação. **Agrarian,** v. 11, n. 41, p. 260-266, 2018b.

SILVA, A. A. *et al*. Carbon and nitrogen stocks in the High Biodiversity Silvopastoral System: applied nucleation enabling low carbon livestock production. **Research, Society and Development**, v. 9, n. 10, 2020. DOI: https://doi.org/10.33448/rsd-v9i10.8589.

SIMON, C. A. *et al*. Efeitos da queima de resíduos do solo sob atributos químicos de um latossolo vermelho distrófico do cerrado. **Nativa**, v. 4, n. 4, 2016. DOI: https://doi.org/10.14583/2318-7670.v04n04a06.

ISSN: 0104-907. ISSN ONLINE: 2595-7686.
Received in 31 Aug. 2021. Accepted in 1 Dec. 2021.

SOUZA, F. M. *et al.* Introdução de leguminosas forrageiras, calagem e fosfatagem em pastagem degradada de "Brachiaria brizantha". **Revista Brasileira de Saúde e Produção Animal**, v.17, n.3, 2016.

TERRA, A. B. C. *et al*. Leguminosas forrageiras na recuperação de pastagens no Brasil. **Revista de Ciências Agrárias**, v. 42, n. 2, p. 11-20, 2019. DOI: http://dx.doi.org/10.19084/rca.16016.

VASCONCELOS, A. L. S. Greenhouse gas emission responses to sugarcane straw removal. **Biomass and Bioenergy**, v. 113, n. 1, p. 15-21, 2018. DOI: https://doi.org/10.1016/j.biombioe.2018.03.002.

ZIMMER, A. H. *et al*. **Degradação, recuperação e renovação de pastagens**. Mato Grosso do Sul: Embrapa Gado de Corte, 2012. 42 p.

ISSN: 0104-907. ISSN ONLINE: 2595-7686.
Received in 31 Aug. 2021. Accepted in 1 Dec. 2021.