Crop-livestock integration in Brazilian lands

https://doi.org/10.56238/sevened2024.023-029

Deise Dalazen Castagnara[1], Kelli Flores Garcez[2], Luiza Vandrielli Goulart Unamuzaga[3], Cibele Regina Schneider[4], Eloisa Mattei[5], Édipo Alex Malavolta Ramão[6], Gabriela Maidana Valença[7], Lueli Fernandes Bragança[8], Cleiton José Ramão[9], Rodrigo Holz Krolow[10], Paulo Sérgio Rabello de Oliveira[11] and Jackson Brazil Acosta Pintanel[12]

ABSTRACT

Integrated agricultural production systems (SIPA's) consist of growing grain-producing crops with forage crops in the same area, in rotation, succession or intercropping. These systems, in addition to diversifying agricultural production, promote efficiency and sustainability in rural production, benefiting crops and livestock, are more sustainable, economically viable agricultural practices aimed at soil conservation. As, among the objectives of integrated systems, when well managed, they are capable of promoting improvements in soil quality, nutrient cycling, environmental adequacy and economic viability of the activities involved. As a result, the Integrated Crop-Livestock (ICL) system becomes a very important method, because it seeks to renew soil conditions, in order to make the most of natural processes, avoiding using external inputs. The ICL system is a viable alternative in edaphoclimatic conditions, there are many potentialities of the systems, enabling an increase in productivity and reduction of expenses for irrigation, fertilizers, soil conditioners and other agricultural inputs, integrating production, environmental conservation and socioeconomic benefits.

Keywords: Agriculture, Production, Integrated systems, Sustainability.

---

[1] E-mail: deisecastagnara@unipampa.edu.br
[2] E-mail: kelligarcez15@gmail.com
[3] E-mail: luizaunamuzaga.aluno@unipampa.edu.br
[4] E-mail: cibeleregina17@hotmail.com
[5] E-mail: eloisa-mattei@hotmail.com
[6] E-mail: ediporamao@gmail.com
[7] E-mail: gabrielavalenca.aluno@unipampa.edu.br
[8] E-mail: luelifernandesb@gmail.com
[9] E-mail: cleiton-ramao@irga.rs.gov.br
[10] E-mail: rodrigokrolow@unipampa.edu.br
[11] E-mail: rabello.oliveira@hotmail.com
[12] E-mail: Jackson-pintanel@irga.rs.gov.br

INTRODUCTION

Integrated agricultural production systems (SIPA's) consist of growing grain-producing crops with forage crops in the same area, in rotation, succession, or intercropping (Barbosa *et al*., 2022). These systems, in addition to diversifying agricultural production, benefiting crops and livestock, are more sustainable, economically viable agricultural practices aimed at soil conservation (Coser *et al*, 2018).

Due to their ability to provide economic and environmental benefits (Barbosa *et al*., 2022) LPIS have received special attention from researchers and have been adopted by farmers in Brazil (Bonetti *et al*., 2015). Thus, Brazil leads the research in LPIS in relation to the rest of the countries in the world, according to Moraes *et al*. (2017), with approximately 11.5 million hectares are occupied by different arrangements of LPIS's. Of these, the subtropical region accounts for 44% of this area (Skorupa; Manzatto, 2019). However, its adoption in crops intended for the cultivation of irrigated rice is still incipient, especially with regard to the availability of data to support management recommendations. In these areas, called lowlands, the cultivation of irrigated rice in spring/summer and ryegrass in autumn and winter is predominant. In Rio Grande do Sul, about 1.1 million hectares are cultivated with flood-irrigated rice (CONAB, 2019) due to the characteristics of the soil in these regions. These have a low rate of water infiltration, low macroporosity and high compaction close to the surface, which makes it difficult for other crops to be inserted, according to Denardin *et al*. (2019) to achieve positive results in LPIS.

Therefore, it becomes a challenge to deploy and conduct systems in LPIS and lowlands. Countering this challenge, as rice cultivation is costly and expensive in terms of labor, water, energy, and as these resources are becoming increasingly scarce, this activity is becoming less profitable (Kumar; Ladha, 2011). Therefore, the implementation of LPIS in current agricultural production models can help generate income in the off-season of summer crops, and/or increase productivity in rice crops.

This increase would be possible because the SIPA's advocate the adoption of no-tillage as a cropping system, thus, the absence or minimal disturbance of the soil minimizes its degradation (Coser *et al*., 2018). In the same way, the constant maintenance of living or dead cover in the soil contributes to the increase in the production of dry matter per unit area, according to Mazzuchelli *et al*. (2020) that can be used as a ground cover (Skorupa; Manzatto, 2019). This also contributes to the increase of soil carbon (C) stocks, according to Guesmi *et al*. (2019) that act as a subsidy for the supply of nutrients, according to Soares *et al*. (2019), with a consequent increase in crop productivity (Sousa *et al*., 2020). How can the SIPA's have their time-culture-space arrangements adjusted according to the needs of each reality, according to Barbosa *et al*. (2022), research contemplating lowland environments can be conducted under the principles of SIPA's. Furthermore, although the benefits of adopting LPIS are known, in lowlands they are still incipient, and require further studies to generate more consistent technical recommendations (Carmona *et al*., 2018).

It is also worth noting that the conventional agricultural system model is in evidence, because over the years the loss of forage diversity and environmental pollution by excess nutrients and pesticide residues, according to Anghinoni *et al*. (2013) has made society currently demand that specialized production models commit to producing food in the most connected way possible with nature (Carmona *et al*., 2018)element.

LITERATURE REVIEW

BRIEF HISTORY OF CROP-LIVESTOCK INTEGRATION

Culturally, Crop-Livestock integration systems are considered as innovative systems of agricultural exploitation. However, they were already developed in Europe since the Middle Ages. At the time, various forms of plantations were used associated with annual or perennial crops, or between fruit crops and timber trees (Lourençano; Cavichioli, 2019). Also, in the sixteenth century there was integration of fruit trees with the livestock production of cattle or sheep, however, due to the mechanization and intensification of agricultural systems, such integration almost disappeared (EMBRAPA, 2019).

In the mid-to-late 1970s, especially in the southern region of Brazil, there were efforts to reverse soil degradation, with integrated terracing systems in watersheds, and the development of technologies for the no-tillage system (Lourençano; Cavichioli, 2019). This scenario encouraged research into sustainable production systems, which harmonized the increase in animal and plant productivity, and preserved natural resources, according to EMBRAPA (2019), thus resulting in the beginning of scientific research on Crop-Livestock Integration (Lourençano; Cavichioli, 2019).

FOOD DEMAND AND THE BRAZILIAN AGRICULTURAL AREA

The increase in the world population, according to Sene; Bacha (2024), which has been accelerated in recent years, according to Cabral Neto *et al*. (2024), will lead to growth in food demand in the medium and long term (Sene; Bacha, 2024). This increase will be intensified by the increase in purchasing power resulting from the development of industries (Cabral Neto *et al*., 2024). Among the countries that will meet this demand, Brazil is a country that will certainly provide an increase in food supply through agricultural and livestock expansion (Cabral Neto *et al*., 2024). This expansion can occur in two ways, either by expanding the cultivated area and/or by increasing its agricultural productivity (Oliveira *et al*., 2013).

In Brazil, according to data from the 2017 Agricultural Census (IBGE, 2019) there are 5,073,324 agricultural establishments. These properties occupy a total area of 351.289 million of the

851 million hectares (ha), that is, 41% of the total area of the country is allocated to agricultural establishments (Sene; Bacha, 2024). Of these areas, 18.1% of the Brazilian agricultural area in 2017 (IBGE, 2019) was occupied by crops (temporary and permanent), 45.4% by pastures (natural and planted), 32.8% by forests (natural and planted) (Sene; Bacha, 2024). When considering the total areas of pastures in comparison to the total area of our territory, we have 160 million hectares of pasture, according to Cabral Neto *et al*. (2024), which correspond to 18.94% of its entire Brazilian territorial extension, evidencing its broad agricultural potential (Sene; Bacha, 2024).

However, about 52% of these pasture areas are at some level, degraded (Cabral Neto *et al*., 2024). This factor means that when compared to the world scenario, Brazil has one of the lowest cattle stocking rates (Lapig, 2022). This aspect causes several consequences, which directly interfere with production performance, increased costs and decreased revenue on properties (Leão *et al*., 2021). In view of this scenario, integrated crop-livestock systems can be a good option for agricultural expansion, according to Cabral Neto *et al*. (2024), inhibiting or eliminating the need for deforestation to advance the agricultural frontier, in addition to generating less environmental impact (Carlos *et al*., 2022).

