Chapter

Advances in Pasture Management and Animal Nutrition to Optimize Beef Cattle Production in Grazing Systems

Andressa Scholz Berça, Eliéder Prates Romanzini, Abmael da Silva Cardoso, Luís Eduardo Ferreira, André Pastori D'Aurea, Lauriston Bertelli Fernandes and Ricardo Andrade Reis

Abstract

The increasing demand of meat requires the adoption of sustainable intensification livestock systems, applying nutritional strategies to reduce any negative contribution from beef cattle to global warming and, at the same time, to increase animal performance and productive efficiency. The pasture management practices and feed supplementation, mainly using non-edible feed with less costs, could minimize environmental and social impacts, resulting in higher productivity with less inputs utilization. Tropical grass submitted to grazing management according to plant height present high soluble protein and low levels of indigestible neutral detergent fiber contents. Energy or rumen undegradable protein supplementation, associated to alternative additives to antibiotics effects, such as probiotics, tannin, essential oils and saponin, can help to fully exploit the animal genetic potential and nutrient utilization efficiency, which decreases greenhouse gases emissions and improves animal performance. Hence, more information about these tools can make the livestock systems in tropical pasture more efficient and eco-friendlier.

Keywords: greenhouse gases, non-edible feed, organic feed additive, supplementation, tropical pastures

1. Introduction

The large territorial extension and the tropical climate favorable to the growth of tropical grasses make pastures the basis for feeding Brazilian beef cattle, being the most practical and economical source to feed cattle in Brazil [1], responsible for the production of 89% of the entire herd, which reaches almost 188 million heads [2].

The economy globalization induces agriculture to become more and more efficient and competitive, therefore, failures in pasture management can be decisive in the success or unsuccess of beef cattle livestock [3]. In this sense, the great challenge of beef cattle production systems on pastures is the use of practices capable to increase the productivity and quality of meat with low environmental impact [4, 5]. For this, enhancing the animal performance and optimizing the use of basal forage resources is the main objective of management strategies to be adopted [6].

In Central Brazil, tropical forages present as a typical characteristic the seasonality of production, concentrating its growth between 70 and 80% in the rainy season, and 20 to 30% in the dry season [7]. The effects of this seasonality in beef cattle are evident through drastic variations in the chemical and structural composition of the forage canopy, which directly reflect on intake, digestibility, and weight gain and, consequently, delay the slaughter age of the animals [8]. The rainy season presents advantages for ruminant production as it has favorable edaphoclimatic conditions for the green leaf and forage mass productions with higher levels of crude protein (CP) and total digestible nutrients (TDN), when compared to the dry season, in addition to be the time to explore the maximum of animal performance and gain per area [9].

In theory, high-quality tropical forages should be able to provide the nutrients needed to meet grazing animals' requirement, including energy, protein, minerals and vitamins. However, the chemical composition of tropical grass forage is rarely in a state of balance between animal requirements and the nutrients needed to obtain high weight gains, due to the quantitative and qualitative seasonality inherent to the pasture system, interfering in the expression of the genetic potential of beef cattle in Brazil [10]. In this sense, the management strategies adopted by the manager can provide differences in the magnitude of responses in animal performance and weight gain per explored pasture area [11].

The intensification of the production system requires, in addition to the use of pasture management techniques, the adoption of nutritional strategies, such as the diet supplementation of grazing cattle, as well as the use of the genetic potential of the animals, through selection and crossings. Such strategies must be consolidated in order to ensure the profitability of the production system, sustainability of the pasture ecosystem and production of quality meat for the consumer market [5, 6]. Faced with such conditions, the search for alternatives to chemical additives that reduce the negative contribution of livestock to global warming and, at the same time, increase performance and productive efficiency is increasing [12]. In this context, the use of organic additives has been established, among these components are condensed tannins, saponins and essential oils. These compounds come from plants, usually its extracts, and have the ability to manipulate ruminal fermentation and animal metabolism, in order to increase performance and promote beneficial effects to the environment [13].

Therefore, this chapter aimed to address aspects related to the production of beef cattle from a sustainable perspective, considering grazing management, the strategic use of diet supplementation for grazing animals, featuring the inclusion of non-edible feed and organic additives on supplement composition and their results.

2. Aspects related to beef cattle in grazing systems

2.1 Livestock contribution to greenhouse gases

As the largest land use system in Brazil, the agricultural sector contributes 40% of the global agricultural gross domestic product, provides income for more than 1.3 billion people and food for at least 800 million people, using vast areas of pasture and a third of agricultural land for food production in the world [14]. However, although it assumes great importance in the economic scenario and is essential for world food, the rapid population growth and the production and consumption of agricultural products is contributing to a substantial emission of greenhouse gases (GHG) to the environment, being responsible for 14.5% of the total human induced GHG emissions in the world [15], which makes the activity often cited as the villain of global warming [16].

Livestock contributes to GHG emissions in the form of methane (CH_4) from enteric fermentation, nitrous oxide (N_2O) from the use of nitrogen (N) fertilizers, and CH_4 and N_2O from animal excreta management and deposition. Furthermore, carbon dioxide (CO_2) is also produced from the use of fossil fuel and energy on farms [5].

The production of enteric CH_4 by ruminants is a fundamental process for the adequate functioning of the digestive system of these animals, but it results in a loss of gross ingested energy and, consequently, reduces animal performance [16], in addition to having its contribution in 3.5% of the world's total GHG emissions [17]. Worldwide, CH_4 is considered the second largest contributor to global warming (16%), right after CO_2 (65%) [17]. The gas from livestock systems originates mainly from enteric fermentation (90%), being the rest produced from the fermentation of animal organic waste [18].

The use of N fertilizers and the deposition of animal excreta (feces and urine) are the main responsible for the losses of N to the environment, causing not only economic losses, but also environmental ones, due to nitrate leaching, volatilization of ammonia (NH_3) and, mainly, N_2O emission [19]. It is estimated that the annual global losses of N via excreta represent almost 26 million tons, and N fertilizers, 17 million tons [20]. The Intergovernmental Panel on Climate Change [17] estimates NH_3 volatilization values of 30% (20–50%) of excreta (urine and feces) and 15% (3–43%) of the urea fertilizer.

Although ruminants contribute with gas emissions to the environment, management strategies are essential for the sustainability of the global food system. In general, the practices involve improving the environmental performance of livestock systems through the management, supplementation, and adequate use of alternative additives to antibiotics; establish sustainable levels of intake of foods of animal origin, as well as using ingredients that are not consumed by humans (non-edible feed) [21, 22].

Indications for reducing CH_4 production include measures that reflect better animal performance and result in shorter production cycles, involving improvement in the composition and quality of forage, by reducing the cell wall and increasing levels of soluble protein and carbohydrates, e.g., improvement of animal genetics, feed supplementation [23]. Furthermore, the use of substances such as additives composed of organic acids, yeast and plant extracts, such as tannin and saponin, also help to reduce methanogenesis by manipulating ruminal fermentation [22].

A common strategy to reduce N losses in the system, both directly through N excretion via feces and urine, and indirectly through the use of fertilizers, is the mixed pastures of grass and legume, due to its association with nitrogen-fixing bacteria, which increases forage productivity and nutritive value [19]. The improvement in the diet quality, in turn, can change the urine and feces composition and, consequently, N losses through excreta [24].

2.2 Grazing management

Animal performance in pastures is mainly determined by forage quality, which is a function of dry matter (DM) intake and forage nutritive value [8]. In turn, the nutritive value is determined by the chemical composition and the nutrients directly responsible for the DM digestibility, CP and neutral detergent fiber (NDF) contents [8]. In this sense, the correct management of pastures affects both pasture chemical composition and structure, in addition to factors such as forage mass, supply of leaves, stem and dead material, which are determinants in the animal ingestive behavior and, consequently, in the nutrient's intake [25].

During the rainy season, the management must be done through strategies that guarantee the longest duration in the supply of quality forage and/or the improvement of forage nutritive value, aiming to achieve greater productivity of the system [26]. In this sense, pasture management should prioritize the adjustment in grazing intensity to obtain high yields per animal and per area, considering the morphophysiological principles that govern the plant growth and its biological limits, in order to allow persistence of the pasture and avoid its degradation [12]. Any management criteria to be adopted, therefore, must consider the adjustment of forage allowance and stocking rate in order to simultaneously control the quality and quantity of available forage and maintain the sustainability of the system [11].

In general, pasture management involves a set of practices aimed at changing the morphology or delaying plant maturity, in order to increase the level of digestible nutrients in the diet for cattle and ensure adequate performance [27]. Furthermore, Sollenberger et al. [28] reported that grazing management should allow for a balance between plant growth, intake, and animal production, to keep a stable production system.

According to Pereira et al. [29], the control of pasture defoliation is crucial to the sustainability of the system, as it is an antagonistic event, that is, the plant uses the leaves to capture light and carry out photosynthesis, producing carbohydrates that allow the maintenance of life and of development. On the other hand, the leaf is the morphological component with the highest nutritive value that compose most of the diet of grazing animals [25]. Therefore, it is necessary to adopt management techniques that prioritize the forage plant and the grazing animal, allowing high forage productivity combined with high animal performance [5].

