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Nitrogen, phosphorus, and potassium cycling in pasture ecosystems

Ciclagem de Nitrogênio, Fósforo e Potássio em Ecossistemas de Pastagem

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Abstract: Inadequate management practices are the main factors that can cause pasture degradation, and one of the key factors is to understand the nutrient cycling in pasture ecosystems. This review aimed to describe the cycling processes of important nutrients in pasture ecosystems (nitrogen, phosphorus, and potassium), analyzing the interactions of soil-plant-animal components. The use of forage legume species intercropped with grasses is a strategy to increase the nitrogen content in the soil, minimizing costs with nitrogen fertilization in pastures. Manure and plant residues are great organic sources of phosphorus and potassium but are also fundamental for supplying microminerals. Nitrogen losses in pastures are mainly caused by leaching, runoff, and volatilization. The addition of phosphorus to the soil must be performed carefully, as there is an increase in phosphorus losses with increasing accumulation in the soil. Phosphorus is often returned to the soil far from where it was used, so the stock transfer represents a loss in pasture ecosystems that can account for approximately 5% of the inputs of phosphate fertilizers. Potassium losses mostly occur by leaching and runoff. Improving management practices is essential for balanced nutrient cycling in pasture ecosystems.

Keywords: animal excreta; fertilization; litter; nutrient cycling; soil nutrients.

Resumo: Práticas inadequadas de manejo são os principais fatores que podem causar a degradação das pastagens, e um dos fatores chaves é entender a ciclagem de nutrientes nos ecossistemas de pastagem. Esta revisão teve como objetivo descrever os processos de ciclagem de nutrientes importantes em ecossistemas de pastagem (nitrogênio, fósforo e potássio), analisando as interações

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entre os componentes solo-planta-animal. Verificou-se que o uso de espécies de leguminosas forrageiras consorciadas com gramíneas é uma estratégia para aumentar o teor de nitrogênio no solo, minimizando os custos com adubação nitrogenada em pastagens campestres. Estrume e resíduos vegetais são as principais fontes orgânicas de fósforo e potássio. As perdas de nitrogênio nas pastagens ocorrem principalmente por lixiviação, escoamento superficial e volatilização. A adição de fósforo ao solo deve ser feita com cautela, pois há um aumento nas perdas de fósforo com o aumento de seu acúmulo no solo. O fósforo é muitas vezes devolvido ao solo longe do local onde foi consumido, de modo que a transferência de estoque representa uma perda nos ecossistemas de pastagem que pode representar aproximadamente 5% das entradas de fertilizantes fosfatados. As perdas de potássio ocorrem principalmente por lixiviação e escoamento superficial. A melhoria das práticas de manejo é essencial para uma ciclagem equilibrada de nutrientes em ecossistemas de pastagem.

Palavras-chave: ciclagem de nutrientes; excrementos animais; fertilização; nutrientes do solo; serapilheira.

1. Introduction

The biogeochemical cycle or nutrient cycling consists of a set of processes that involve the displacement, changes, and transformations of chemical elements in the different systems of the planet Earth: lithosphere, biosphere, hydrosphere, and atmosphere [(1,2)]. In pasture ecosystems, mineral nutrient cycling plays a key role in plant nutrition, as the nutrients circulate through various compartments (soil-plant-animal-atmosphere), alternating between periods of availability or non-availability for plant uptake. Understanding the dynamics of each soil nutrient cycling in the pasture and how management practices can affect them is essential for the sustainability of pasture systems [(3, 4)].

Adequate soil management and nutrient inputs such as nitrogen, phosphorus, and potassium are essential for developing sustainable pasture-based livestock production systems. However, continuous nutrient inputs in agriculture systems can also generate serious environmental problems, ranging from local water and air pollution to global climate changes [(5)]. Therefore, quantifying nutrient inputs and outputs is essential to the sustainable management of the pastures.

To understand nutrient cycling in a pasture ecosystem, in addition to the evaluation of the inputs (fertilization, N_2 fixation, supplementation) and outputs by the export of elements, it must be taken into account how these nutrients are lost and return to the environment (e.g., volatilization, leaching, runoff). Thus, this review aimed to discuss the nutrient cycling dynamics (input and outputs) of nitrogen, phosphorus, and potassium in tropical pastures, pointing out strategies to improve the efficiency of their utilization.