DEGRADATION OF SOILS AND PASTURES AND BIOMES

Soil degradation induced by traditional agricultural or livestock production systems has been studied by Cabral Neto *et al*. (2024), as it is an important factor in compromising the sustainability of agricultural production (Macedo; Araújo, 2019). In agriculture, traditional agricultural production systems, which are those of annual crops, with continuous crops, without crop rotation, in which there is excessive soil preparation, as is the case with the conventional cultivation of irrigated rice (Cabral Neto *et al*., 2024).

Traditional soil preparation, combined with inadequate practices and monoculture, has caused low productivity, degradation of soil and natural resources (Lourençano; Cavichioli, 2019). These effects are the result of the damage caused to the physical and chemical quality of the soil (Cabral Neto *et al*., 2024). Also, with the growing increase in demand for food, there was an intensification of agricultural activity, according to Lourençano; Cavichioli (2019), with aggravation of the aforementioned losses and problems with invasive pests and diseases (Cabral Neto *et al*., 2024). And with constant technological evolution, modern agricultural activity has been standardized into simplified monoculture systems, in addition to the use of machinery, agrochemicals, and irrigation (Lourençano; Cavichioli, 2019).

In pasture degradation, there is a decrease in the supply of forage for animal feed, since there is a loss of the ability to sustain plant production due to soil depletion and overgrazing (Senne; Bacha, 2024). This generates a vicious cycle, intensifying environmental and economic problems on properties (Cabral Neto *et al*., 2024). It is estimated that in Brazil, in 2020, there were 40.16 million ha of pastures with severe degradation (Senne; Bacha, 2024).

Soil degradation in agricultural and/or pastoral environments, in addition to harming the conservation of ecosystems, also leads to the degradation of Brazilian biomes (Cabral Neto *et al*., 2024). For this reason, they have been questioned and require intervention for their mitigation. The recovery of these areas, with the objective of maintaining soil quality and promoting higher biomass yield, consequently, leads to an increase in productivity rates and allows competitiveness in the economic sector (Souza *et al*., 2021). Part of these degraded areas, once recovered, represents a good opportunity for the country to expand its plant and animal production and meet the expansion of world food demand, without having to deforest new areas (Sene; Bacha, 2024).

The degradation process needs to be controlled in the early stages, as the impacts are more drastic over time (Cabral Neto *et al*., 2024). There are several ways of intervening in pastures, such as recovery, in which the same cultivar is maintained and the productive potential of forage is restored; renewal, which is the introduction of a new species replacing the one that is degraded; and finally, the reform, which is characterized by corrections or repairs after the establishment of a pasture (Rocha; Viana-Filho, 2021). The recovery of degraded areas takes place from the integration of techniques involving air, soil, water, fauna and flora, in order to obtain ecological balance with a view to achieving sustainability and being productive in the long term (Cabral Neto *et al*., 2024). In general terms, it means using all the strategies necessary for the quality of the soil to reach standards similar to, or even higher than, its original condition.

Some integrated systems have been widely used, such as the no-tillage system (NTS), integrated crop-livestock system (ICL) and integrated crop-livestock-forest system (ICLF), which have numerous benefits aimed at improving the physical quality of the soil, favoring carbon accumulation and greater water availability (Silva *et al*., 2021). Aiming to associate production and environmental conservation, and with a view to recovering areas that are already in a state of degradation, integration systems emerge as options for the adoption of more sustainable food production practices (Sene; Bacha, 2024). From this perspective, the interaction between crops and livestock is a good strategy to achieve these goals, since it is directly linked to sustainability (Junior *et al*., 2020).

CONCEPTUALIZATIONS AND BENEFITS OF ILP

Integrated systems are strategies for sustainable production, where agricultural, livestock and/or forestry activities are integrated, carried out in the same cultivation area (Lourençano; Cavichioli, 2019). The interaction between crops enables rotation in the use of agricultural production systems, and aims to raise the quality of the final product, allowing natural conservation, especially in degraded areas (Silva *et al*., 2022). When the forestry component is contemplated, the use of these systems enables the production of grains, meat and wood, with sustainability and conservation of natural resources, according to Magalhães (2019) by allowing the combination of two or more agricultural activities in the same productive area, that is, bringing together agriculture, livestock and/or forestry on the same farm (Sene; Bacha, 2024).

Integration systems have numerous advantages, especially in relation to the traditional cultivation system, according to Lourençano; Cavichioli (2019), because in integrated systems, crops can be intercropped, in succession or in rotation (Cordeiro *et al*., 2015). With this, there is an improvement in productivity, use of residual fertilization from the crop and supply of nutrients and organic matter to the soil, according to Lourençano; Cavichioli (2019) as the main results of the synergistic effects between its components (Cordeiro *et al*., 2015).

As among the objectives of integrated systems we have the intensification of land use, environmental adequacy and economic viability of the activities involved, according to Cordeiro *et al*. (2015), in addition to the benefits mentioned above, there is also a reduction in the emission of greenhouse gases (GHG) per unit of food produced (Reis *et al*., 2020). An improvement in soil quality is also obtained, according to Reis *et al*. (2020) by the formation of straw, which will be used for the no-tillage system, and diversifies the cultivation of forages, according to Alvarenga *et al*. (2010) allowing the recovery of degraded pastures, water conservation and increased animal performance (Reis *et al*., 2020). There are many benefits obtained from the implementation of the system, which provide diversification of production, as well as increased production efficiency and reduction of environmental damage (Cabral Neto *et al*., 2024).

There is also a significant reduction in the application of inputs, since it breaks the cycle of pests and reduces invasive plants, in addition to reducing the cost of production or pasture reform (Lourençano; Cavichioli, 2019). Also, aiming at the effective use of available resources, the possibility of implementing diversified production systems, leading to the rationalization of the use of inputs, in addition to improving soil and water quality, resulting in greater profitability per area (Cabral Neto *et al*., 2024). Thus, in summary, production in an integration system brings several benefits, not only for the producer, with the reduction of production costs over time; reduction of idleness in the use of agricultural areas; diversification in production and income stability, but also in the environment, where there is improvement in the physical, chemical and biological conditions of the soil; there is an increase in cycling and efficiency in the use of nutrients; enables the recovery of areas with degraded pastures; there is an increase in animal welfare and productivity (Cordeiro *et al*., 2015).

DIFFICULTIES IN IMPLEMENTATION AND CONDUCTION

Integrated systems provide several benefits, however, as they are more complex production systems, it may be necessary to consider some difficulties present in this system, such as soil compaction by animal trampling (Lourençano; Cavichioli, 2019). However, these negative impacts are limited to the surface layers, in addition to being temporary and reversible, for the most part (Vilela *et al*., 2011). Compaction combined with the removal of vegetation, also caused by trampling, can lead to a series of soil problems, as well as a decrease in water infiltration, increasing surface soil erosion, consequently reducing plant growth (Lourençano; Cavichioli, 2019).

For this reason, it is necessary to properly manage pastures, avoiding overgrazing/overgrazing and ensuring the maintenance of remaining residual dry matter. Also, even if the presence of the animal causes trampling and compaction, grazing stimulates the root growth of forage plants, that is, the harm can be compensated by the benefits. Thus, both obviously depend on a series of factors to be considered in an integrated system, including: soil type, moisture content, animal stocking rate, forage mass, species and vigor of the forage used (Lourençano; Cavichioli, 2019). There is also a need for financial investment for the implementation and maintenance of the system, so small farmers find it difficult in this regard (Balbino *et al*., 2012a). For the reasons described, even with several benefits, there is still resistance to the adoption of new technologies by producers, in short, due to the requirement of their qualification, in addition to the need for technicians and specialized labor (Lourençano; Cavichioli, 2019).