2.2.1 Grazing height

Pasture management based on the adjustment of grazing intensity can be done following several criteria, such as grazing pressure, forage allowance, residual forage mass, residual leaf area index (LAI), height, and others [11]. The adoption of height as a management criterion allows the control of forage mass and stocking rate, being able to relate pasture growth with its use and, consequently, with the canopy structure and responses in intake and animal performance [30]. In addition, height is a functional and practical field indicator, which can be correlated to other management criteria, such as forage allowance and light interception (LI) [31]. Also, grazing height directly affects the ingestive behavior of grazing animals [5].

According to Reis et al. [8], grazing management must adjust the frequency and intensity of defoliation, so that the animal can harvest forage at the appropriate physiological age, which directly affects the nature and concentration of structural carbohydrates in the cell wall and nitrogenous compounds, which are the main determinants of forage quality. Thus, the authors report that pastures kept under continuous stocking and efficiently managed can provide continuous intake of young leaves and, consequently, greater forage digestibility when compared to the intermittent stocking system.

Pasture management under different grazing intensities promotes different responses in forage mass accumulation and nutritive value. Studies conducted at FCAV/Unesp Campus de Jaboticabal, Brazil generated consistent data on the effects of different heights of tropical pasture management in the rainy season [30, 32–37]. The afore mentioned authors evaluated Marandu grass pastures in a continuous stocking and variable stock grazing system, at three heights: 15, 25 and 35 cm. As the grazing height increased, there was a reduction in CP and an increase in fiber contents, higher senescence rate and higher leaf elongation rate, the latter two being related to higher LAI, which intercepts a greater amount of solar radiation. On the other hand, canopies kept at a lower height showed reduced growth and senescence, lower forage accumulation, and restriction in the green material allowance, which limited intake and animal performance. In summary, the authors concluded that Marandu grass pastures managed under continuous stocking, during the rainy season, should be managed at 25 cm height, in order to maximize forage intake and individual daily weight gain in the growing phase, without a marked decline in weight gain per area.

In this sequence of studies, Marandu grass pastures managed under continuous stocking at 25 cm height corresponded to 95% of LI and, according to Delevatti et al. [38], this management results in pastures with a higher proportion of leaves, higher protein fraction, lower proportions of dead material and insoluble neutral detergent fiber (iNDF).

In Marandu grass pastures subjected to rotational grazing, 95% LI values during regrowth were also obtained with an average sward pre-grazing height of around 25 cm [39, 40]. According to Pedreira et al. [40], the management strategy of entering animals at 95% LI reduces the amount of self-shadowed material in the canopy and, therefore, reduces tissue death. Furthermore, in a rotational system, the height of the post-grazing residue interferes in the pasture intake due to changes in the canopy structure and the stratum explored by the animals during grazing [39].

2.2.2 Nitrogen fertilization

According to Reis et al. [11], the growth, development and chemical composition of forages are determining factors in animal performance, and, in turn, are affected by physiological aspects inherent to the plant and environmental conditions. Thus, N is the most limiting element for the development of forage grasses, due to the amount of nutrient extracted by the plant and the low residual effect of N in the soil after its application, also to losses through volatilization, leaching and immobilization by microorganisms [41].

In this scenario, the use of fertilization in pastures has been intensified in recent years, aiming to increasing the forage nutritive value and the stocking rate, which, consequently, increases the production per unit of area [38]. The pasture stocking rate, in turn, depends directly on the productivity of the forage plant, which is affected by several factors such as precipitation, temperature, light intensity, soil fertility and fertilization, especially with N [42].

According to Rezende et al. [43], the effect of N fertilization on yield is related to the initial tillering after cutting, as it promotes rapid expansion of the leaves, quickly replenishing photosynthetic tissues and increases tillers formation, responsible for higher DM production. In addition, N fertilization increases the concentration of CP, decreases N insoluble in neutral detergent and allows for greater efficiency in the rumen microbiota cellulolytic activity, factors that optimize animal performance [6]. The efficiency of N utilization by forage plants, however, is quite divergent, ranging from 5 to 89.2 kg of DM/kg of N applied [44].

The CP ruminal degradability of tropical and temperate forage plants is naturally high and increases with increasing N dose applied to the pasture [6]. Specially in tropical grass pasture management situations in which the high degradability of N compounds associated to the high content of structural carbohydrates with slow degradation is observed, the lack of balance between N and carbon skeletons arising from the degradation of carbohydrates in the rumen, compromises efficiency of nitrogen use (ENU) and microbial protein synthesis [45]. This condition, however, generates excessive losses of N compounds in the ruminal environment in NH_3 form in the urine, generating a protein deficit in relation to the requirements for high gains [9], which, in addition to resulting in economic losses, can be harmful to the environment through N losses in the form of volatilized NH_3, N_2O emission and nitrate leaching [4, 46].

In summary, pasture management practices during the rainy season, including maintenance N fertilization, adjustment in stocking according to the amount of forage available, provide pasture persistence, which surely dilutes production costs and gas emissions resulting from the inadequate land use and the prolonged period of pasture use [8].

2.3 Diet supplementation

In intensive production systems, supplementation is adopted as a technological tool to enhance the pastures use, aiming a compatible production with the genetic merit of the animals and profitability [27]. In general, supplementation allows the production of earlier animals, the increase in pastures support capacity, higher gain per animal and per area, the reduction of the time needed to reach slaughter weight, which, consequently, shortens the rearing and finishing grazing animals, in addition to the production of better-quality meat and carcass [9].

Thus, there is an increase in livestock offtake rates and a rapid turnover of invested capital, improving the efficiency and profitability of this system [47]. Furthermore, in grazing management systems that aims to optimize performance per animal and per area, it is possible to minimize the environmental impacts of beef cattle production in tropical grass pastures [4, 48].

The amount of protein and energy needed to optimize the use of nutrients, however, will depend on the pasture chemical composition and the crude protein/digestible organic matter (DOM) ratio, since ENU depends on the energy availability [11]. Therefore, supplementation must be preceded by the characterization of the quantity and quality of available forage, especially regarding the characteristics of carbohydrates and N compounds, to ensure the supply of nutrients that limit ruminal microbial activity [33].

2.3.1 Supplementation during dry season

Under conditions in Central Brazil, dry season is the most critical phase of grazing cattle production system. During this season, animals consume forage with low nutritional value, characterized by a high content of indigestible fiber and CP contents below critical level (7% CP), thus limiting its intake and, consequently, productive performance [27, 49]. Therefore, if there is no supplementation of cattle diet during this season, in order to supply the deficient nutrients of forage, there will be a reduction in weight gain or even negative performance, since the body nutrients are mobilized for maintenance, increasing the slaughter age, the fixed cost of the activity, and reducing livestock offtake rates [8].

According to Reis et al. [11], in the dry season, protein is the most limiting nutrient and, therefore, the one with the greatest need for supplementation, since it is a determinant in the capacity for fibrous substrates degradation by ruminal microorganisms and, consequently, in the passage rate and dry matter intake. In this sense, strategic supplementation during dry season involves the supply of protein, considering the ruminal events of digestion, fermentation, synthesis of N compounds and intake of low-quality forage. The live weight gains obtained through supplementation at this phase can be low, ensuring maintenance of animal weight, moderate (up to 300 g/animal/d), and even high (from 600 to 700 g/animal/d), enabling earlier slaughter of animals [8]. An advantageous alternative is the use of multiple supplements (protein and energy), which result in gains in the order of 150 to 300 g/animal/d with 0.5 to 2% BW and 700 to 1000 g/animal/d with 8 to 10% BW supplement.

2.3.2 Supplementation during rainy season

Although the rainy season is characterized by presenting edaphoclimatic conditions favorable to forage production, the way in which these conditions occur, associated to the management strategies adopted and the interactions between pasture quality and quantity and nutrient supply via supplement, can provide differences in the magnitude of responses to supplementation on animal performance and gain per area [48].

During this period, when forages are classified as medium to high-quality, with N compounds above the minimum recommended (7% CP) for full activity of bacteria using structural carbohydrates and with levels of rumen ammonia ($N\text{-}NH_3$) above 5 mg/dL, the objective of supplementation associated with grazing management strategies that maximize the production of grazing stratum, is to prevent deleterious effects in the use of potentially digestible NDF (pdNDF) in forage [49, 50]. According to Huhtanen et al. [50], pdNDF is a nutritionally more adequate entity for evaluating forage quality and corresponds to the portion of NDF that is potentially digested by ruminal microorganisms, and the digested amount is related to the retention time in the fermentation compartments, being short to complete the digestion of all the ingested pdNDF.

According to Santos et al. [51], values of average daily gain (ADG) above 800 g during the rainy season are hardly reached by cattle kept in tropical pastures without the use of supplementation with concentrate. Despite the high cost of the additional gains inherent to the concentrate in this period (100 to 200 g/animal/day), this can result in a considerable reduction in finishing phase time, on pasture or feedlot, with possible economic returns [6, 33, 36, 52].