2. Biogeochemical cycle of nitrogen, phosphorus, and potassium

Controlled by biotic and abiotic factors, the biogeochemical cycles, or nutrient cycling, consist of the flow of nutrients in the different compartments of an ecosystem. In pasture ecosystems, these compartments are the soil, plants, animals, and the atmosphere. The availability of macro- and micronutrients in the edaphic environment is influenced by changes in one or more of these mentioned components [6].

Nitrogen (N), phosphorus (P), and potassium (K) are macronutrients of relevant importance for plant nutrition and, consequently, for animal production[7]. Nitrogen deficiency in soil is a force for the degradation of pastures since this compound is directly related to the synthesis of essential biomolecules in the plant, such as amino acids and nucleic acids. Phosphorus and potassium are important in plant metabolism, participating in different stages of photosynthesis and growth [8, 9, 10]. The search for strategies that reduce pasture degradation and increase the productivity of the system requires knowledge about the cycling of these nutrients, especially the mechanism and pathway of their input and output in the biosystem[3].

3. Pathways of nitrogen input into the system

The largest reserves of nitrogen in pasture ecosystems are the soil, vegetation, herbivore residues, and the atmosphere [11]. In most agricultural lands in the world, N is considered the most limiting nutrient for crops, especially in grass monocultures. This element is involved in the synthesis of amino acids and proteins used in various metabolic processes in plants. For plant species, such as C_3 (e.g., forage legumes), which require a higher concentration of rubisco in their tissues, N content in tissue is so important that most of these forage species (e.g., legumes) have a symbiotic association with N-fixing bacteria to guarantee their N supply[12, 13].

N can be naturally or artificially added to the soil of pasture ecosystems. In the first case, it is incorporated into the system via biological fixation, animal waste (urine, feces), litter deposition, rainfall, and atmospheric deposition[12, 13] (Figure 1). Although the atmosphere has a high percentage of N_2 (78%) in its gas composition, the contribution to the supply of N for crops, including cultivated pastures, is considered very low[6, 11]. The atmospheric deposition can occur via lightning or mineral-based reduction of N [13].

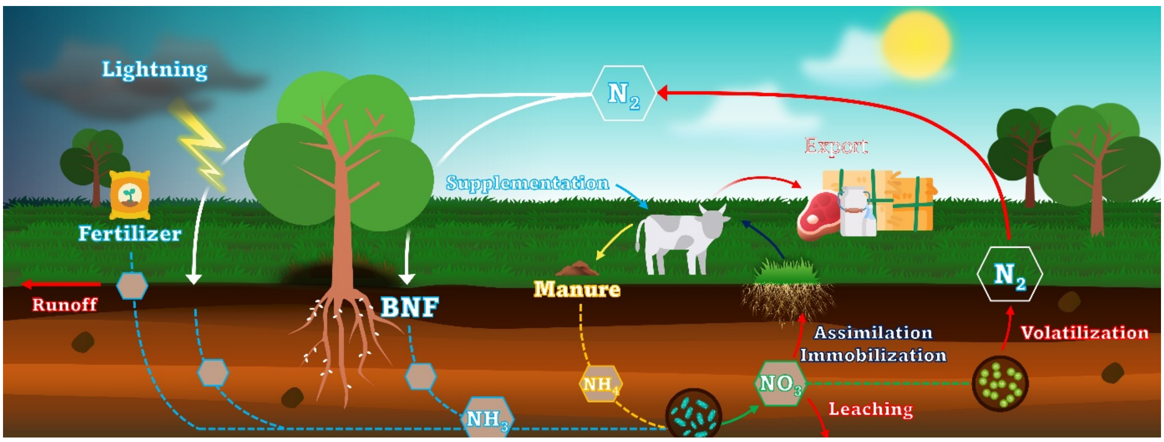

Figure 1 Inputs and outputs of N in pasture ecosystems. BNF=Biological nitrogen fixation.