INTEGRATED SYSTEMS MODALITIES

Integration consists of the implementation of different production systems of grains, fibers, meat, milk and agroenergy in the same area, in intercropping, which can be sequential or rotational (Vilela *et al*., 2011). Integrated systems have been disseminated throughout the country, in different combinations of their components, namely: crop-livestock integration (ICL), crop-livestock-forest integration (ICLF), livestock-forest integration (IPF) and crop-forest integration (ILF) (Vilela *et al*., 2015; EMBRAPA, 2019). In crop-livestock integration (ICL) or agropastoral, there is integration of the components: agricultural, with annual or perennial production (grains, pastures), and livestock (EMBRAPA, 2019). In this system, the combination of two components is adopted: agricultural (crop), with annual or perennial production (grains, pastures), and livestock (beef cattle, milk), which can be in rotation, intercropping or succession, but in the same area and in the same agricultural year, or for multiple years (Lourençano; Cavichioli, 2019). This system seeks the diversity of forage crops, the reduction of the application of inputs on the property (Lourençano; Cavichioli, 2019). The most used species are intercropped into winter species (white oats, black oats, ryegrass), and summer species (sorghum, millet, soybean, beans) (Assis *et al*., 2019).

The integrated crop-livestock-forest (ICLF) system, or agrosilvopastoral, is the combination of three components: agricultural (crop), forestry (tree and/or fruit species) and livestock (beef cattle, dairy), aims at the efficiency of the biological cycles of plants, animals and their residues, where it minimizes and improves the use of inputs, in addition to reducing impacts on the environment (Assis *et al*., 2019). When the forestry component is integrated, the benefits observed are: the afforestation of pastures, allowing the grass to remain green in the drought, in addition to the thermal comfort provided to the animals (Lourençano; Cavichioli, 2019). It also enables the recovery of degraded areas, as it optimizes the use of the soil through the production of grains and wood in pasture areas (Lourençano; Cavichioli, 2019). Thus, it can be varied among its components, arriving at an integration that best suits its area, soil and climate (Cordeiro *et al*., 2015). This integration system is part of agroforestry systems, being subdivided with another nomenclature, namely: agropastoral; agroforestry; silvopastoral and silvoagricultural (Lourençano; Cavichioli, 2019).

Livestock-forest integration (IPF) or silvopastoral, integrates the livestock component (pasture and animal) and the forestry component in the form of consortium (Lourençano; Cavichioli, 2019). The most suitable trees for planting are those that best respond to expectations of economic return and have a lower risk of loss due to damage caused by cattle, so producers usually opt for: eucalyptus, Australian cedar, teak, pink cedar, guanandi and African mahogany (Vilela *et al*., 2015; EMBRAPA, 2019). And finally, the crop-forest integration (ILF) or silviagricultural, integrates the forestry and agricultural component (crop), through the intercropping of tree species with agricultural, annual or perennial crops (Lourençano; Cavichioli, 2019). Trees are planted between the rows of crops so that there is the production of leaf biomass and an increase in the content of organic matter in the soil (Assis *et al*., 2019; EMBRAPA, 2019).

Crop-forest integration (ILF) integrates the forestry and agricultural component (cropping) by the intercropping of tree species with agricultural crops, annual or perennial. And in turn, the integrated crop-livestock-forest (ICLF) is the integration of the three components: agricultural (crop), forestry (tree and/or fruit species) and livestock (beef cattle, dairy), in rotation, intercropping or succession, in the same area. This system aims at the efficiency of the biological cycles of plants, animals and their residues, minimizing the use of inputs and reducing impacts on the environment (EMBRAPA, 2019).

VARIATIONS OF INTEGRATED SYSTEMS IN BRAZIL

In any region where the implementation of an integrated production system begins, good planning is required. This should include a detailed project of all stages of the process, considering the different aspects, including: edaphoclimatic conditions, existence of infrastructure for the supply of inputs, storage and flow of production (Lourençano; Cavichioli, 2019). Thus, it can be applied to any rural producer, regardless of the size of their property (Kichel *et al*., 2014).

In Brazil, due to the edaphoclimatic diversity of our territory, we have great variability of integrated systems implemented (Lourençano; Cavichioli, 2019). In the Amazon region, the crop-forest and livestock-forest systems are widespread, where forest species such as paricá, eucalyptus, teak and African mahogany are used (Balbino *et al*., 2011). In these systems, the most common forage species are: brachiarão, kikuyu, gingergrass, Jaraguá, Pueraria, and composing the livestock, there are cattle, buffaloes and woolly sheep. The ICF system is usually used in degraded areas, with grain planting between two and three harvests, with a predominance of rice, corn, soybeans and cowpea in rainfed crops, thus disseminated in regions suitable for these crops (Lourençano; Cavichioli, 2019).

In the caatinga, in turn, the system with the greatest applicability is ICLFS, due to the response to the pressures for food production. They are part of the exploitation of perennial woody species, associated with crops and pastures (Balbino *et al*., 2011). In the Cerrado, ICLFS are used with the agricultural species of cotton, soybeans, corn, sorghum, beans, rice and sunflower. In the Atlantic Forest of the southern region, systems based on the succession of crops in the summer are predominant (Lourençano; Cavichioli, 2019). In the Southeast, there is a predominance of forage rotations with annual crops of soybean, corn and cotton for straw production. In the Northeast, the predominant systems are livestock-forest (EMBRAPA, 2019). In practically half of Rio Grande do Sul, the most common system is the crop-livestock system. Finally, in the Pantanal, the most used system is the extensive livestock-forest system, adapted to the characteristics of the place (Balbino *et al*., 2011).

INTEGRATED SYSTEMS AND METHANE EMISSION MITIGATION

Results and benefits from the adoption of the Integrated Crop-Livestock (ICL) system There are many benefits obtained from the implementation of the ICL system, among them the improvement of the animal diet, which culminates in a reduction in slaughter time, thus generating lower rates of methane gas emission (CH_4) per animal production (Cabral Neto *et al*., 2024). These aspects provide better economic direction, in addition to preventing new areas of native vegetation from being converted into pastures (Carlos *et al*., 2022). The technology used for pasture recovery has the ability to remove carbon from the atmosphere, in order to fix it in the soil (Cabral Neto *et al*., 2024).

Some evidence points out that it is possible to neutralize emissions from the Land Use, Land Use Change and Forestry (LULUCF) sector, since, by recovering 27.5 million hectares (Mha) by the year 2030, about 6.028 million tons (Mt) of carbon dioxide equivalent (CO_2eq) are accumulated in the soil, which is equivalent to 463.7 Mt CO_2eq per year (Cabral Neto *et al.*, 2024). These data contribute to a positive mitigation balance for the country (Assad *et al.*, 2021). When properly managed, pastures accumulate carbon at significant levels, being similar to, or even higher than native vegetation, according to Cordeiro *et al.* (2024), in addition to promoting higher nutritional quality for the herd (Cabral Neto *et al.*, 2024). Degraded pastures, on the other hand, in addition to interfering with animal performance, provide the loss of accumulated carbon (Cabral Neto *et al.*, 2024).

Thus, it can be considered that the ICL system is a powerful alternative to the difficulties encountered in the production chain, since it reduces the commitment to the environment and maximizes the production and revenues of the property (Assis *et al.*, 2019). In general terms, the purpose of the ICL system is to promote interactions between soil, plant, animal, and atmosphere, which culminate in a reduction in risks and costs, as well as in the increase of production efficiency, mitigation of Greenhouse Gas (GHG) emissions, and reduction of pests (Cabral Neto *et al.*, 2024). In view of broader aspects, the system allows for diversified food production, in addition to mitigating possible risks related to food insecurity in underdeveloped countries (Capitani; Farina, 2022). Aiming at the effective use of available resources, there is the possibility of implementing diversified production systems, leading to the rationalization of the use of inputs, in addition to improving soil and water quality (Cabral Neto *et al.*, 2024). These benefits can be obtained in properties of all sizes and even in properties that require the exploration of permanent preservation areas (Martins; Rezende, 2020).

TYPES OF CROP-LIVESTOCK INTEGRATION

The Integrated Crop-Livestock System or Agropastoral System, aims to increase productivity and achieve favorable environmental levels from the rotation and diversification in pasture and crop production in NTS, using the same surface at different times. There are several methodologies to be adopted within the ILP System, which can and should be adapted according to the needs of each region, namely: Barreirão, Santa Brígida, Santa Fé, São Mateus and Gravataí (Camporezi, 2022).

The Barreirão System is a type of technology that provides the establishment of pasture followed by the harvest of grains, that is, it takes place from the total preparation of the area, with correction and fertilization before the insertion of grain crops, in which, at the same time, forage and perennial grasses, especially brachiaria grasses, are inserted (Bungestab *et al.*, 2018). The Santa Brígida System aims to promote the increase of nitrogen input to the soil from the biological fixation of atmospheric nitrogen, this practice is consolidated with the insertion of green manures in the corn production system. In this organization, there can be processing for subsequent cultivation, since the supply of nitrogen from legumes provides a decrease in the supply of mineral nitrogen (Queirós *et al*., 2020).