2.3.3 Energy supplementation

The main objective of grazing cattle supplementation is to increase the intake of energy and nutrients relative to those found in exclusive pasture diets [27]. When forage and easily fermentable carbohydrates are provided, fibrolytic microorganisms must compete with non-fibrous carbohydrate (NFC) for substrates such as NH_3, peptides, sulfur, and branched-chain carbon skeletons for their growth. An adequate supplementation strategy would be to maximize the use of forage by optimizing its digestion, increasing the passage rate of indigestible residue, and consequently increasing the intake of TDN [9].

According to Poppi and McLennan [26], high weight gains depend mainly on the supply of amino acids and energy transported to bovine tissues, a condition that is rare in animals under exclusive grazing. In this context, the same authors reported that energy supply can be an effective strategy to provide extra protein to the animal, as it allows NH_3, which is usually lost in urine, feces, or saliva, to be captured and incorporated into microbial protein. Microbial protein production, in turn, varies depending on the nature of the energy substrate supplied, such as starch, soluble fiber, pectin or sugars [53].

In intensive production systems, tropical grasses managed with high N doses (200 to 500 kg/N/ha) during the rainy season present about 40 to 50% of nitrogenous compound content in soluble form [54]. This fact, associated with the high content of structural carbohydrates with lower degradation rates, promotes a lack of synchrony between N and carbon skeletons arising from the degradation of carbohydrates in the rumen, disfavoring microbial protein synthesis and the efficiency of ruminal N-NH_3 utilization [26].

For Poppi and McLennan [26], this condition causes excessive losses of nitrogenous compounds in the ruminal environment in the NH_3 form, decreasing the microbial protein synthesis and generating a metabolizable protein (MP) deficit in relation to the requirements for high gains. Also, according to the researchers, maximum efficiency in microbial protein synthesis is reached when 160 g CP/kg DOM is observed, while values close to 210 g CP/kg DOM result in appreciable N loss.

According to Reis et al. [8], the main limitations for ruminal microbial growth would be related to the forage available for grazing, allowing low assimilation of available N in ruminal microbial protein, due to the high degradability of N compounds or lower carbohydrate degradation rate from fibrous forage. Thus, the supply of energy supplements with sources of rapid availability in the rumen can promote better animal performance by optimizing the microbial assimilation of N from N compounds with high degradability in the forage [45].

In a review by Reis et al. [11], the authors reported that during the rainy season, tropical grasses have DM digestibility between 55 and 65%, in addition to CP between 7.9 and 17.4% in their composition, which can result in different CP/DOM ratios. Assessing experiments conducted in the rainy season, it was observed that even in animals receiving only mineral salt, ruminal N-NH_3 values are above the critical level of 5 mg/dL of rumen fluid [30, 34]. However, only when the animals were supplemented, in the first 6 hours after supplementation, optimal levels of N-NH_3 were found in the rumen for maximum microbial growth, i.e., greater than 20 mg of N-NH_3/dL of ruminal fluid.

According to Leng [55], the inclusion of grains in roughage diets can reduce fiber digestibility, and this phenomenon is inherent to two effects that interfere in cellulolytic bacteria growth: a specific effect (drop in pH) and a non-specific (carbohydrate effect). In ruminants raised on tropical pastures, the variation in ruminal pH as a function of dietary supplementation seems to be relatively small, not affecting growth of bacteria that use fibrous carbohydrates. In this sense, the availability of soluble carbohydrates is responsible for the depression of fiber digestibility, as reported by Rooke et al. [56] and Huhtanen [57], reflecting the high effectiveness of long fibers that act in the maintenance of ruminal conditions [58].

The goal of a supplementation program for grazing animals is, therefore, to satisfy their requirements through an interactive and associative action between the basal forage and the supplemental sources. Thus, it is possible to enhance the positive associative effects and minimize negative interactions, in order to increase intake and optimize forage use, and not only the direct meeting of animal requirements via supplement [27].

2.3.4 Protein supplementation

Protein is the main limitation in cattle production systems on tropical pasture both in the dry and rainy seasons, especially when the pastures have low nutritive value [59]. At that time, although some tropical grasses have CP levels that meet the animal's nutritional requirements, part of this protein may be unavailable to the action of ruminal microorganisms, as it is linked to fibrous fraction [8]. Therefore, the formulation of a protein or protein-energy supplement for grazing cattle must consider the protein fraction available of forage, to provide enough N to use the energy substrates contained in the plant, such as digestible cellulose and hemicellulose [33].

The additional supply of N for animals consuming low nutritive value forage favors the growth of fibrolytic bacteria, increases the digestibility and microbial protein synthesis and, thus, allows to increase the voluntary intake of forage and improve the energy balance of the grazing animal [60]. The success of this supplementation strategy is associated to characteristics of pdNDF fraction, which will be the main source of energy to meet the demand of microorganisms [11]. Once the N requirements for the maintenance of ruminal microorganisms are met, the supplement can provide protein and energy for additional gains, according to the desired performance [60].

According to Pathak [61], cattle need two types of protein: rumen degradable protein (RDP), which is necessary to meet the requirements of ruminal microorganisms, and rumen undegraded protein (RUP), to meet the requirements of animals. In this scenario, dietary protein acts as a source of MP for ruminants, which in turn corresponds to the sum of the microbial protein synthesized from the RDP, with the RUP absorbed in the intestine.

Microbial protein synthesis depends on adequate sources of N and carbohydrates. In this sense, Rodríguez et al. [62] report that the structure of dietary proteins defines their degradation in the rumen and the contribution to available N to microorganisms. Ammonia is the main source of N in rumen microorganisms, but the availability of amino acids, peptides, and both increase the growth of cellulolytic and amylolytic bacteria [63], mainly due to direct incorporation into microbial protein or increased availability of carbon skeletons that can be used as an energy source or in the synthesis of microbial amino acids [64].

In mixed forage and concentrate diets, microbial protein synthesis can be increased due to better synchronization of nutrient release, adequate ruminal environment for maintenance of different species of microorganisms, increased amounts and types of substrates, higher nutrient intake and, consequently, an increase in the rate of passage of solids and liquids [65]. While forages can supply N as highly degradable protein or non-protein nitrogen (NPN), concentrates can supply N primarily as peptides and/or amino acids needed for microbial protein synthesis [26]. According to Pathak [61], efficiency tends to increase when readily fermentable carbohydrate is supplemented in less than 30% of the total diet but decreases when the level of supplementation is greater than 70%.

In pasture systems, even during rainy season, the synchronism between protein and energy in the rumen is rarely achieved, due to variations in forage quality and different rates of substrate utilization [7]. However, urea recycling is an important ruminant mechanism, capable of ensuring adequate levels of N-NH_3 in the rumen throughout the day, however when there is excess protein in the diet, there may be losses of N to the environment [9]. In this sense, the great challenge in choosing the sources and amount of CP in the supplement is to equate its use according to energy availability, ensuring adequate levels of N-NH_3 and minimizing losses in feces and urine [9].

Protein supplements can be composed by two protein sources: true protein and NPN. True protein sources have different RDP contents, such as cottonseed meal and corn gluten, which have about 65 and 18% RDP in their composition, respectively [66].

Non-protein nitrogen sources are completely soluble in the rumen and used by ruminal bacteria for microbial protein synthesis, and its use is common, mainly due to its lower cost, when compared to other conventional protein source, such as soybean meal [67]. According to Araújo et al. [68], the main source of NPN used in Brazil is urea, which has become an advantageous alternative by its easy availability in the market, high concentration of N in its composition and low unit cost. Additionally, urea is a source of N-NH_3 for fibrolytic microorganisms and, because of its low acceptability, it can be used as a controlling agent for supplement intake by animals. However, it is essential to respect the limits of urea inclusion in the diet, to avoid causing poisoning in animals and high N loss in urine. For more efficient use of nutrients, urea should be mixed with energy components rich in non-fibrous carbohydrates, true protein, and sulfur.

In pasture production systems, it is necessary to optimize the use of nutrients and forage digestibility to maximize weight gain, even though the supplement promotes direct input of nutrients required by animal [66]. In this scenario, protein supplementation can increase forage intake due to the supply of N-NH_3 to ruminal microorganisms, and a consequent increase in energy intake, responsible for the increase in animal performance. However, the intensity of the response to a protein supplement will depend on pasture availability and quality [33].

2.4 Non-edible feed

In animal nutrition, corn is the main ingredient in energy supplements, and contains around 72% starch, 9% CP, low fiber content, in addition to being the largest source of metabolizable energy (ME) among cereals [69]. However, corn is an ingredient traditionally consumed by humans and monogastric animals which, in the context of system sustainability, generates competition between livestock and society [70]. Likewise, cottonseed meal and soybean meal are the most conventionally used protein ingredients in animal feed, due to the high CP content, which varies between 30 and 50%, and RUP, which contributes to increase the protein flow to the intestine [71–73]. Despite being important protein sources, they are costly ingredients that increase the production costs of beef cattle systems.

In the search for alternative feed not consumed by humans and for less costly ingredients in cattle nutrition, agroindustry co-products have gained prominence in the market and in research, especially in Brazil.