The use of forage legumes in grass pastures is essential to add N to the systems via biological fixation of the atmospheric N_2 (Figure 1), contributing to meeting part of the grass demands. It generally increases the production and persistence of the plants in the pasture, consequently improving animal nutrition and production[12]. Forage legumes make the N available in the soil via biological fixation or during the decay of litter, roots, and nodules[14]. The presence of legume species intercropped with crops or grass species can impact the soil microbiota; generally, the C: N ratio (carbon and nitrogen) of the litter is reduced, which can influence microbial activity and biomass[15, 16, 17]. Many studies have shown the positive effects of adding legume species in grass pastures or intercropping with other crops and usually reported increases in forage production or reduction in the demands for inorganic N applications[14, 16, 18].

Regarding N inputs to the soil via litter deposition, one of the most important indicators that reflect the litter quality is the C:N ratio, where plants with higher levels of N in their biomass, such as legumes, provide residues with a low C:N ratio, which results in rapid decomposition and, consequently, a higher rate of N mineralization for plants[19, 20]. Dablin et al.[21] observed that adding legume trees in degraded tropical grass pastures significantly increased the total N contents of the litter in those pastures. Investigations led by Xavier et al.[22] showed that the use of legume trees in a silvopastoral system intercropped with the tropical grass *Urochloa* spp. increased both litter deposition and the N return to soil compared to the grass monocropping system.

Silvopastoral systems using legume trees can improve the efficiency of nutrient cycling and have the potential to recover degraded pastures and, at the same time, provide a forage with higher crude protein content[23, 24, 25]. In addition to the C: N ratio, other factors in the litter must be considered to determine the mineralization of N in the soil, which includes the N profile of the decomposing material (NH_3/NH_3, amino acids, crude protein), lignin, and polyphenols content[26]. According to Maluf et al.[27], the decomposition rate of plant residues is significantly influenced by N concentrations. The input of low-quality litter can be considered a major contributor to the increase in the degradation of tropical and subtropical pastures[11], as some of the required nutrients (e.g., microminerals) may take some time to be available at a specific time for plant growth.

Another way of adding N to the pasture ecosystem is by using inorganic fertilizers, which can have a pronounced impact on N availability and plant growth responses because they generally display quick mineralization[28, 29]. There are many sources of inorganic N fertilizers, for example, urea (CH_4N_2O), ammonium nitrate (NH_4NO_3), ammonium sulfate [$(NH_4)_2SO_4$], these differing in terms of N content, as also, in their availability and mineralization rates. Nevertheless, fertilizing pastures with inorganic N fertilizers is a relatively expensive management practice, with the potential to cause several environmental impacts via N leaching, accumulation (soil, water), and volatilization[30, 31, 32]. The use of N fertilizers also has the potential to accelerate the litter decomposition rate of the pastures; Apolinário et al.[33] tested the effects of different levels of inorganic N on the litter decomposition of *U. decumbens* pasture and found a decrease in C: N ratio and an increase in the decomposition rate, as a function of inorganic N fertilizer.

Another N input source to the soil of a grassland ecosystem is animal waste (urine, feces). The concentration of N in the feces and urine of grazing animals mostly depends on the content of these nutrients ingested in the diet. If it is a pasture-based diet, N is mostly recycled from the forage consumed; however, if the grazing animals receive some supplementation (e.g., urea, protein), the N ingested will be added to the pasture system via urine or feces. Animal waste deposition and distribution play a key role in nutrient cycling in pastures; in addition to the N, they add other compounds to the soil, such as sodium (Na) and potassium (K) – present mainly in urine – and phosphorus (P), calcium (Ca) and magnesium (Mg), released mostly via feces[6, 34]. Macro- and micromineral contents present in the wastes of grazing animals have different bioavailability to the plants, which is mainly associated with their mineralization rates by soil decomposers and interaction with other nutrients and soil pH[35, 36].

Grazing animals tend to deposit their wastes in very specific places, such as near water fountains and shaded places (e.g., below trees), resulting in the inefficiency of nutrient recycling and distribution, which may represent great losses of nutrients from the pasture ecosystem. It also causes higher concentrations of nutrients in certain places, which can lead to pollution or the absence of plant growth due to toxicity, for example. This means that animal grazing behavior directly affects the deposition of excreta and, consequently, the distribution of nutrients in the pasture, which can lead to an unbalanced distribution of the soil fertility between the different areas of the pasture[37]. However, the use of intermittent grazing and other techniques, such as strategically moving animals in the pasture and spreading water fountains and shades, can help to reduce this unbalanced distribution of excreta in the pasture.