The Santa Fé System promotes the insertion of forage species of the genus Urochloa and Megathyrsus, mainly by intercropping, in a grain production system. It aims to produce forage in the off-season, in addition to producing straw for the NT of the next crop (Ponciano *et al*., 2021). The São Mateus System aims to promote NTS to introduce, along with pasture, crops in rotation. It is directed to regions that have sandy soils, poor in nutrients and with impaired water retention capacity, and those where rainfall distribution is irregular during the year, causing water restriction (Fontaneli; Fontaneli,; Panisson, 2022). The Gravataí System is based on the intercropping of cowpea (*Vigna unguiculata*) and grasses of the genus Brachiaria, such as B. ruziziensis and B. brizantha cvs. BRS Paiaguás and BRS Piatã, in order to obtain greater accumulation of forage with high nutritional value, as well as high crude protein (CP) content and digestibility (Camporezi, 2022).

In general terms, the Barreirão System promotes increased profitability with the diversification of the activity, in addition to expanding animal support capacity, as well as resistance during the dry season and suppression of termites and invasive plants (Cabral Neto *et al*., 2024). The Santa Fé and Santa Brígida System, on the other hand, from forage straw, provides an improvement in the physical, chemical and biological conditions of the soil, benefiting the development of a next cultivar in that location under NT, in addition to offering the possibility of increasing the supply of forage to meet the needs of cattle during the dry season. there is also, in these systems, the feasibility of using the area for agriculture in the summer and livestock during the winter (Leão *et al*., 2021).

FORAGE COMPONENTS IN SIPA'S

As in the rest of Brazil, in the southern region the activity is based on the use of pastures as the main food resource. Also, as the well-defined cold season, characterized by the reduction of the photoperiod, low temperatures and the occurrence of frost, limits the production and quality of tropical forages, according to Peretti *et al*. (2017), forage strategies should be adopted to fill this food gap. LPIS in Brazil comprise a great diversity of forage species due to the diversity of our edaphoclimatic conditions. However, of the pastures cultivated in winter, the most used species is ryegrass (*Lolium multiflorum* Lam.) according to Bohn *et al*. (2020), due to its productive potential and good adaptation to the environmental conditions of the region (Dotto; Robaina; Scotti, 2022). In addition to being a good alternative to compose subtropical systems of crop-livestock integration, according to Moraes *et al*. (2014), as it has a high potential for dry matter production, according to Peterson *et al*. (2019) can be used for both grazing and ground cover (Bohn *et al*. 2020).

As the SIPA's aim at social, environmental and economic sustainability, among the challenges, the adoption of pasture management strategies that aim to maximize plant and animal production are extremely important (Dotto; Robaina; Scotti, 2022). Thus, in addition to the choice of forage species, the grazing method and the fertilization strategy must be defined in order to meet the principles mentioned. In continuous stocking, the animals have unlimited and uninterrupted access to the entire area to be grazed during the entire grazing period, and in rotational stocking, there is an alternation between defoliation and rest (Dotto; Robaina; Scotti, 2022). Due to the interspersion of rest and grazing periods, in the rotating stocking, the regrowth process occurs in isolation from the grazing process (Ongaratto; Romanzini, 2021). On the other hand, continuous stocking is characterized by milder changes in pasture condition over the period (Dotto; Robaina; Scotti, 2022). This is the most suitable option for adoption in SIPA systems, as the constant soil cover maintained by the higher residual grazing height provides the sponge effect, minimizing soil compaction (Coser *et al*., 2018).

In ryegrass, when used for grazing, in its management it is recommended the entry of animals into the area when the ryegrass is approximately 30 cm high, for a better use of the pasture (Flores *et al*., 2008). However, grazing management should prioritize a pasture height always higher than 10-15 cm to stimulate regrowth (Peretti *et al*., 2017). The period of use of ryegrass pastures can last up to 80 days, subject to the climate, soil fertilization and especially area management (Pelegrini *et al*., 2010). Although it is a forage species extensively studied in the southern region of Brazil, its dynamics in LPIS in lowlands is not yet fully elucidated. Thus, studies contemplating the performance of ryegrass inserted in alternative LPIS systems in lowlands will support technical recommendations for the management of this pasture.

ANIMAL COMPONENT IN SIPA'S

The livestock phase of LPIS in the sub-tropical regions of Brazil is commonly adopted in the winter period and the main plant species used are winter forage grasses (Bertol *et al*., 2022). Of these, ryegrass is the predominant one in lowlands, with dry matter productions that can reach 10 tons/ha and total digestible nutrient concentrations that can reach more than 80%, providing excellent animal performance (Fontaneli *et al*., 2016). However, this is dependent on the management of grazing intensity in the livestock phase, which determines the amount of forage available to the animal: higher grazing intensities will provide lower forage availability and vice versa (Bertol *et al*., 2022). This is directly linked to the animal load used, which is one of the main challenges for increasing the area of LPIS in Southern Brazil. There are paradigms linked to the consumption of forage material that would cover the soil and the potential compaction of the soil by animal trampling, according to De Faccio Carvalho *et al*. (2021), that is, both are linked to the grazing intensity of the livestock phase (Bertol *et al*., 2022).

Although grazing should be moderate to minimize soil compaction and maximize forage production, it should be present, as it is responsible for plant root growth. In other words, the animal component is fundamental for the sustainability of the system, because in addition to promoting defoliation with root growth of forage plants, it also provides the cycling of nutrients through feces and urine. Integrated crop-livestock systems are based on the premise that livestock activity can contribute to organic residues, improvement of soil physical and chemical characteristics, crop rotation, interruption of the cycle of plant diseases and reduction of losses resulting from climate variability. Additionally, these systems can provide fresh and highly nutritious forages for livestock, including in winter, while in other systems forage can be scarce (Vinholis *et al*., 2021). For this reason, the adoption of animals with genetic potential can enhance the SIPA's, providing greater animal gain and greater efficiency in the use of the forages offered.

AGRICULTURAL COMPONENT IN SIPA'S

In the subtropical regions of Brazil, the agricultural cultivation phase of SIPA's is commonly adopted in the summer period, and includes irrigated rice (*Oryza sativa*), soybean (*Glycine max*) and/or corn (*Zea mays) crops*. In lowlands, corn is rarely cultivated, except when used to produce silage for animal feed. Rice cultivated in the irrigated form is the predominant crop in lowlands in the agricultural phase. However, the sustainability of its cultivation has been declining season after season, with increased production costs and reduced water availability.

Soybeans are the most important economic commodity in Brazil and widely used around the world. In recent years, new areas have been used for soybean production, mainly in the lowlands of agricultural fields in southern Brazil historically managed by cattle ranching (Theisen; Scivittaro, 2023). However, most areas presented limiting factors for production, such as low soil fertility and reduced water retention, reducing the potential for grain yield. However, the gains related to soybean cultivation would not be directly economic.

As it is a leguminous crop, it has the ability to fix nitrogen biologically. Also, its pivoting root system could contribute to the decompaction of the superficial layers of the soil, contributing in the long term to the improvement of its structure. Combined, these characteristics could contribute to a more favorable soil condition for ryegrass, providing higher DM productivity and higher animal load (Silva *et al*., 2020).

ECONOMIC COMPONENT IN SIPA'S

The adoption of technologies enables productivity gains and/or lower production costs through the use of new inputs and new combinations of resources (Vinholis *et al.*, 2022). These gains have been observed in Brazilian agriculture. In recent decades, the generation and adaptation of agricultural technologies to tropical conditions has enabled the country to sustain a consistent increase in food production. In 2020, agribusiness GDP reached 26.6% of share in the national GDP (Center for Advanced Studies in Applied Economics, 2020). Monoculture crop production and conventional livestock farming not integrated with crops were designed for a rapid increase in productivity and food supply (Vinholis *et al*., 2021). Thus, monoculture is the predominant plant and animal production system in Brazil, based on the intense use of natural resources, chemical formulas, and non-renewable energy (Mendonça *et al*., 2020).