2.4.1 Citrus pulp

The orange juice and other citrus fruit industry, whose production leadership is in Brazil, generates bagasse or citrus pulp as a co-product, which comprises between

45 and 58% of the total fruit, consisting of peels, membranes, vesicles, and seeds of orange or another citrus. Nutritionally, it is characterized as an intermediate product between roughage and concentrates, rich in pectin, cellulose, and hemicellulose polysaccharides [74, 75].

Citrus pulp has been widely used to replace corn, presenting in its composition 85–90% of the energy value of this ingredient [76], in addition to having little or no negative effect on ruminal fermentation compared to starch-rich diets [74] .

In general, the pulp is characterized by high DM digestibility, high soluble fiber content, high soluble carbohydrate content and highly digestible cell wall [77]. In its chemical composition, citrus pulp has approximately 89–90% DM; 6–11% CP; 2–12% of ether extract (EE), this value depending on whether or not the oils are extracted during processing; 6% mineral matter (MM), 57–74% non-nitrogen extract (NNE); 7–8% crude fiber; 25–41% NDF; 14% of acid detergent fiber (ADF); 1% lignin, 0.2% starch, 22–25% pectin; 3.88 mg vitamin C/100 g by-product, 1.6–1.8% calcium and low phosphorus content (0.08–0.75%) [74, 78, 79].

Pectin consists of a structural carbohydrate, a component of the soluble fiber fraction, which in turn is a polymer of galacturonic acid [80]. According to Muller and Prado [77], co-products with a high concentration of pectin have great potential for use in ruminant nutrition, as it presents high energy density, in addition to favorable fermentation, without the production of lactic acid, which maintains adequate conditions for ruminal functioning.

Because it contains an extremely low starch content, citrus pulp can favor ruminal pH, preventing a sharp decrease during digestion, which can cause metabolic disturbances, in addition to providing maximum cellulolytic activity and a higher acetate:propionate ratio [64, 81–85].

In a study conducted by Oliveira et al. [34] evaluating three supplements, one mineral, one corn-based protein-energy supplement and the other based on citrus pulp, the authors concluded that citrus pulp as an energy source in supplements provided at 0.3% of body weight (BW) can be used in the supplementation of Nellore bulls during the rainy season, without compromising forage intake and fiber digestibility, improving ruminal microbial efficiency.

2.4.2 Dried distiller's grain (DDG)

Protein ingredients in the diet are usually considered the costliest. Thus, the search for alternatives that reduce production costs and even that do not generate competition with food consumed by humans in livestock systems has been increasingly intensified.

An alternative protein ingredient is dried distillers' grain with soluble (DDGs), a co-product of ethanol from corn or sorghum production, which has been gaining attention in animal nutrition for meeting the energy and protein demands of diets in pasture or feedlot systems [71]. In Brazil, however, most industries produce DDG without soluble, resulting from dry milling of corn processing for ethanol production [66]. DDG is typically characterized by its high protein content with low ruminal degradation, presenting between 50 and 62% of RUP in its composition, responsible for the greater supply of MP to the ruminant [86]. Comparatively, the RUP content of DDG is higher than that of cotton and soybean meal, 50 and 20%, respectively [87].

Chemical composition of DDG, however, varies depending on the type, variety and quality of grains, soil conditions, fertilization, irrigation, production and harvesting methods, in addition to factors related to processing in distilleries [88].

Tjardes & Wright [89] demonstrate variations in the nutritional characteristics of DDGs, ranging from 88 to 90% in DM content, 25 to 32% of CP, 43 to 53% in RDP, 47 to 57% in RUP, 39 to 45% of NDF, 8.8 to 12.4% of lipids and 85 to 90% of TDN in studies conducted with beef cattle. Furthermore, the co-product contains highly fermentable fiber and low starch content, which reduces the risk of acidosis in cattle consuming a high-grain diet, improving rumen health, in addition to being a source of minerals [90]. According to Fonseca et al. [86], in Brazil, the DDG produced by most companies does not have the reconstitution of the soluble fraction, presenting lower values of EE and non-fibrous carbohydrates.

In a study of Buckner et al. [91], the authors tested the inclusion of up to 40% of DDGs in the total DM diet and observed that the inclusion of the co-product resulted in higher ADG compared to the control diet. Other studies that evaluated the use of corn DDG at levels of 0; 50 and 100% replacement for conventional protein sources (cotton meal and soybean meal) reported that DDG can 100% replace the protein source during the rearing phase on tropical pastures without any adverse effects on ADG, enteric CH_4 emissions or N excretion [66, 92]. Furthermore, Hoffmann et al. [93] reported that the use of DDG does not affect animal performance finished in pasture or conventional feedlot, emphasizing that it is a viable alternative to replace conventional supplements in a tropical environment.

However, although DDG has the potential to replace conventional protein sources, its inclusion is limited mainly due to seasonal availability. In addition, unlike Brazil, countries such as the United States in some plants, use sulfuric acid for acidic starch hydrolysis during the processing of DDGs and for cleaning equipment, the excess of which can cause negative environmental impacts and even on the carcass quality [94, 95].

Other alternatives of agroindustry co-products that have been used in ruminant supplementation involve corn gluten, glycerin, and peanut crop residues, such as skin and husks.

2.5 Feed additives

In recent decades, the excessive use of antibiotics in animal production has resulted in a considerable increase in resistant bacteria, making it difficult to treat infectious animal diseases and compromising food safety [22]. These compounds are traditionally known as additives, which are defined as "substances intentionally added to feed, with the purpose of preserving, intensifying or modifying its properties, as long as it does not harm its nutritive value, such as antibiotics, dyes, preservatives, antioxidants among others" [96]. In general, additives are used to increase feed efficiency and animal performance, and are divided into different types, including ionophores, antimicrobials/antibiotics, microbial additives, organic acids, and plant extracts such as tannins, saponins and essential oils [97].

Ionophores are the most researched additives in ruminant diets, especially sodium monensin, and its use started in 1976 in beef cattle diets in the United States [98]. The action of ionophores in the rumen occurs through changes in the microbial population, selecting gram-negative bacteria that produce succinic and propionic acids or that ferment lactic acid, and inhibiting gram-positive bacteria that produce acetic, butyric, lactic and hydrogen (H_2) acids, precursor of enteric CH_4 production [98]. Due to this mechanism of action, the use of ionophores in ruminants can optimize energy metabolism, changing the proportion of volatile fatty acids (VFA) produced in the rumen and reducing CH_4 production, as well as improving N metabolism by ruminal microorganisms, decreasing the absorption of NH_3 and increasing the amount of protein that reaches the small intestine, in addition to reducing disorders arising from abnormal fermentation in the rumen, such as ruminal acidosis, bloat and coccidiosis [99].

Antibiotic additives have been used to promote growth for over 55 years, helping to reduce the cost of animal production. However, due to food safety, there are few antibiotics approved by agencies in different countries around the world [22]. The main products used include virginiamycin, bacitracin, flavomycin and tyrosine. In general, antibiotics act directly on rumen metabolism, as they modify the microbial rumen population to optimize ruminal fermentation and nutrient conservation, promoting antibacterial activity on gram-positive bacteria, activity against fungi and protozoa. Furthermore, antibiotics modify the ruminal digestibility of feed, reduce N degradation and enteric CH_4 production, and can control subclinical diseases by suppressing infectious bacteria [100].

Microbial additives are composed of live cells of microorganisms and/or their metabolites, including yeasts, fibrolytic enzymes and probiotics, especially *Aspergillus orizae, Sacchariomyces cerevisae* and *Lactobacillus ssp*, and their use has increased because they are "natural" substances that promote growth to improve production efficiency in ruminants [101]. In general, microbial additives act in the production of antimicrobial compounds (acids, bacteriocins, antibiotics), prevent the establishment of unwanted microorganisms, reestablish the microflora of the digestive tract, and also improve immunity and stimulate animal growth [101]. Furthermore, the use of fibrolytic enzymes can stimulate endogenous ruminal activity and increase the rate and extent of forage digestion by ruminants, due to the improvement in the colonization of feed particles [102].

According to Carro & Ungerfeld [103], organic acids are an alternative to antibiotics and in ruminant nutrition, the most used as additives include malic, fumaric, aspartate, citric, succinic, and pyruvic. As they do not produce detectable residues in meat, the use of organic acids does not cause risks to food safety, however their cost is high. In the rumen, these additives can favor the use of lactate and prevent a sharp drop in pH, preventing ruminal acidosis, and reduce the production of enteric CH_4.

As an alternative to antibiotics, many plants and plant extracts have received attention for their ability to manipulate ruminal fermentation and animal metabolism, in order to increase performance and promote beneficial effects to the environment [13]. Natural compounds commonly used in ruminant nutrition include condensed tannins, saponins and essential oils.