4. Pathways of nitrogen output from the system

The biogeochemical cycle of nitrogen has many pathways for the output of this element from the pasture ecosystem. In addition to harvests and exportation by animal products, which are responsible for exporting large amounts of the nutrients contained in plant tissues[38], it is interesting to consider other factors that directly impact the availability of nutrients that can lead to significant losses of nitrogen, such as runoff, erosion, leaching [mainly as nitrate (NO_3^-) in permeable soils], and volatilization [ammonia (NH_3), molecular nitrogen (N_2) and nitrogen oxides (NO, N_2O)][39].

Nutrients with high mobility in the soil, such as N, are easily leached, especially in deeper soils, being carried out by rainwater or irrigation. The faster the N leaches in the soil profile, the more difficult it becomes for crops with short root systems to uptake this element[3]. The forms that N is absorbed by the plant root system are nitrate (NO_3^-) and ammonium (NH_4^+)[40], and it can also be absorbed in some organic forms (e.g., amino acids, peptides, nucleotides)[41].

Among the main factors influencing the dynamics of N, the C:N ratio of the soil organic matter (SOM) determines the decomposition rate, interfering with the mineralization or immobilization of N by soil microbes[42, 43]. When microbial activity acts on the decomposition of SOM, inorganic forms of nutrients are released, a process known as "mineralization." However, it should be considered that microbes also can act as temporary sinks of N, as they can keep part of the N for their growth. When inorganic ions are converted into organic forms in the microbes (e.g., amino acids, enzymes), the process called "immobilization" takes place. A significant portion of N is immobilized by soil microbes for protein synthesis. Therefore, the decomposition of organic materials with low concentrations of N may lead to the unavailability of this element for both microbes and plants[39, 43]. The immobilization of N by soil microbes may have an essential role in reducing the potential outputs that can occur in the free forms of N in the soil.

Another way of extracting N from the soil is through crop harvesting. Menezes et al.[44] evaluated the extraction of N by corn fertilized with liquid pig manure and observed that the extraction of nitrogen in the aerial part 20 days after planting was 42 g of N per kg^{-1} of DM when using manure and 28 g of N per kg^{-1} of DM without residue application. During the plant's vegetative development, especially during the exponential growth phase, dry matter accumulation can reach up to 70-80% of the total final dry mass, which requires large amounts of nutrients, especially N. Melesse et al.[38] reported concentrations of nitrogen in different forage species (grass and legumes) varying from 11 to 55 $g.kg^{-1}$ DM. Some pasture management practices can intensify nutrient exportation (e.g., forage conservation) because it is common that a forage produced in a place will be consumed and excreted far from there.

5. Pathways of phosphorus input into the system

Phosphorus (P) is an essential macronutrient for plant growth with high demand in agricultural production systems[45]. In plants, P has many roles in the metabolism, including the composition of the DNA, cell division, early root growth, tillering, seed formation, photosynthesis, and respiration process (ADP, ATP), among others [9, 10]. However, P levels in the soil of agricultural systems have been depleted or unavailable, becoming a worldwide problem[46, 47]. Continuous P additions are necessary to maintain optimal production levels of the crops and pastures. Improving P availability and fertilization efficiency by reducing its losses can contribute to the sustainability of pasture ecosystems [48].

P management in pasture ecosystems is particularly challenging, given the diversity in pasture dynamics (soil type, plant and animal species, grazing methods), and the complexity of P cycling. For example, the manure produced by grazing animals is deposited in patches, usually close to resting places (drinkers, feeding stations, shades)[49], which can lead to a saturation of P deposited in some specific parts of the pasture. Furthermore, the manure that returns P to pasture (Figure 2) is spatially heterogeneous, making nutrient cycling difficult [50]. Unlike nitrogen, P mobility in the soil is considered very low, and most P applied via inorganic fertilizers can quickly become unavailable to plants [47, 51].