However, some of these production systems have shown signs of saturation and negative environmental impacts (Vinholis *et al*., 2021). However, in the face of an imminent scarcity of natural resources, production systems need to be rethought (Mendonça *et al*., 2020). Crop-livestock integration systems have been developed as an alternative that offers increased productivity and greater environmental sustainability (Vinholis *et al*., 2021). These systems enable the economic exploitation of production areas throughout the year, allowing greater production of grains, milk and meat, at lower costs due to the interaction between crops and pasture. In economic theory, any economic gains obtained from the diversification of production systems are justified by the so-called "scope economy", which occurs when the cost of producing two items in a given production system is lower than when the same items are produced separately (Mendonça *et al*., 2020).

However, measuring and demonstrating the economy of scope in production systems is not so simple, according to Gameiro *et al*. (2016), probably due to the difficulty in calculating the cost of production of an integrated system, especially for farmers (Araújo; Mendonça, 2020). This can be explained because there is no "standard protocol" for estimating the cost of an integrated system, which means that there are several ways to conceptualize costs in nature-related production systems. The different possibilities of CLI system configurations in relation to the crops implanted and the management carried out are challenged to demonstrate the economic advantages of this system (Araújo; Mendonça, 2020).

INTEGRATED SYSTEMS IN SOUTHERN BRAZIL

LPIS are production models planned in space and time, in the same area or in different areas, jointly or sequentially, with the purpose of associating agricultural production with beef or dairy cattle, benefiting from the synergism between activities to increase productivity levels and promote greater income diversification. in a sustainable way (Sandini *et al*., 2011; Anghinoni *et al*., 2013).

Currently, research institutes promote the diversification of crops integrated with livestock production in soil conservation management, in areas historically intended for rice cultivation, from the introduction of soybeans, corn, Sudan grass and winter forages. What has been studied are irrigated rice production systems that vary the diversity of agricultural crops and the temporal intensity of the pasture phase and the cultivation of irrigated rice (Moraes *et al*., 2017).

Although areas intended for integrated production systems of agricultural production have the potential to mitigate environmental problems, meet consumption demand and economic development, the sector lacks studies for the application of sustainable tools and strategies (Carmona *et al*., 2018). It is also worth noting that the conventional agricultural system model is in evidence, because over the years the loss of forage diversity and environmental pollution by excess nutrients and pesticide residues, according to Anghinoni *et al*. (2013) has made society currently demand that specialized production models commit to producing food in the most connected way possible with nature (Carmona *et al*., 2018)element.

In lowlands, irrigated rice is predominant in spring/summer and ryegrass in autumn and winter. This practice occurs in approximately 1.1 million hectares in Rio Grande do Sul (CONAB, 2019) due to the characteristics of the soil in these regions. However, it is known that rice cultivation is costly and expensive in terms of labor, water, energy, and as these resources are becoming increasingly scarce, this activity is becoming less profitable (Kumar; Ladha, 2011). Therefore, the implementation of LPIS in current agricultural production models can help generate income in the off-season of summer crops.

The soil of areas cultivated with rice tends to have a low rate of water infiltration, low macroporosity and high compaction close to the surface, which makes it difficult to insert other crops, according to Denardin *et al*. (2019) to achieve positive results in LPIS. One of the most recent concepts studied in LPIS is system fertilization, which refers to the biological cycling of nutrients between the phases of a rotation system, that is, it is believed that in a system that includes agriculture and livestock, there can be a use of the nutrients deposited in the soil for successive crops (Assmann *et al*., 2017). In the highlands this concept is already applied and studied by Souza (2008), but in the lowlands there is much to be explored. According to Carvalho (2018), the insertion of animals in LPIS areas modifies some properties of the system, such as nutrient recycling and soil aggregation, promoting the improvement of its quality. Knowing that the recycling of nutrients to the soil through cattle in the pasture is possible, there are still studies that prove the benefits of introducing forage and animal components to these systems.

ANNUAL RYEGRASS (*Lolium multiflorum*) IN LOWLANDS

Native pastures are the main source of food for cattle in the Pampa of Rio Grande do Sul, but they have better nutritional value in the warmer seasons of the year (Flores *et al*., 2008). Not only in the Pampas region, but throughout southern Brazil, the well-defined cold season, characterized by the reduction of the photoperiod, low temperatures and the occurrence of frost, limits the production and quality of tropical forages (Peretti *et al*., 2017). The cold season is the most restricted in forage production, characterized by the scarcity and loss of quality of feed fed to the animals (Pavinato *et al*., 2014). This seasonality in forage production has been one of the main factors responsible for the low production rates in Brazilian livestock, where climatic factors such as precipitation and temperature are the most important (Gerdes *et al*., 2005). However, the same climatic conditions that limit the production of tropical forages favor the strategic use of annual forage species, adapted to these conditions (Peretti *et al*., 2017).

Annual ryegrass is one of the most cultivated winter species in Rio Grande do Sul, according to Bohn *et al*. (2020), in addition to being a good alternative to compose subtropical systems of crop-livestock integration (Moraes *et al*., 2014). According to Gerdes *et al*. (2005), ryegrass is characterized by high productivity and excellent nutritional value. This crop is resistant to cold, has a high capacity for natural reseeding, is resistant to crop diseases and for the animal, acceptance is great when grown in intercropping with other grasses and legumes (Cassol *et al*., 2011). Because it has a high potential for dry matter production, according to Peterson *et al*. (2019) can be used for both grazing and ground cover, according to Bohn *et al*. (2020) and can also be used in the form of silage and hay (Pedroso *et al*., 2004).

To further improve its productive potential, research aimed at the genetic improvement of ryegrass has aimed to select cultivars that are even more productive, earlier and better adapted to different edaphoclimatic conditions. When used for grazing, in its management it is recommended the entry of animals into the area when the ryegrass is approximately 30 cm high, for a better use of the pasture (Flores *et al*., 2008). Animals should be removed from the area when the plants reach a residual height of 10-15 cm to stimulate regrowth (Peretti *et al*., 2017). The period of use can last up to 80 days and depends on climate, soil fertilization and especially area management (Pelegrini *et al*., 2010). There are several studies elucidating the productive potential of ryegrass in various regions of southern Brazil (Lang *et al*., 2004; Lopes *et al*., 2009; Battiston *et al*., 2020, Bohn *et al*., 2020), but as the rice-ryegrass-soybean rotation in the Lowlands is recent, studies that measure ryegrass production in this LPIS model are scarce in the scientific literature.

NUTRITIONAL VALUE OF FORAGE PLANTS

The nutritional value of a forage is defined by its chemical composition and the potential for use by animals to generate energy and convert it into production. Thus, the result of a chemical analysis becomes an important tool for the correct balance of the animals' diet, with greater responses in milk and meat production (Serafim *et al*., 2017). In the analytical quantification of the nutritive value of foods, several parameters are used, such as dry matter (DM), mineral matter (MM), crude protein (CP) or total nitrogen (N), neutral detergent fiber (NDF), acid detergent fiber (ADF), lignin, digestibility, among others (De Macêdo Carvalho *et al*., 2021). However, the estimates of nitrogen and crude protein content, and the fibrous fractions are the most relevant. These are determined by analyzing neutral detergent fiber, acid detergent fiber that can be fractionated to lignin, cellulose and hemicellulose.

In order to determine the nutritional value of a forage species, it is necessary to carry out studies that allow the joint evaluation of the chemical composition (MS, OM, PB, EE, NDF, FDA and lignin), digestibility and secondary constituents that can interfere in the intake and use of the forage consumed by ruminants (De Macêdo Carvalho *et al*., 2021). Thus, based on the chemical composition, estimates can be made to contribute to the nutritional assessment, such as those that allow us to know the levels of total carbohydrates (CHOT), non-fibrous carbohydrates (NFC) and structural carbohydrates (EC) (Sniffen *et al*., 1992). Still other parameters can be estimated from the chemical composition, such as dry matter intake expressed as a percentage of live weight (DMSPV) obtained from NDF (Mertens *et al*., 1997). The dry matter digestibility (DIGMS) and total digestible nutrients (TDN) that can be estimated from the ADF, according to Bolsen, (1996), and the relative forage value (VRF) estimated from the DGMS and the CMSPV (Bolsen, 1996).

In addition to the parameters described, others can be estimated to determine the nutritional value of a forage in its natural or preserved form, for use in ruminants. However, when considering the protein fraction and the fibrous constituents, we can quickly estimate the nutritional value of a forage. The protein content in forage is also a determinant in nutritional value because it has a positive correlation with dry matter intake, according to Oliveira *et al*., (2017), and this effect is partially due to the increase in degradable protein in the rumen and improved feed digestibility (Cardoso *et al*., 2014).