Condensed tannins (CT) are complexes composed of polyphenols, found in tropical legumes and other C3 plants, which bind to proteins, metal ions and polysaccharides, such as starch, cellulose, and hemicellulose [104]. When they exceed 6% of DM in the diet, CT are considered antinutritional factors because they reduce intake, fiber digestibility and animal performance, however in adequate doses (2–4% DM), CT can promote beneficial effects, especially in the regarding GHG emissions by ruminants [105]. These compounds can reduce protein degradation in the rumen and reduce NH_3 concentration along with less urinary N excretion [106]. Besides, CT can also reduce fiber fermentation in the rumen, which consequently reduces H_2 and acetate formation, in addition to inhibiting the growth of methanogenic microorganisms, thus reducing the production of enteric CH_4 [106, 107].

Saponins, in turn, are glycosides naturally present in some plants, such as *Medicago sativa* (alfafa) and *B. decumbens* and are used in animal nutrition as growth inhibitors of ruminal protozoa and modulators of ruminal fermentation in cattle [108]. Essential oils, on the other hand, comprise secondary metabolites of some plants, responsible for their odor and color, and are obtained by vaporization or distillation in water. According to Stevanović et al. [109], among the main essential oils, the most used are thymol present in thyme (*Thymus vulgaris*), oregano (*Origanum vulgaris*), limonene extracted from citrus pulp and guaiacol extracted from guaiac resin or clove oil from India. As a mechanism of action, these oils reduce the rate of deamination of amino acids, the rate of NH_3 production, with an increase in the ruminal escape of N into the intestine. Furthermore, it can increase the concentration of total VFA without affecting other fermentation parameters and even inhibit methanogenesis.

In the context of organic additives, the Fator P (Premix®, Patrocinio Paulista, Brazil) was designed and developed using 100% natural and national technology, being formed by a complex combination of amino acids, probiotics, and essential fatty acids, such as omega 3 and omega 6, in addition to organic minerals and surfactants. The use of this additive in the diet of ruminants can improve fiber digestion, ruminal metabolism, nutrient absorption and, thus, animal performance, in addition to meeting new market trends, associating sustainability and profitability.

Several metabolic studies conducted using the Fator P in ruminant diet demonstrated greater stability and performance of animal metabolism, through better intake and absorption of fibrous feed and, mainly, in the energy availability from diet, which resulted in a 20% increase in weight gain [110–112]. Furthermore, the additive promotes improvements in carcass quality and milk composition, can benefit the female reproduction and the immune system, thus reducing costs with sanitary management. In the context of sustainability, the Fator P optimizes the dynamics of ruminal microorganisms which, associated with greater stability in ruminal fermentation, can reduce GHG emissions per arroba produced by up to 36%, in addition to not causing microbial resistance, and can be used without restrictions, as opposed to conventional additives [112].

The use of these organic additives, therefore, can help to fully exploit the genetic potential of animals and pastures and improve the efficiency of use, in addition to reducing environmental damage, especially with lower emissions of greenhouse gases. In a study evaluating the use of this additive, Leite et al. [113] reported that it increased DM intake of the animals during the initial phase in a feedlot system and did not change the performance, when compared to the conventional additive, monensin.

3. Final considerations

Although livestock is considered the villain of global warming, grazing and nutritional management strategies are essential to mitigate GHG emissions. Proper grazing management results in forage with a higher nutritive value, allowing for more efficient use of nutrients, which increases animal performance. The intensification of pasture use implies the adoption of diet supplementation at different times of the year, aiming to maximize the productive animal performance. Supplementation of beef cattle during rearing in rainy season is an effective strategy to intensify the system due to the period of efficient animal gain and pasture quality. The use of alternative additives to antibiotics can promote better productive responses, in addition to reducing enteric CH_4 production and N_2O emission by excreta. However, when adopting pasture management and supplementation techniques, it is necessary to assess the economic and environmental impacts.

Acknowledgements

Financial support was provided by Premix® Company.

Conflict of interest

The authors declare no conflict of interest.

Notes/thanks/other declarations

The authors thank the members of UnespFor (Unesp Jaboticabal/SP Forage Team).

Author details

Andressa Scholz Berça[1*], Eliéder Prates Romanzini[1], Abmael da Silva Cardoso[1], Luís Eduardo Ferreira[2], André Pastori D'Aurea[2], Lauriston Bertelli Fernandes[2] and Ricardo Andrade Reis[1]

1 São Paulo State University, Jaboticabal, São Paulo, Brazil

2 Premix Company, Ribeirão Preto, São Paulo, Brazil

*Address all correspondence to: dessaberca@yahoo.com.br

References

[1] McManus C, Barcellos JO, Formenton BK, Hermuche PM, Carvalho OA, Guimarães R, Gianezini M, Dias EA, Lampert Vd, Zago D, Neto JB. Dynamics of Cattle Production in Brazil. Plos One. 2016;11(1):e0147138. DOI: 10.1371/journal.pone.0147138

[2] Abiec - Associação Brasileira das Indústrias Exportadoras de Carnes. Beef Report: Perfil da Pecuária no Brasil [Internet]. 2021. Available from: http://abiec.com.br/publicacoes/beef-report-2021/. [Accessed: 2021-07-20].

[3] Dubeux Jr, JCB, Sollenberger JCB, Muir JP, Tedeschi LO, Dos Santos MV, da Cunha MV, Dilorenzo N. Sustainable intensification of livestock production on pastures. Archivos Latinoamericanos de Producción Animal. 2017; 25:3-4

[4] Cardoso AS, Berndt A, Leytem BJR, Alves IDN, DeCarvalho LH, De Barros Soares S, Urquiaga, Boddey RM. Impact of the intensification of beef production in Brazil on greenhouse gas emissions and land use. Agricultural Systems. 2016; 143:86-92. DOI: 10.1016/j.agsy.2015.12.007

[5] Cardoso AS, Barbero RP, Romanzini EP, Teobaldo RW, Ongaratto F, Fernandes MHMR, Ruggieri AC, Reis RA. Intensification: A key strategy to achieve great animal and environmental beef cattle production sustainability in Brachiaria grasslands. Sustainability. 2020; 12:6656. DOI: 10.3390/su12166656

[6] Delevatti LM, Romanzini EP, Koscheck JFW, Araujo TLR, Renesto DM, Ferrari AC, Barbero RP, Mullinikis JT, Reis RA. Forage management intensification and supplementation strategy: Intake and metabolic parameters on beef cattle production. Animal Feed Science and Technology. 2019;247:74-82. DOI: 10.1016/j.anifeedsci.2018.11.004

[7] De Jesus FLF, Sanches AC, De Souza DP, Mendonça FC, Gomes EP, Santos RC, Da Silva JLB. Seasonality of biomass production of irrigated Mombaça 'Guinea grass'. Acta Agriculturae Scandinavica, Soil e Plant Science. 2021;1-9. DOI: 10.1080/09064710.2020.1863456

[8] Reis RR, Ruggieri AC, Oliveira AA, Azenha MV, Casagrande DR. Suplementação como estratégia de produção de carne de qualidade em pastagens tropicais. Revista Brasileira de Saúde e Produção Animal. 2012;642-655. ISSN 1519 9940.

[9] Poppi DP, Quigley SP, Silva TACCD, McLennan SR. Challenges of beef cattle production from tropical pastures. Revista Brasileira de Zootecnia. 2018;47:1-9. DOI: 10.1590/rbz472016041

[10] Valadares Filho S, Silva FAZ, Benedeti PDB, Paulino MF, Chizzotti ML. Nutrient requirements of beef cattle in tropical climates. EAAP Scientific Series. 2019. DOI: 10.3920/978-90-8686-891-9

[11] Reis RA, Ruggieri AC, Casagrande DR, Páscoa AG. Suplementação da dieta de bovinos de corte como estratégia do manejo das pastagens. Revista Brasileira de Zootecnia. 2019;38:147-159. DOI: 10.1590/S1516-35982009001300016

[12] Peyrald JL. The role of grassland-based production system for sustainable protein production. In: Proceedings of the Annual meeting of the Brazilian

society of Animal Science; July 2017; Foz do Iguaçu, Brazil. 2017. p.243-255. hal-01591147

[13] Hart KJ, Yáñez-Ruiz DR, Duval SM, McEwan NR, Newbold CJ. Plant extracts to manipulate rumen fermentation. Animal Feed Science and Technology. 2008;147:8-35. DOI: 10.1016/j.anifeedsci.2007.09.007

[14] Herrero M, Havlík P, Valin H, Notenbaert A, Rufino MC, Thornton PK, Obersteiner M. Biomass use, production, feed efficiencies, and greenhouse gas emissions from global livestock systems. In: Proceedings of the National Academy of Sciences; December 2013; Cambridge. 2013. p. 20888-20893. DOI: 10.1073/pnas.1308149110

[15] FAO – Food and Agriculture Organization of the United Nations. Tackling climate change through livestock. A global assessment of emissions and mitigation opportunities. Rome, FAO, 115p., 2013.

[16] Berça AS, Cardoso AS, Longhini VZ, Tedeschi LO, Boddey RM, Berndt A, Reis RA, Ruggieri AC. Methane production and nitrogen balance of dairy heifers grazing palisade grass cv. Marandu alone or with forage peanut. Journal of Animal Science. 2019;97:4625-4634. DOI: 10.1093/jas/skz310

[17] IPCC - Intergovernmental Panel on Climate Change. 2019 Refinement to the 2006 IPCC Guidelines for National Greenhouse Gas Inventories [Internet]. 2019. Available from: https://www.ipcc-nggip.iges.or.jp/public/2019rf/index.html [Accessed 2021-05-15].