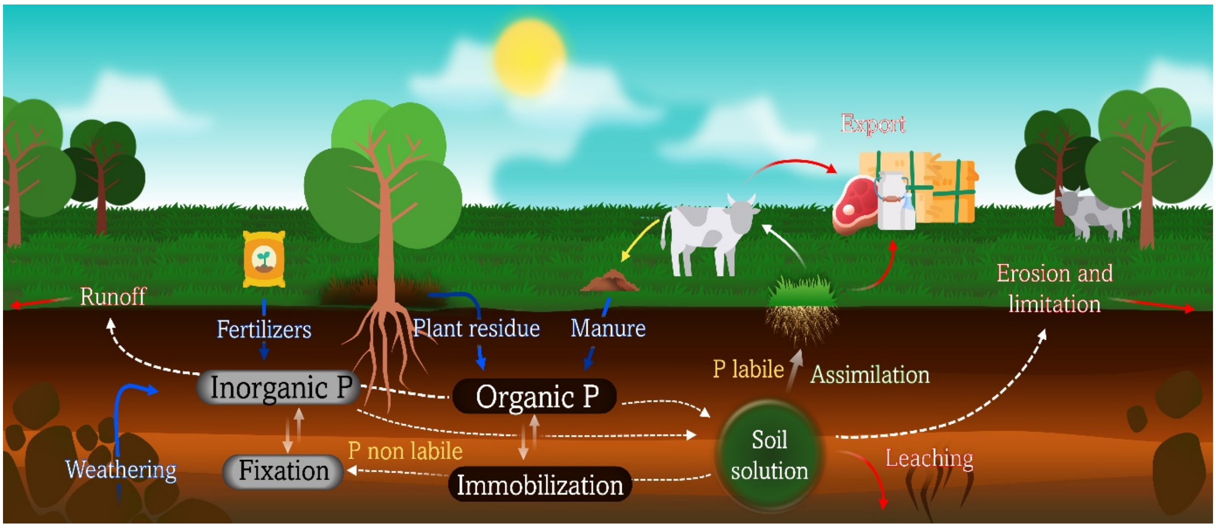

Figure 2 Inputs and outputs of P in a pasture ecosystem.

According to Sharpley et al.(52), a problem regarding the P cycle is the failure to recover and reuse P from manure and waste. Grazing animal wastes (urine and feces) can carry up to 81% of the P ingested(53). The content of P in animal wastes can improve the efficiency of the use of this mineral and reduce soil deficiency in pasture systems; however, it depends on the management strategies to improve its distribution(48). Kumaragamage and Akinremi(54), reported that the strategies to reduce P losses via animal waste include generating low-P manures, processing manure to reduce the total and soluble P, and adopting better management practices in terms of waste deposition or application.

Furthermore, another factor that limits the use of P by plants is its availability. Inorganic P, as orthophosphates (e.g., PO_4^{3-})(55, 56), when added to soil, are immobilized in forms not immediately available to plants. When available, they are absorbed from the soil solution and incorporated into the plant or microbial biomass. In grazing systems, P is subsequently transferred to the plant-animal biomass and can be exported from the pasture ecosystem as an animal (or plant) product. The P in the pasture biomass is returned or mineralized in the soil via animal wastes, plant residues, and microbial biomass during their decomposition(57).

Manure and plant residues are organic sources of P for the soil and reduce the need for external P inputs through inorganic fertilizers(48). Also, biofertilizers applied to the pasture can add significant amounts of P(58). In addition, soil microbes decompose SOM, which is a significant source of slow-release organic P(59). Manure deposited by grazing cattle may have cumulative benefits of decreasing P sorption, thus improving long-term P cycling efficiency(48). In addition, the management of animals in the pasture can improve nutrient cycling. According to Assman et al.(60), mild grazing intensities result in a higher rate of P release from pasture and manure residues.

6. Pathways of phosphorus output from the system

Among P loss pathways in tropical pastures, fixation/adsorption emerges as an extremely important route for reducing P availability in these systems. The tropical climate favors the development of more weathered soils, resulting in predominantly acidic soils[61]. In their clay fraction, several weathered soils contain iron (Fe) and aluminum (Al) oxides along with clays from the kaolinite group. Such components play a crucial role in fixing P in the soil since their charges are mainly positive in acidic environments, attracting a variety of anions, including phosphate (PO_4^{-3}).