Likewise, the levels of fibrous constituents directly interfere with consumption capacity and digestibility. NDF is a determinant of CMSPV because the higher the NDF content of a forage, the slower its digestion will be, and therefore, the longer it will be retained in the rumen environment, causing the filling effect (Mertens *et al*., 1996). In the filling effect, the animal is satiated by the physical effect provided by the fiber of the digesting forage, thus limiting the consumption of a larger volume of DM (Oliveira *et al*., 2017). For this reason, the higher the NDF content of a forage, the lower its consumption capacity, and the lower the WASPS (Detmann; Gionbelli; Huhtanen, 2014). As described by Mertens (1992) proposed a maximum intake value of 1.2% of live weight in NDF, however, as the CMSPV is influenced by the physiological state of the animals, when in production as dairy cows they will have a higher demand for CMSPV than beef cattle in maintenance, for example (Cardoso *et al*., 2014). Thus, it is important to know the CMSPV of each forage to balance its inclusion in the diets so that there is no limitation of consumption by filling effect, thus avoiding the limitation of animal performance.

In its composition, NDF has lignin, cellulose and hemicellulose. While the last two are potentially digestible, according to Silva; Queiroz (2009) lignin is indigestible and because it is made up of phenolic compounds, it is toxic to rumen microorganisms. Thus, in addition to repelling the approach of microorganisms to the particles, it inhibits the digestion of fibrous carbohydrates by imposing a physical barrier to the microorganisms, preventing the attack on the cell wall of the ingested forage. These cell wall constituents have their content increased with plant maturation, reducing the nutritive value of the forage. This process occurs through the directing of photosynthetic carbon to the plant structure (Battiston *et al*., 2020). This accumulation of structural cell wall dilutes the proportion represented by cell content with an increase in the fibrous portion and simultaneous reduction of soluble carbohydrates from cell content, through growth stimulation and the use of reserves (Battiston *et al*., 2020).

DIGMS is a measure of the proportion of food consumed that is digested and metabolized by the animal (De Macêdo Carvalho *et al*., 2021). It is an important parameter for evaluating the nutritional value of forages because in addition to the potential for nutrient supply, they also act in the CMSPV. Both DIGMS and NDF digestibility interfere with DMSPV, according to Cardoso *et al*. (2014), as they influence the rate of fiber degradation in the rumen environment, reducing the feeling of satiety and stimulating consumption in animals (Oliveira *et al*., 2017). It is estimated that the maximum DM intake occurs in forages with digestibility values in the diets 66 and 68%, according to Cardoso *et al*. (2014), however, it is difficult for a tropical forage to have digestibility higher than 60%, noting that consumption under these conditions is always limited by filling (Nascimento *et al*., 2009). In this way, the use of winter forage grasses enhances not only the LPIS and the use of fallow areas in the winter period, but also the performance of the animals due to the higher nutritional value of the forage.

The relative forage value (VRF) is a widely accepted forage quality index in the U.S. hay market, and has been used to characterize pastures. VRF is calculated by combining estimates of digestibility and forage intake that are obtained from NDF and ADF values. The VRF combines the estimates of digestibility and intake of forages into a single number calculated from the ADF and NDF levels (Ward; Ondarza, 2008). The parameter of 100% would be equivalent to alfalfa hay, so when estimating the VRF of different forages, these are indirectly compared to alfalfa. However, its use in forages under grazing should be used with discretion, because as it is dependent on parameters that change with plant growth, it is subject to the same dynamism.

ANIMAL COMPONENT AND ANIMAL WELFARE IN ICL

It is characterized by the harmony between the animal and the environment, considering the physical and physiological conditions and high quality of life of the animal. It also refers to the animal's ability to adapt to the woolly environment (Lourençano; Cavichioli, 2019). Physiological stress is one of the main indicators used in the assessment, because as it increases, well-being decreases. Currently, to establish the degree of animal welfare in a production system, the concept of the "five freedoms" is used, where they define conditions for this.

Physiological freedom is characterized by the supply of water and food in quantity and quality appropriate to the conditions of the animals; environmental freedom, characterized by a correctly planned environment, which has physical and thermal comfort; sanitary freedom, characterized by the absence of pain, injuries and diseases, met by the correct sanitary management of animals; behavioral freedom, characterized by the possibility of expressing behaviors characteristic of the species; and psychological freedom, which is characterized by the absence of fear and stress, where the conditions of the environment are facilitated, avoiding animal suffering (Alves; Nicodemus; Silva, 2015; Alves; Porfírio Da Silva; Karvatte Junior, 2019). Integration systems, when well planned, meet all these precepts and, when compared to traditional pasture production systems, generate better animal welfare.

This is because the trees present in the pasture, as a forest component of the integration system, promote considerable changes in the local microclimate, such as wind speed, temperature, vapor saturation pressure, air humidity and incident solar radiation, according to Lourençano; Cavichioli (2019), the latter being reduced by up to 30%, depending on the forest species, and also protecting them from excessive cold (Alves; Nicodemus; Silva, 2015; Alves; Porfírio Da Silva; Karvatte Junior, 2019). On the other hand, it is important to pay attention to the amount of shade offered, as it is essential that there are uncovered areas (simple rows), so that the density of the shadows does not harm the development of forage, thus compromising animal nutrition and crops, in addition to interfering with air movement, compromising the efficiency of temperature regulation of the animals (Alves; Nicodemus; Silva, 2015; Alves; Porfírio Da Silva; Karvatte Junior, 2019).

CONCLUSION

Integrated agricultural production systems (SIPA's) present an alternative potential to increase productivity and minimize the effects of environmental impact, from the rotation and diversification in the production of grain crops with forage crops in the same area. Due to the great diversity of ICL systems, they can be applied in all regions of Brazil, and in all sizes of properties and bring benefits to producers, consumers, and especially to the environment and production systems.

REFERENCES

1. Alvarenga, R. C., et al. (2010). Sistema integração lavoura-pecuária-floresta: Condicionamento do solo e intensificação da produção de lavouras. *Informe Agropecuário, 31*(257), 59–67.

2. Alves, F. V., & Nicodemo, M. L. F., & Porfírio-da-Silva, V. (2015). Bem-estar animal em sistema de integração lavoura-pecuária-floresta.

3. Alves, F. V., Porfírio-da-Silva, V., & Karvatte Junior, N. (2019). Bem-estar animal e ambiência na ILPF. *Embrapa Gado de Corte*, 209–223.

4. Anghinoni, I., Carvalho, P. C. D. F., & Costa, S. G. D. A. (2013). Abordagem sistêmica do solo em sistemas integrados de produção agropecuária. *Tópicos em Ciência do Solo, 8*(2), 221–278.

5. Araújo, L. G. S. de, & Mendonça, M. de S. (2020). Desenvolvimento sustentável: Histórico e estratégias - Uma revisão bibliográfica. *A Educação Ambiental Em Uma Perspectiva Interdisciplinar*, 173–183.

6. Arenhardt, E. G. A., et al. (2015). The nitrogen supply in wheat cultivation dependent on weather conditions and succession system in southern Brazil. *African Journal of Agricultural Research, 10*(48), 4322–4330.

7. Assad, E. D. (2021). Sistemas agrícolas adaptados às mudanças climáticas. *Ciência e Cultura, 73*(1), 35-40.

8. Assis, P. C. R., et al. (2019). Atributos físicos, químicos e biológicos do solo em sistemas de integração lavoura-pecuária-floresta. *Agrarian, 12*(43), 57–70.

9. Assmann, T., et al. (2017). Adubação de sistemas em integração lavoura-pecuária. *Congresso Brasileiro de Sistemas Integrados de Produção Agropecuária*, (December), 67–84.

10. Balbino, L. C., et al. (2011). Evolução tecnológica e arranjos produtivos de sistemas de integração lavoura-pecuária-floresta no Brasil. *Pesquisa Agropecuária Brasileira, 46*(10), 1–12.

11. Balbino, L. C., et al. (2012). Informações agronômicas. *Informações Agronômicas, 19*, 1–18.

12. Barbosa, L. R., et al. (2022). Organic matter compartments in an Ultisol under integrated agricultural and livestock production systems in the Cerrado. *Ciência Rural, 52*(10).

13. Battiston, J., et al. (2020). Chemical compounds and kinects of in vitro ruminal degradation of white oats URS Guapa under distinct levels of nitrogen fertilization. *Arquivo Brasileiro de Medicina Veterinária e Zootecnia, 72*(2), 581–589.