[18] GLEAM - Global Livestock Environmental Assessment Model – GLEAM. 2019. Available from: http://www.fao.org/gleam/en/[Accessed 2021-05-15].

[19] Longhini VZ, Cardoso AS, Berça AS, Boddey RM, Reis RA, Dubeux JC, Ruggieri AC. Nitrogen supply and Rainfall affect Ammonia emissions from Dairy Cattle excreta and Urea applied on warm-climate pastures. Journal of Environmental Quality. 2020; 49:1453-1466. DOI: 10.1002/jeq2.20167

[20] Xu R, Tian H, Pan S, Prior AS, Feng Y, Batchelor WD, Yang J. Global ammonia emissions from synthetic nitrogen fertilizer applications in agricultural systems: Empirical and process-based estimates and uncertainty. Global Change Biology. 2019;25:314-326. DOI:10.1111/gcb.14499

[21] Foley JA, Ramankutty N, Brauman KA, Cassidy ES, Gerber JS, Johnston M, Zaks DP. Solutions for a cultivated planet. Nature. 2011;478:337-342. DOI: 10.1038/nature10452

[22] Tedeschi LO, Callaway TR, Muir JP, Anderson RC. Potential environmental benefits of feed additives and other strategies for ruminant production. Revista Brasileira de Zootecnia. 2011;40:291-309.

[23] Hatfield RD, Kalscheur KF. Carbohydrate and Protein Nutritional Chemistry of Forages. Forages: The Science of Grassland Agriculture. 2020;2:595-607. DOI: 10.1002/9781119436669.ch33

[24] Hristov AN, Ott T, Tricarico J, Rotz A, Waghorn G, Adesogan A, Firkins JL. Special topics - Mitigation of methane and nitrous oxide emissions from animal operations: III. A review of animal management mitigation options. Journal of Animal Science. 2013;11:5095-5113. DOI: 10.2527/jas.2013-6585

[25] Ruggieri AC, Cardoso AS, Ongaratto F, Casagrande DR, Barbero RP, Brito LF, Azenha MV, Oliveira AA,

Koscheck JHW, Reis RA. Grazing Intensity Impacts on Herbage Mass, Sward Structure, Greenhouse Gas Emissions, and Animal Performance: Analysis of Brachiaria Pastureland. Agronomy. 2020;11:1750. DOI: 10.3390/agronomy10111750

[26] Poppi DP, McLennan SR. Protein and energy utilization by ruminants at pasture. Journal of Animal Science. 1995;73:278-290.

[27] Paulino MF, Figueiredo DD, Moraes EHBK, Porto MO, Sales MF, Acedo TS, Valadares Filho SDC. Suplementação de bovinos em pastagens: uma visão sistêmica. Simpósio de produção de gado de corte. 2004;4:93-144.

[28] Sollenberger LE, Newman YC, Macoon B. Pasture Design and Grazing Management. Forages: The Science of Grassland Agriculture. 2020;2:803-814. DOI: 10.1002/9781119436669.ch44

[29] Pereira JC, Gomes FK, Oliveira MD, Lara MA, Bernardes TF, Casagrande DR. Defoliation management affects morphogenetic and structural characteristics of mixed pastures of brachiaria grass and forage peanut. African Journal of Range e Forage Science. 2017;34:13-19. DOI: 10.2989/10220119.2017.1315960

[30] Casagrande DR, Ruggieri AC, Moretti MH, Berchielli TT, Vieira BR, Roth APTP, Reis RA. Sward canopy structure and performance of beef heifers under supplementation in *Brachiaria brizantha* cv. Marandu pastures maintained with three grazing intensities in a continuous stocking system. Revista Brasileira de Zootecnia. 2011;40:2074-2082. DOI: 10.1590/S1516-35982011001000002

[31] Baldissera TC, Pontes LS, Giostri AF, Barro RS, Lustosa SBC, De Moraes A, De Faccio Carvalho PC. Sward structure and relationship between canopy height and light interception for tropical C4 grasses growing under trees. Crop and Pasture Science. 2016;67:1199-1207. DOI: 10.1071/CP16067

[32] Azenha MV. Morfogênese e dinâmica do perfilhamento do capim-marandu submetido a alturas de pastejo em lotação contínua com e sem suplementação [dissertation]. Jaboticabal: Faculdade de Ciências Agrárias e Veterinária – UNESP; 2010.

[33] Barbero RP, Malheiros EB, Araújo TLR, Nave RLG, Mullinikis JT, Berchielli TT, Ruggieri AC, Reis RA. Combining Marandu grass grazing height and supplementation level to optimize growth and productivity of yearling bulls. Animal Feed Science and Technology. 2015;209:110-118. DOI: 10.1016/j.anifeedsci.2015.09.010

[34] Oliveira AP, Casagrande DR, Bertipaglia LMA, Barbero RP, Berchielli TT, Ruggieri AC, Reis RA. Supplementation for beef cattle on Marandu grass pastures with different herbage allowances. Animal Production Science. 2016;56:123-129. DOI: 10.1071/AN14636

[35] Vieira BR, Azenha MV, Casagrande DR, Costa DFA, Ruggieri AC, Berchielli TT, Reis RA. Ingestive behavior of supplemented Nellore heifers grazing palisadegrass pastures managed with different sward heights. Journal of Animal Science. 2017;4:696-704. DOI: 10.1111/asj.12696

[36] Koscheck FJW, Romanzini EP, Barbero RP, Delevatti LM, Ferrari AC, Mullininks JT, Mousquer CJ, Berchielli TT, Reis RA. How do animal performance and methane emissions vary with forage management intensification and supplementation?.

Animal Production Science. 2020;1:1201-1209. DOI: 10.1071/AN18712

[37] Barbero RP, Malheiros EB, Aguilar NM, Romanzini EP, Ferrari AC, Nave RLG, Mullinks JT, Reis RA. Supplementation level increasing dry matter intake of beef cattle grazing low herbage height. Journal of Applied Animal Research. 2020;48:28-33. DOI: 10.1080/09712119.2020.1715985

[38] Delevatti LM, Cardoso AS, Barbero RP, Leite RG, Romanzini EP, Ruggieri AC, Reis RA. Effect of nitrogen application rate on yield, forage quality, and animal performance in a tropical pasture. Scientific Reports. 2019;9:1-9. DOI: 10.1038/s41598-019-44138-x

[39] Trindade JKD, Silv SCD, Souza Júnior SJD, Giacomini AA, Zeferino CV, Guarda VDA, Carvalho PCDF. Composição morfológica da forragem consumida por bovinos de corte durante o rebaixamento do capim-marandu submetido a estratégias de pastejo rotativo. Pesquisa Agropecuária Brasileira. 2007;6: 883-890. DOI: 10.1590/S0100-204X2007000600016

[40] Pedreira BC, Pedreira CGS, Da Silva SC. Estrutura do dossel e acúmulo de forragem de Brachiaria brizantha cultiva Xaraés em resposta a estratégias de pastejo. Pesquisa Agropecuária Brasileira. 2007;2:281-287. DOI: 10.1590/S0100-204X2007000200018

[41] Boddey RM, Macedo R, Tarré RM, Ferreira E, Oliveira OC, Rezende CP, Cantarutti RB, Pereira JM, Alves BJR, Urquiaga S. Nitrogen cycling in Brachiaria pastures: The key to understanding the process of pasture decline. Agriculture, Ecosystems e Environment. 2004;103:389-403. DOI: 10.1016/j.agee.2003.12.010

[42] Sollenberger L, Coleman SW, Vendramini JMB. A interação planta-herbívoros em pastagens. In: Reis RA, Bernardes TF, Siqueira GR, editors. Handbook of Forragicultura Ciência, Tecnologia e Gestão dos Recursos Forrageiros. 1st ed. Gráfica Multipress: Jaboticabal, Brazil; 2014. p. 69-80.

[43] Rezende AV, Lima JF, Rabelo CHS, Rabelo FHS, Nogueira DA, Carvalho M, Faria Jr CNA, Barbosa LA. Características morfofisiológicas da Brachiaria brizantha cv. Marandu em resposta à adubação fosfatada. Agrarian. 2011;4:335-343.

[44] Balsalobre MAA, Corsi M, Santos PM, Cárdenas RR. Composição química e fracionamento do nitrogênio e dos carboidratos do capim-tanzânia irrigado sob três níveis de resíduo pós-pastejo. Revista da Sociedade Brasileira de Zootecnia. 2003;32:519-528.

[45] Detmann E, Valente EE, Batista ED, Huhtanen P. An evaluation of the performance and efficiency of nitrogen utilization in cattle fed tropical grass pastures with supplementation. Livestock Science. 2014;165:141-153.