P adsorption in soil can occur in three distinct phases: initially, the phenomenon occurs rapidly due to the presence of highly reactive oxyhydroxide sites, which exchange their OH^- and OH^{2+} ligands. In the second phase, adsorption occurs in areas with lower reactivity. The third phase occurs slowly, characterized by P precipitation, as reported by Parfitt[62].

Among the features in soil, it has been reported that high contents of oxide can lead to intense adsorption of P, reducing the labile fraction of P[63]. The presence of the group of phyllosilicates that encompass clay minerals such as kaolinite[64] and the group of Fe and Al oxyhydroxides (e.g., hematites, goethites, and gibbsites)[65] display great affinity for P due to the presence of hydroxyl in their active sites. According to Pavinato et al.[66], the Southern region of Brazil has the highest proportion of soils with high fixation capacity, as the soils in this region are mainly derived from basalt and contain large amounts of clay with Fe and Al oxides capable of fixing P.

In several areas of the Northeast region of Brazil, where the soils are characterized by the predominance of sandy particles, the P fixation rate is minor[67]. Nevertheless, although P has low mobility in soils, loss through leaching or erosion (Figure 2) occurs more significantly in sandy soils than through fixation processes[68]. In a general overview, in the Southeast and North regions of Brazil, P fixation shows medium to high values, respectively, due to the quantity and quality of the clay fraction, in addition to the base saturation level, which varies according to the pedogenetic factors of each soil[69].

Although organic matter (OM) initially contributed to the retention and stock of P, it is important to note that it also contains humic and fulvic acids, in addition to other organic anions. Furthermore, OM displays a significant presence of carboxylic groups (-COOH) that occupy adsorption sites on clays, and Fe and Al oxides in place of P[70]. Thus, the presence of OM can raise the effectiveness of phosphate fertilizer, as organic acids will be released. These organic acids compete for fixation sites, increasing P availability for plants. However, it is important to highlight that the effectiveness of this process depends on the organic source used and its mineralization rate, which will be influenced by the type of soil and climatic conditions[71].

The soil pH is crucial, as it influences the availability of P in the solution. Weathered and very acidic soils, such as those found in humid tropical and subtropical regions, are characterized by significant fixation of considerable amounts of P[68]. The effectiveness of phosphates is more pronounced when the soil pH is close to 6.5[72] due to the high concentration of iron and aluminum oxides in acidic soils, substances that favor P adsorption. However, in alkaline soils, the predominance of calcium and magnesium carbonate can also restrict the availability of P, with a significant impact on absorption and use by plants[73, 74].

In Brazil, most soils have acidic characteristics with a pH of around 5.6, associated with the weathering process and leaching of bases[69]. Liming represents an alternative to mitigate the nutrient deficit from acidification in weathered soils with low pH, predominantly used in several crop systems in Brazil. This management technique makes it possible to adjust soil pH and reduce acidity. Liming can promote more favorable conditions for plant development by adjusting the acid-base balance to the pH range of 6 - 7, where most crops grow better due to the availability of most of the essential nutrients for plant growth[75, 76].

The place where P is deposited by cattle can strongly influence its retention in pastures (Figure 2). It is important to mention that P is often returned to the soil away from the area where it was consumed so that stock transfer between areas of the pasture can represent a loss of approximately 5% of P input requirements via fertilizers[77].

Pastures under grazing conditions are a significant source of phosphorus input to surface waters. Nellesen et al.[78] observed a greater P loss in pastures with unrestricted access to streams. Effective P management strategies must involve techniques to reduce continuous soil trampling and excessive manure inflows into vulnerable sites. Keeping the vegetation cover of pastures can reduce losses in both particulate and dissolved P forms. The use and distribution of drinkers away from rivers and dams can reduce the time the animals remain in areas near watercourses and reduce the deposition of excrement in only one area[79]. Another alternative to increase the homogeneity in excreta deposition on the soil is rotational grazing. This management, when well performed, can also be effective in reducing runoff and erosion of the pasture by reducing the impact of trampling[80]. Management practices, such as adjusting stocking rates and grazing methods, distribution of shaded structures (e.g., trees and shelters) and supplement feeding sites, spreading drinkers, efficient fertilization, and forage diversity can affect the efficiency of nutrient cycling in pastures[81]. Another pathway of P loss in a pasture ecosystem is crop exportation[44] in pastures; the exportation of nutrients can occur through animal products or when the forage is harvested and consumed far from the grazing systems it was planted/harvested.