14. Bertol, F. D. Z., et al. (2022). Liming and grazing intensities effects on soil mineral nitrogen throughout the pasture cycle in a subtropical integrated crop-livestock system. *Revista Brasileira de Ciência do Solo, 46*(3).

15. Bohn, A., et al. (2020). Nitrogen fertilization of self-seeding Italian ryegrass: Effects on plant structure, forage and seed yield. *Ciência Rural, 50*(6).

16. Bolsen, K. K. (1996). Silage technology. In *Australian Maize Conference, 2.*, Queensland. *Anais… Queensland: Gatton College*, 1-30.

17. Bonetti, J. D. A., et al. (2015). Influence of the integrated crop-livestock system on soil and soybean and brachiaria yield. *Pesquisa Agropecuária Tropical, 45*(1), 104–112.

18. Bungenstab, D. J., et al. (2018). Forrageiras em sistemas de produção de bovinos em integração (Capítulo 24).

19. Cabral Neto, O., et al. (2024). Fundamentos e características do sistema de integração lavoura-pecuária no estado do Tocantins: Uma revisão da literatura. *Revista Multidisciplinar do Nordeste Mineiro, 3*(3).

20. Camporezi, J. S. (2022). Composição química e morfológica de pastos safrinha na integração lavoura pecuária. Trabalho de conclusão de curso, Faculdade de Ciências Agrárias e Tecnológicas – Unesp, Dracena.

21. CONAB. (2019). Acompanhamento da safra brasileira - Grãos. *Obs. Agrícola, 1*(1), 1-60.

22. Capitani, D., & Farina, J. (2022). Viabilidade energética e econômica da produção de biogás a partir de dejetos bovinos em um sistema de integração lavoura-pecuária. *REUNIR: Revista de Administração Contabilidade e Sustentabilidade, 12*(3), 14-29.

23. Cardoso, E. S., et al. (2014). Reguladores de consumo de bovinos em pastagem: Recentes avanços. *Revista Eletrônica Nutritime, 11*(5), 3672-3682.

24. Carlos, S. D. M., et al. (2022). Custos de recuperação de pastagens degradadas nos estados e biomas brasileiros. *Observatório de Conhecimento e Inovação em Bioeconomia*, Fundação Getúlio Vargas - FGV-EESP, São Paulo.

25. Carmona, F., Denardin, L., Martin, A., Anghinoni, I., & Carvalho, P. C. de F. (2018). Sistemas integrados em produção agropecuária em terras baixas.

26. Carvalho, C. B. de M., et al. (2021). Métodos de análise da composição química e valor nutricional de alimentos para ruminantes. *Research, Society and Development, 10*(10), e523101019047.

27. Carvalho, P. C. de F., et al. (2018). Animal production and soil characteristics from integrated crop-livestock systems: Toward sustainable intensification. *Journal of Animal Science, 96*(8), 3513–3525.

28. Cassol, L. C., et al. (2011). Produtividade e composição estrutural de aveia e azevém submetidos a épocas de corte e adubação nitrogenada. *Revista Ceres, 58*(4), 438–443.

29. Cordeiro, L. A. M., et al. (2015). Integração lavoura-pecuária-floresta: O produtor pergunta, a Embrapa responde. Brasília, DF: Embrapa.

30. Coser, T. R., et al. (2018). Short-term buildup of carbon from a low-productivity pastureland to an agrisilviculture system in the Brazilian savannah. *Agricultural Systems, 166*(September), 184–195.

31. De Faccio Carvalho, P. C., et al. (2021). Land-use intensification trends in the Rio de la Plata region of South America: Toward specialization or recoupling crop and livestock production. *Frontiers of Agricultural Science and Engineering, 8*(1), 97–110.

32. De Macêdo Carvalho, C. B., et al. (2021). Métodos de análise da composição química e valor nutricional de alimentos para ruminantes. *Research, Society and Development, 10*(10), 1-10.

33. Denardin, L. G. de O., et al. (2019). No-tillage increases irrigated rice yield through soil quality improvement along time. *Soil and Tillage Research, 186*(July 2018), 64–69.

34. Detmann, E., Gionbelli, M. P., & Huhtanen, P. (2014). A meta-analytical evaluation of the regulation of voluntary intake in cattle fed tropical forage-based diets. *Journal of Animal Science, 92*(10), 4632–4641.

35. Dotto, A. V. E., Robaina, L. E. de S., & Sccoti, A. A. V. (2022). Analysis of the use and occupation of land in the municipality of São Martinho da Serra – RS. *Geografia Ensino & Pesquisa, 26*.

36. Embrapa. (2019). Integração lavoura-pecuária-floresta: Noções técnicas. Disponível em: <https://www.embrapa.br/tema-integracao-lavoura-pecuaria-floresta-ilpf/nota-tecnica>. Acesso em: 10 set. 2019.

37. Flores, et al. (2008). *Revista Brasileira de Zootecnia* Produção de forragem de populações de azevém anual no estado do Rio Grande do Sul Forage production of annual ryegrass populations in the state of Rio Grande do Sul, Brazil.

38. Fontaneli, R. S., et al. (2016). A contribuição das forrageiras de inverno para a pecuária de leite.

39. Fontaneli, R. S., Fontaneli, R. S., & Panisson, F. T. (2022). Sistemas integrados de produção agropecuária em plantio direto. In: Sistema plantio direto no Brasil. Passo Fundo: Aldeia Norte, 245-258.

40. Gameiro, S. (2014). Avaliação da cobertura vegetal por meio de índices de vegetação (NDVI, SAVI e IAF) na Sub-Bacia Hidrográfica do Baixo Jaguaribe, CE. *Terræ, 2000*.

41. Gerdes, L., et al. (2005). Chemical composition and digestibility of forage mass in irrigated aruanagrass pastures or oversown with a mixture of winter forage species. *Revista Brasileira de Zootecnia, 34*(4), 1098–1108.

42. Guesmi, H., Salem, H. B., & Moujahed, N. (2019). Integration crop-livestock under conservation agriculture system. *Journal of New Sciences, 65*, 4061-4065.

43. IBGE - Instituto Brasileiro de Geografia e Estatística. (2019). Censo agropecuário 2017: Resultados definitivos. Rio de Janeiro, RJ: IBGE.

44. Junior, A. A. B., et al. (2020). Tecnologias de produção de soja. 1ª edição – Londrina: Embrapa Soja, Capítulo 6, 119-131.

45. Kichel, A. N., et al. (2014). Sistema de integração lavoura-pecuária-floresta (ILPF) - Experiência no Brasil. *Boletim de Indústria Animal, 71*(1), 94–105.

46. Kumar, V., & Ladha, J. K. (2011). Direct seeding of rice: Recent developments and future research needs. 1. ed. *Elsevier Inc., 111*.

47. LAPIG - Laboratório de Processamento de Imagens e Geoprocessamento. (2022). Dados mapeamento da qualidade de pastagem brasileira entre 2000 e 2020.

48. Lang, C. R. (2004). Pastejo e nitrogênio afetando os atributos químicos do solo e rendimento de milho no sistema de integração lavoura-pecuária. *Tese de Doutorado*, Universidade Federal do Paraná, Curitiba. 89p.

49. Leão, A., et al. (2021). Guia recuperação de solos degradados no Cerrado: Alternativas para produção sustentável. *The Nature Conservancy*. Brasília: Embrapa.

50. Lopes, M. L. T., et al. (2009). Sistema de integração lavoura-pecuária: efeito do manejo da altura em pastagem de aveia preta e azevém anual sobre o rendimento da cultura da soja. *Ciência Rural, 39*, 1499-1506.

51. Lourençano, L. S., & Cavichioli, F. A. (2019). Sistema Integração Lavoura-Pecuária-Floresta. *Revista Interface Tecnológica, 16*(2), 214–225.

52. Macedo, M. C. M., & Araújo, A. R. D. (2019). Sistemas de produção em integração: alternativa para recuperação de pastagens degradadas. In Bungenstab, D. J., Almeida, R. G., Laura, V. A., & Balbino, L. C. (Eds.), *ILPF: Inovação com integração de lavoura, pecuária e floresta* (pp. 295–317). Brasília, DF: Embrapa.

53. Magalhães, C. A. de S. (2019). Embrapa Agrossilvipastoril: Primeiras contribuições para o desenvolvimento de uma agropecuária sustentável. *Embrapa Agrossilvipastoril*, 164-173.