[46] Aboyage IA, Oba M, Castillo AR, Koenig KM, Iwaasa AD, Beauchemin KA. Effects of hydrolyzable tannin with or without condensed tannin on methane emissions, nitrogen use, and performance of beef cattle fed a high-forage diet. Journal of Animal Science. 2018;96:5276-5286. DOI: 10.1093/jas/sky352

[47] Goés RHT, Alves DD, Mancio AB, Zercoudakis JT. Efeito Associativo na suplementação de bovinos a pasto. Arquivo de Ciências Veterinária e Zoologia da UNIPAR. 2004;7:169-169.

[48] Reis RA, Barbero RP, Hoffmann A. Impactos da qualidade da forragem em sistemas de produção de bovinos de corte. Informe Agropecuário. 2016;292:36-53.

[49] Paulino MF, Detmann E, Valadares Filho SC. Suplementação animal em pasto: energética ou protéica? In: Proceedings of Simpósio sobre manejo estratégico da pastagem; Viçosa, Brazil; 2006. p.359-392.

[50] Huhtanen P, Sudekum KH, Nousiainen J, Shingfield KJ. Forage conservation, feeding value and milk quality. Grassland in a changing world. 2010;15:379-400.

[51] Santos FAP, Correia PS, Ramalho TR, Costa DFA. Sistemas intensivos de recria de bovinos com suplementação em pastagens e confinamento. In: Proceedings of Simpósio sobre Bovinocultura de Corte: Requisitos de qualidade na bovinocultura de corte; Piracicaba, Brazil; 2007. p. 183-219.

[52] Romanzini EP, Barbero RP, Reis RA, Hadley D, Malheiros EB. Economic evaluation from beef cattle production industry with intensification in Brazil's tropical pastures. Tropical Animal Health and Production. 2020;52:2659-2666. DOI: 10.1007/s11250-020-02304-8

[53] Dewhurst RJ, Davies DR, Merry RJ. Microbial protein supply from the rumen. Animal Feed Science and Technology. 2000;85:1-21. DOI: 10.1016/S0377-8401(00)00139-5

[54] Johnson CR, Reiling BA, Mislevy P, Hall MB. Effects of nitrogen fertilization and harvest date on yield, digestibility, fiber, and protein fractions of tropical grasses. Journal of Animal Science. 2001;79:2439-2448. DOI: 10.2527/2001.7992439x

[55] Leng RA. Factors affecting the utilization of "poor-quality" forages by ruminants particularly under tropical conditions. Nutrition Research Review. 1990;3:277- 303. DOI: 10.1079/NRR19900016

[56] Rooke JA, Lee NH, Armstrong DG. The effects of intraruminal infusions of urea, casein, glucose syrup and a mixture of glucose syrup and casein on nitrogen digestion in the rumen of cattle receiving grass silage diets. British Journal of Nutrition. 1987;57:89-98. DOI: 10.1079/BJN19870012

[57] Huhtanen P. The effects of intraruminal infusions of sucrose and xylose on the nitrogen and fibre digestion in the rumen of cattle receiving diets of grass silage and barley. Agriculture and Food Science. 1987;59:101-120. DOI: 10.23986/afsci.72274

[58] Mertens DR. Regulation of forage intake. In: Fahey Jr, editor. Forage quality, evaluation and utilization. American Society of Agronomy: Madison; 1994. p.450-493.

[59] Costa DFA, Correia PS, Dorea JRR, De Souza J, De Souza Congio CF, Pires AV, Santos FAP. Strategic supplementation of growing cattle on tropical pastures improves nutrient use and animal performance, with fewer days required on the finishing phase. Animal Production Science. 2020;81:480-493. DOI: 10.1071/AN20005

[60] Reis WLS, Detmann E, Batista ED, Rufino LMA, Gomes DI, Bento CBP, Valadares Filho SC. Effects of ruminal and post-ruminal protein supplementation in cattle fed tropical forages on insoluble fiber degradation, activity of fibrolytic enzymes, and the ruminal microbial community profile. Animal Feed Science and Technology. 2016;218:1-16. DOI: 10.1016/j.anifeedsci.2016.05.001

[61] Pathak AK. Various factors affecting microbial protein synthesis in the rumen. Veterinary World. 2008;6:186.

[62] Rodriguez R, Sosa A, Rodriguez Y. Microbial protein synthesis in rumen and

its importance to ruminants. Cuban Journal of Agricultural Science. 2007;41:287-294.

[63] Kozloski GV. Ruminants Biochemistry. 3rd ed. Santa Maria: UFSM; 2011. 216p. ISBN 9788573911503.

[64] Van Soest PJ. Nutritional ecology of the ruminant. 2nd ed. Cornell University; 1994. 476p.

[65] Gomes MJ, Hovell FD, Chen XB, Nengomasha EM, Fikremariam D. The effect of starch supplementation of straw on microbial protein supply in sheep. Animal Feed Science and Technology. 1994;49:277-286.

[66] Hoffmann A, Cardoso AS, Fonseca NVB, Romanzini EP, Siniscalchi D, Berndt A, Ruggieri AC, Reis RA. Effects of supplementation with corn distillers' dried grains on animal performance, nitrogen balance, and enteric CH_4 emissions of young Nellore bulls fed a high-tropical forage diet. Animal. 2021;15:100155. DOI: 10.1016/j.animal.2020.100155

[67] Tadele Y, Amha N. Use of different non protein nitrogen sources in ruminant nutrition: a review. Advances in Life Science and Technology. 2015;29:84-89.

[68] Araújo HPDO, Paula NFD, Martello HF, Teobaldo RW, Pereira LB, Mora LM, Antunes HCF. Urea and Tannin in multiple supplements: Ingestive behavior of grazing beef cattle. Acta Scientiarum. Animal Sciences. 2020;42. DOI: 10.4025/actascianimsci.v42i1.47607

[69] Loy DD, Lundy EL. Nutritional properties and feeding value of corn and its coproducts. In: Corn. AACC International Press; 2019. p. 633-659.

[70] Mottet A, Teillard F, Boettcher P, De' Besi G, Besbes B. Review: domestic herbivores and food security: current contribution, trends and challenges for a sustainable development. Animal. 2018;12:188-198. DOI: 10.1017/S1751731118002215

[71] Swiatkiewicz S, Arczewska-Wlosek A, Józefiak D. The use of cottonseed meal as a protein source for poultry: An updated review. World's Poultry Science Journal. 2016;72:473-484. DOI: 10.1017/S0043933916000258

[72] Paula EM, Broderick GA, Danes MAC, Lobos NE, Zanton GI, Faciola AP. Effects of replacing soybean meal with canola meal or treated canola meal on ruminal digestion, omasal nutrient flow, and performance in lactating dairy cows. Journal of Dairy Science. 2018;101:328-339. DOI: 10.3168/jds.2017-13392

[73] Hoffmann A, Cardoso AS, Fonseca NVB, Romanzini EP, Siniscalchi D, Berndt A, Ruggieri AC, Reis RA. Effects of supplementation with corn distillers' dried grains on animal performance, nitrogen balance, and enteric CH_4 emissions of young Nellore bulls fed a high-tropical forage diet. Animal. 2021;1:100155. DOI: 10.1016/j.animal.2020.100155

[74] Bampidis VA, Robinson PH. Citrus by-products as ruminant feeds: a review. Animal Feed Science and Technology. 2006;128:175-217. DOI: 10.1016/j.anifeedsci.2005.12.002

[75] Franzolin R, Franzolin MHT. População protozoários ciliados e degradabilidade ruminal em búfalos e bovinos zebuínos sob dieta à base de cana-de-açúcar. Revista Brasileira de Zootecnia. 2000;29:1853-1861. DOI: 10.1590/S1516-35982000000600034

[76] NRC - National Research Council. Nutrient Requirements of Beef Cattle. 7th

ed. Washington, DC, USA: Natl. Acad. Press, 2000.

[77] Muller M, Prado IN. Metabolismo da pectina para produção de carne e leite em ruminantes. In: IN Prado, editor. Conceitos sobre a produção com qualidade de carne e leite. Maringá, Brazil: 2004. pp. 115-146.

[78] Oluremi OIA, Ojighen VO, Ejembi EH. The nutritive potentials of sweet orange (*Citrus sinensis*) rind in broiler production. International Journal of Poultry Science. 2006;5:613-617.