7. Pathways for potassium input into the system

Potassium is a macronutrient required in high amounts by crops because it plays important roles in regulating water flow, enzymatic activation, opening and closing stomata, and transporting carbohydrates[8]. It is found available in the soil in the form of cation (K^+), adsorbed, or in soil solution (Figure 3). It is absorbed by plants in the same form. Potassium is a nutrient mostly added to the pastures through fertilization, inorganic or organic, and also added by animal feeding or mineral supplements.

The main sources of inorganic K fertilizers are KCl, K_2O, and K_2SO_4[82, 83]. Organic fertilizers, especially animal wastes, are the main sources of recycling this element in the pasture

(70-90%). It can be returned to the pasture immobilized in organic matter or in ionic forms that are water-soluble and readily available for plant uptake. Therefore, the dynamics of this nutrient in the soil and its cycling depend on the type of production system. According to Assmann et al.[(60)], pasture and manure residues can release K in a high proportion, and, unlike P, potassium availability is not much influenced by grazing intensity. K availability essentially depends on soil reserves and fertilizer applications. In soils with low cation exchange capacity (CEC), as in most Brazilian soils, there is considerable leaching of this nutrient[(84)].

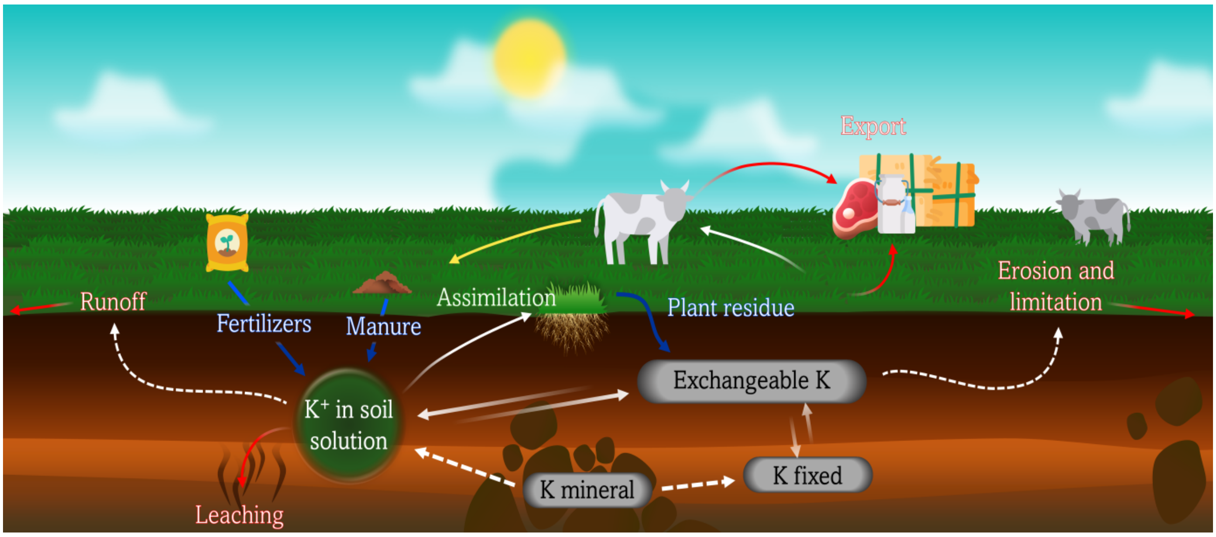

Figure 3 **Inputs and outputs of K in pasture ecosystem.**

Similar to what was described for N and P, another input route for K in pasture ecosystems is through animal supplementation, using both animal feed and mineral supplements (Figure 3). The K content in most grasses and legumes ranges around 30-40 g. kg^{-1} DM[(38)], which can represent a significant intake of this nutrient by grazing animals. Considering an animal unit (453.5 kg) consuming, for example, 12 kg DM per day, its intake of K can range around 360-480 g per day. Another source of K input into the pasture is biofertilizers; Coelho et al.[(58)] reported K values ranging from 7 to 119 g. kg^{-1} DM in different biofertilizers.