54. Martins, M. R., & Rezende, M. L. (2020). Uso da integração lavoura-pecuária-floresta e proteção de áreas de preservação permanente em propriedades familiares. *Revista Em Extensão, 19*(1), 98–105.

55. Mazzucchelli, R. D. C. L., et al. (2020). Changes in soil properties and crop yield as a function of early desiccation of pastures. *Journal of Soil Science and Plant Nutrition, 20*(3), 840–848.

56. Mertens, D. R. (1996). Formulating dairy rations: using fiber and carbohydrate analyses to formulate dairy rations. In *Information conference with dairy and forage industries*. Madison: US Dairy Forage and Research Center.

57. Moraes, A., et al. (2014). Sistemas de integração lavoura-pecuária. In Reis, R. A., et al. (Eds.), *Forragicultura: Ciência, tecnologia e gestão dos recursos forrageiros* (pp. 203-218). Jaboticabal: Gráfica Multipress.

58. Moraes, A., et al. (2017). Avanços técnico-científicos em SIPA no subtrópico brasileiro. In J. Jamhour & T. S. Assmann (Orgs.), *I Congresso Brasileiro de Sistemas Integrados de Produção Agropecuária e IV Encontro de Integração Lavoura-Pecuária no Sul do Brasil* (165 p.). Pato Branco: UTFPR Câmpus Pato Branco.

59. Nascimento, M. L., Farjalla, Y. B., & Nascimento, J. L. (2009). Consumo voluntário de bovinos - Bovines voluntary intake. *Revista Eletrônica de Veterinária, 10*, 1–27.

60. Oliveira, P. de, et al. (2013). Evolução de sistemas de integração lavoura-pecuária-floresta (ILPF): estudo de caso da Fazenda Santa Brígida, Ipameri, GO. *Embrapa Cerrados, 318*(1), 50.

61. Oliveira, B. C. de, et al. (2017). Mecanismos reguladores de consumo em bovinos de corte. *Nutritime Revista Eletrônica, 14*(4), 6066–6075.

62. Ongaratto, F., & Romanzini, E. P. (2021). Ecossistema pastoril: Serviços ecossistêmicos, características do dossel e emissão de gases do efeito estufa. *Zootecnia: Pesquisa e Práticas Contemporâneas, 1*(January), 83–107.

63. Pavinato, P. S., et al. (2014). Production and nutritive value of ryegrass (cv. Barjumbo) under

nitrogen fertilization. *Revista Ciência Agronômica, 45*(2), 230–237.

64. Pedroso, C. E. S., et al. (2004). Produção de ovinos em gestação e lactação sob pastejo em diferentes estádios fenológicos de azevém anual. *Revista Brasileira de Zootecnia, 33*, 1345–1350.

65. Pellegrini, L. G. de, et al. (2010). Produção e qualidade de azevém-anual submetido a adubação nitrogenada sob pastejo por cordeiros. *Revista Brasileira de Zootecnia, 39*(9), 1894–1904.

66. Peretti, J., et al. (2017). Composição química e cinética de degradação ruminal da aveia branca (Avena sativa L.) cv. IPR126 sob diferentes níveis de nitrogênio. *Revista Brasileira de Saúde e Produção Animal, 18*(1), 89–102.

67. Peterson, C. A., et al. (2019). Winter grazing does not affect soybean yield despite lower soil water content in a subtropical crop-livestock system. *Agronomy for Sustainable Development, 39*(2).

68. Ponciano, V. F. G., et al. (2021). Sistema Santa Fé auxilia na redução do escoamento superficial e melhoria da qualidade da água? *Colloquium Agrariae, 17*(1), 01–09.

69. Queirós, L. (2020). Sistemas integrados de produção agropecuário. *Trabalho de conclusão de curso*, Instituto Federal Goiano – Campus Iporá.

70. Reis, J. C., et al. (2020). Assessing the economic viability of integrated crop-livestock systems in Mato Grosso, Brazil. *Renewable Agriculture and Food Systems, 35*(6), 631–642.

71. Rocha, J. V. F. (2021). Utilização da integração lavoura-pecuária na recuperação de áreas degradadas. *Trabalho de conclusão de curso*, Pontifícia Universidade Católica de Goiás, Goiânia, Goiás.

72. Sandini, I. E., et al. (2011). Residual effect of nitrogen in the maize production in crop livestock integration. *Ciência Rural, 41*(8), 1315–1322.

73. Sene, S. M. de, & Bacha, C. J. C. (2024). Adoção dos sistemas integrados na agropecuária do Brasil. *Revista de Economia e Sociologia Rural, 62*(1), 1–21.

74. Serafim, R. S., Antonelli, A., & Santos, M. A. T. (2017). Determinação da matéria seca e proteína bruta pelo método convencional e microondas. *Zootecnia Animal Science, 1*, 1139–1143.

75. Silva, P. L. F., et al. (2022). Estresse efetivo de solo arenoso sob integração lavoura-pecuária nos tabuleiros costeiros do Rio Grande do Norte (Brasil). *Revista Brasileira de Meio Ambiente, 10*(3).

76. Silva, D. J., & Queiroz, A. C. (2009). *Análise de alimentos (métodos químicos e biológicos)* (3a ed.). Viçosa: [s.n.].

77. Silva, A. G., et al. (2020). Variabilidade dos atributos físicos do solo e dinâmica da palhada em sistema integração lavoura-pecuária no Cerrado. *Revista Brasileira de Milho e Sorgo, 18*(3), 429–440.

78. Silva, P. L. F. D., Andrade, R. R., & Oliveira, L. D. (2021). Soil physical quality of Arenosol in the semi-arid environment under integrated agricultural systems. *Brazilian Journal of Biosystems Engineering*, 15(4), 598–616.

79. Skorupa, L. A., & Manzatto, C. V. (2019). Avaliação da adoção de sistemas de integração lavoura-pecuária-floresta (ILPF) no Brasil. In *Embrapa Meio Ambiente* (pp. 340–379).

80. Sniffen, C. J., et al. (1992). A net carbohydrate and protein system for evaluating cattle diets: II-Carbohydrate and protein availability. *Journal of Animal Science*, 70, 3562–3577.

81. Soares, M. T. S., et al. (2019). Resposta inicial do eucalipto após aplicação de dejetos líquidos de suínos no oeste do Paraná. In *Simpósio Internacional Sobre Gerenciamento de Resíduos Sólidos Agroindustriais e Agropecuários* (6th ed.).

82. Souza, E. D. D. (2008). Evolução da matéria orgânica, do fósforo e da agregação do solo em sistema de integração agricultura-pecuária em plantio direto (Tese de Doutorado em Ciência do Solo). Programa de Pós-Graduação em Ciência do Solo, Universidade Federal do Rio Grande do Sul, Porto Alegre, RS, Brasil.

83. Souza, G. S. de, et al. (2021). Sistemas silvipastoris e preparo do solo na renovação de pastagens degradadas no Espírito Santo. In F. G. Gonçalves et al. (Eds.), *Sistemas integrados de produção: Pesquisa e desenvolvimento de tecnologias* (pp. XX–XX). Guarujá, SP: Científica Digital.

84. Theisen, G., & Scivittaro, W. B. (2023). Arroz irrigado e soja em terras baixas e mitigação das mudanças climáticas. *Sistemas de produção de arroz irrigado e soja em terras baixas e mitigação das mudanças climáticas*.

85. Vilela, L., et al. (2011). Sistemas de integração lavoura-pecuária na região do Cerrado. *Pesquisa Agropecuária Brasileira*, 46(10), 1127–1138.

86. Vilela, L., et al. (2015). Integração lavoura-pecuária-floresta: O potencial brasileiro e o papel dos engenheiros agrônomos. *Relatório de Pesquisa* (p. 7).

87. Vinholis, M. D. M. B., et al. (2021). The effect of meso-institutions on adoption of sustainable agricultural technology: A case study of the Brazilian Low Carbon Agriculture Plan. *Journal of Cleaner Production*, 280.

88. Vinholis, M. de M. B., et al. (2022). Sistemas de integração lavoura-pecuária-floresta no estado de São Paulo: Estudo multicascos com adotantes pioneiros. *Revista de Economia e Sociologia Rural*, 60(1), e234057.

89. Ward, R., & Beth de Ondarza, M. B. (2008). Relative feed value (RFV) vs. relative forage quality (RFQ).