[79] Watanabe PH, Thomaz MC, Ruiz US, Santos VM, Masson GC, Fraga AL, Silva SZ. Carcass characteristics and meat quality of heavy swine fed different citrus pulp levels. Arquivo Brasileiro de Medicina Veterinária e Zootecnia. 2010;62:921-929. DOI: 10.1590/S0102-09352010000400023

[80] Santos FAP, Carmo CDA, Bittar CMM, Pires AV, Pedroso AM, Pereira EM. Milho com diferentes graus de moagem em combinação com polpa cítrica peletizada ou casca de soja para vacas leiteiras no terço médio da lactação. Revista Brasileira de Zootecnia. 2007;36:1183-1191. DOI: 10.1590/S1516-35982007000500027

[81] Cullen AJ, Harmon DL, Nagaraja TG. In vitro fermentation of sugars, grains and by-product feeds in relation to initiation of ruminal lactate production. Journal of Dairy Science. 1986;69:2616-2623. DOI: 10.3168/jds.S0022-0302(86)80709-3

[82] Strobel HJ, Russell JB. Effect of pH and energy spilling on bacterial protein synthesis by carbohydrate limited cultures of mixed rumen bacteria. Journal of Dairy Science. 1986;69:2941-2953. DOI: 10.3168/jds.S0022-0302(86)80750-0

[83] Belyea RL, Steevens BJ, Restrepo RJ, Clubb AP. Variation in composition of by-product feeds. Journal of Dairy Science. 1989;72:2339-2345. DOI: 10.3168/jds.S0022-0302(89)79366-8

[84] Van Soest PJ, Robertson JB, Lewis BA. Methods of dietary fiber, neutral detergent fiber, and nonstarch polysaccharides in relation to animal nutrition. Journal of Dairy Science. 1991;74:3583-3597. DOI: 10.3168/jds.S0022-0302(91)78551-2

[85] Porcionato MAF, Berchielli TT, Franco GL. Avaliação dos parâmetros ruminais da polpa cítrica peletizada. 1-Degradação da MS e FDN. In: Proceedings of Reunião Anual da Sociedade Brasileira de Zootecnia. Viçosa: 2000. p. 347.

[86] Fonseca NVB, Cardoso AS, Hoffmann A, Leite RG, Ferrari AC, Fernandes MHMR, Reis RA. Characterization and effects of DDG on the intake and digestibility of finishing bulls in feedlots. Acta Scientiarum. 2020:43. DOI: 10.4025/actascianimsci.v43i1.51877

[87] Santos FAP, Pedroso AM. Suplementação proteica e energética para bovinos de corte em confinamento. In: Pires AV, editor. Bovinocultura de corte. Piracicaba: FEALQ, 2010. p. 257-280.

[88] Bottger C, Sudekum KH. European distillers dried grains with solubles (DDGS): Chemical composition and in vitro evaluation of feeding value for ruminants. Animal Feed Science and Technology. 2017;224:66-70. DOI: 10.1016/j.anifeedsci.2016.12.012

[89] Tjardes J, Wright C. Feeding corn distiller's co-products to beef cattle. Animal and Range Sciences. 2002:1-5.

[90] Freitas TB, Relling AE, Pedreira MS, Junior HAS, Felix TL. Effects of sodium

hydroxide treatment of dried distillers' grains on digestibility, ruminal metabolism, and metabolic acidosis of feedlot steers1. Journal of Animal Science. 2016;94:709-717. DOI: 10.2527/jas.2015-9431

[91] Buckner CD, Mader TL, Erickson GE, Colgan SL, Mark DR, Karges KK, Bremer VR. Evaluation of dry distillers' grains plus solubles inclusion on performance and economics of finishing beef steers. The Professional Animal Scientist. 2008;24:404-410. DOI: 10.15232/S1080-7446(15)30884-6

[92] Ferrari AC. Aportes nutricionais na recria a pasto e sistemas na terminação de tourinhos Nelore: metabolismo, desempenho e qualidade da carne [thesis]. Jaboticabal: Faculdade de Ciências Agrárias e Veterinária - UNESP, 2019. 150p.

[93] Hoffmann A, Berça AS, Cardoso ADS, Fonseca NVB, Silva MLC, Leite RG, Ruggieri AC, Reis RA. Does the Effect of Replacing Cottonseed Meal with Dried Distiller's Grains on Nellore Bulls Finishing Phase Vary between Pasture and Feedlot?. Animals. 2021;11:85. DOI: 10.3390/ani11010085

[94] Smith WB, Banta JP, Foster JL, Redmon LA, Tedeschi LO, Rouquette FM. Impact of DDGS Supplementation of Cattle Grazing Bermudagrass on the Plant-Animal-Environment Nexus. Journal of Animal Science. 2016;95:62-63. DOI: 10.2527/ssasas2017.0127

[95] Council US Grains. A guide to distiller's dried grains with solubles (DDGS). 2013. Available from: http:// www. ddgs. umn. edu/prod/groups/ cfans/@ pub/@ cfans/@ ansci/ documents/ass et/cfans_asset_417244. pdf [Accessed 2021/06/25].

[96] Lanna DPD, Medeiros SR. Uso de aditivos na bovinocultura de corte. In: Santos FAP, Moura JC, Faria VP, editors. Requisitos de qualidade na bovinocultura de corte. Piracicaba: Fealq, 2007. p.297-324.

[97] Danieli B, Schogor ALB. Uso de aditivos na nutrição de ruminantes: revisão. Veterinária e Zootecnia. 2020;27:1-13. DOI: 10.35172/rvz.2020.v27.444

[98] Azzaz HH, Murad HA, Morsy TA. Utility of ionophores for ruminant animals: a review. Asian Journal of Animal Sciences. 2015;9:254-265. DOI: 10.3923/ajas.2015.254.265

[99] Tedeschi LO, Fox DG, Tylutki TP. Potential environmental benefits of ionophores in ruminant diets. Journal of environmental quality. 2003;32:1591-1602. DOI: 10.2134/jeq2003.1591

[100] McGrath J, Duval SM, Tamassia LF, Kindermann M, Stemmler RT, De Gouvea VN, Celi P. Nutritional strategies in ruminants: A lifetime approach. Research in Veterinary Science. 2018;116:28-39. DOI: 10.1016/j.rvsc.2017.09.011

[101] Arowolo MA, He J. Use of probiotics and botanical extracts to improve ruminant production in the tropics: A review. Animal Nutrition. 2018;4:241-249. DOI: 10.1016/j.aninu.2018.04.010

[102] Tirado-Gonzalez DN, Miranda-Romero LA, Ruíz-Flores A, Medina-Cuéllar SE, Ramírez-Valverde R, Tirado-Estrada G. Meta-analysis: effects of exogenous fibrolytic enzymes in ruminant diets. Journal of Applied Animal Research. 2018;46:771-783. DOI: 10.1080/09712119.2017.1399135

[103] Carro MD, Ungerfeld EM. Utilization of organic acids to manipulate ruminal fermentation and improve

ruminant productivity. In: Rumen microbiology: from evolution to revolution. Springer, New Delhi, 2015. p. 177-197. DOI: 10.1007/978-81-322-2401-3_13

[104] Muir JP, Terrill T, Valencia E, Stuart W, Jones PD, Moskidis J, Wolfe R. The wide range of condensed tannins in Caribbean Basin plants and their applicability to ruminant production systems. In: Proceedings of Caribbean Food Crops Society Annual Meeting. St. Kitts and Nevi: Caribbean Food Crops Society, 2009. p.46-52. DOI: 10.22004/ag.econ.256353

[105] Martin C, Morgavi DP, Doreau M. Methane mitigation in ruminants: from microbes to the farm scale. Animal. 2009;4:351-365. DOI: 10.1017/S1751731109990620

[106] Patra AK, Saxena J. Exploitation of dietary tannins to improve rumen metabolism and ruminant nutrition. Journal of the Science of Food and Agriculture. 2011;91:24-37. DOI: 10.1002/jsfa.4152

[107] Beauchemin KA, Kreuzer M, O'Mara F, McAllister TA. Nutritional management for enteric methane abatement: a review. Australian Journal of Experimental Agriculture. 2008;48:21-27. DOI: 10.1071/EA07199

[108] Silva NV, Costa RG, Freitas CRG, Galindo MCT, Silva RS. Alimentação de ovinos em regiões semiáridas do Brasil. Acta Veterinaria Brasilica. 2010;4:233-241. DOI: 10.21708/avb.2010.4.4.1906

[109] Stevanovic ZD, Bosnjak-Neumuller J, Pajic-Lijakovic I, Raj J, Vasiljevic M. Essential oils as feed additives—future perspectives. Molecules. 2018;23:1717. DOI: 10.3390/molecules23071717

[110] Fernandes LB, D'Áurea AP, Ferreira LE. Sustainable and efficient production of growing steers in the tropical pastures. In: Proceedings of 10th International Symposium on the Nutrition of Herbivores; 2-6 September 2018; Clermont, France; 2018. p.470

[111] D'Aurea AP, Fernandes LB, Ferreira LE, Pinto LD, Shiozaki FA. Welfare and Sustainability in Beef Cattle Production on Tropical Pasture. In: Procceedings of International Conference on Animal Welfare, Development, Conservation and Control; 22-23 April 2019; Newyork, USA; 2019. 13:4.

[112] Oliveira AP, Romanzini EP, Leite RG, Delevatti LM, Fernandes LB, D'Áurea AP, Reis RA. Feeding behavior during adaptation phase of beef cattle in feedlot reducing the use of conventional growth promoters. In: EAAP Scientific Series. Wageningen Academic Publishers, 2019. p.2538-2547. DOI: 10.3920/978-90-8686-891-9

[113] Leite RG, Romanzini EP, Delevatti LM, Hoffmann A, Ferrari AC, D'Áurea AP, Fernandes LB, Oliveira AP, Reis RA. Organic additives used in beef cattle feedlot: Effects on metabolic parameters and animal performance. Journal of Animal Science. 2019;00:1-9. DOI: 10.1111/asj.13183