8. Pathways of potassium output from the system

As K is one of the main minerals in the forage[(39)], significant amounts of this nutrient can be exported during harvesting and also by the exportation via animal products (e.g., milk and meat)[(85, 86)]. Understanding the uptake rate and the total amount of K accumulated in crops during the growing season and its removal during harvest is necessary to assess the outputs of this element from the grazing system.

Potassium can also leave the grassland ecosystem through leaching or runoff due to its high solubility (Figure 3). Furthermore, as K is bound to clays and organic materials and adsorbed on fine soil particles, it can be eroded by runoff water and carried out by strong winds (e.g., ashes after burning pasture biomass)[87, 88, 89]. Soil particles eroded from the field carry adsorbed K with them. Water erosion occurs mainly on the soil surface or at shallow depths by runoff, but particles can also be transported to depth and lost via field drains[87].

K losses through runoff depend on rainfall intensity, the timing of precipitation events, the K fertilizer management, and the cation exchange capacity of the soil[90, 91]. Significant losses of this nutrient may occur due to its presence in crop residues and at the surface layer of the soil. K can occur free in plant tissues, which facilitates removal by water after senescence[92]. K is a nutrient that can leave the pasture ecosystem through wind erosion. The stronger the wind speed, the more the soil is prone to erosion[33], especially small dry particles[93,94].

In a silvopastoral system with signal grass (*Urochloa decumbens*) and the legumes gliricidia (*Gliricidia sepium*) and sabiá (*Mimosa caesalpiniifolia*) in Itambé, state of Pernambuco, Herrera et al.[95] reported a reduction in soil K^+ from 2013 to 2017, associated with pasture and trees development over time. The greater extraction of K^+ may be due to the higher accumulation of this nutrient in the biomass components, with younger trees showing a higher demand for nutrients in leaves and branches[96,97]. Furthermore, estimates indicate that K^+ can be stored at approximately 0.8 (16 g kg^{-1}) and 0.7 Mg ha^{-1} (14 g kg^{-1}) in the biomass of gliricidia and thrush, respectively [98, 99].

The development and implementation of best management practices for fertilizer use, with a focus on source, rate, timing, and placement, are necessary for the short term to increase the productivity and economic return of fertilizer inputs[100]. The source of K must be a factor to be adjusted in fertilizer recommendations to limit its losses in pastures. For example, the use of slow-release (polymer-coated) KCl can reduce K leaching compared to traditional KCl; however, the slow-release rate may not be sufficient to meet crop demands for K[101]. It is known that when K fertilizers are applied by surface diffusion, the presence of a cover crop can reduce K runoff losses[74].

9. Conclusion

Nutrient cycling between different compartments is characteristic of pasture ecosystems. The analysis of nutrient dynamics in pastures must take into account inputs and losses of elements and their biogeochemical cycles. Manure and litter are the main sources for returning nutrients to the pasture ecosystem, which occurs through decomposition by microorganisms. Knowledge of the factors that control the release of nutrients from litter and manure in pastures, combined with the study of nutrient loss mechanisms, can contribute to making more sustainable management systems.

There is more than one route for nutrients to enter the pasture ecosystem. Nitrogen can be incorporated through biological fixation, litter deposition, animal excrement, rainfall, and atmospheric deposition. Among the main routes of nutrient loss are erosion, leaching, runoff, and volatilization. In addition, the extraction of nutrients by plants and their consumption by grazing animals is also a considerable variable in the output of nutrients from pastures via product exportation. The redistribution of nutrients can be influenced by grazing, consumption, pasture defoliation, and their return to the soil via excreta. Management practices such as adjustment of the stocking rate and grazing methods and the distribution of shaded structures supplement feeding structures, and drinkers can affect the efficiency of nutrient cycling in pastures.

Conflict of interest

No potential conflict of interest was reported by the author(s).

Author contributions

Nascimento DB, Lopes MLS, Izidro JLPS, Bezerra RCA, Amaral TNE, Dias WS, Barros ML, Oliveira ARS, Farias Sobrinho JL, and Coêlho JJ: conceptualization, collected data, resources, writing (original draft); Gois GC: writing (original draft), revision and editing. All authors reviewed and approved the final manuscript.

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