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Land use change and greenhouse gas emissions: an explanation about the main emission drivers

Mudanças de uso da terra e emissão de gases de efeito estufa: uma explanação sobre os principais *drivers* de emissão

Natan Lima Abreu*[1], Eleanatan Syanne da Cruz Ribeiro[2], Camila Eduarda Souza de Sousa[1], Lorena Maués Moraes[2], João Victor Costa de Oliveira[2], Letícia de Abreu Faria[2], Ana Cláudia Ruggieri[1], Abmael da Silva Cardoso[3], Cristian Faturi[2], Aníbal Coutinho do Rêgo[4], Thiago Carvalho da Silva[2]

1 Universidade Estadual Paulista (UNESP), Jaboticabal, São Paulo, Brazil
2 Universidade Federal Rural da Amazônia (UFRA), Belém, Pará, Brazil
3 University of Wisconsin, Madison, United States of America
4 Universidade Federal do Ceará (UFC), Fortaleza, Ceará, Brazil
* corresponding author: nl.abreu@unesp.br

Abstract: Global warming is attributed to the increase in greenhouse gas (GHG) emissions, such as carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O). Land use changes significantly impact on GHG emissions, accounting for approximately 44% of the country's emissions in 2019. This review addresses the main pathways of GHG formation in the soil, focusing on the influence of land use changes on GHG emissions. It is found that soil CO_2 emissions are related to root respiration, microorganisms, and organic matter (OM) decomposition in the soil. Changes in land use can alter soil characteristics, favoring increased CO_2 emissions. Soil CH_4 emissions occur under anaerobic conditions by methanogenic microorganisms; however, land use changes, such as forest conversion to pasture, can increase CH_4 emissions due to a higher concentration of methanogenic microorganisms in the soil. On the other hand, N_2O is produced in the soil during nitrification and denitrification processes by microorganisms, and nitrogen fertilization in agricultural areas can increase N_2O emissions, especially when associated with soil moisture and the availability of organic carbon. It is important to understand the dynamics of GHG formation and emissions resulting from land use changes because efficient management strategies can reduce these emissions and contribute to Brazil's goals for GHG reduction as established in international agreements.

Keywords: Carbon stock; methane in the soil; nitrous oxide in the soil.

Resumo: O aquecimento global é atribuído ao aumento das emissões de gases de efeito estufa (GEE), como dióxido de carbono (CO_2), metano (CH_4) e óxido nitroso (N_2O). As mudanças no uso da terra têm impactos significativos nas emissões de GEE, sendo responsáveis por aproximadamente 44% das emissões do país em 2019. Essa é uma revisão que aborda as principais rotas de formação dos GEE no solo com foco na influência das mudanças do uso da terra nas emissões de GEE. Constata-se que as emissões de CO_2 pelo solo estão relacionadas à respiração de raízes, microrganismos e decomposição da matéria orgânica (MO) do solo, assim mudanças no uso da terra podem alterar as características do solo, favorecendo a intensificação das emissões de CO_2. As emissões de CH_4 pelo solo ocorrem

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em condições de anaerobiose por microrganismos metanogênicos, no entanto as mudanças no uso da terra, como a conversão de florestas em pastagens, podem aumentar as emissões de CH_4 devido a uma maior concentração de microrganismos metanogênicos no solo. Já o N_2O é produzido no solo durante o processo de nitrificação e desnitrificação por microrganismos, e a fertilização nitrogenada em áreas agrícolas pode aumentar as emissões de N_2O, especialmente quando associada à umidade e disponibilidade de carbono orgânico no solo. Destaca-se a importância de compreender as dinâmicas de formação e emissão de GEE decorrentes das mudanças de uso da terra, pois estratégias eficientes de manejo podem reduzir essas emissões e contribuir para o cumprimento das metas do Brasil em relação à redução de GEE estabelecidas em acordos internacionais.

Palavras-chave: estoque de carbono; metano no solo; óxido nitroso no solo.

1. Introduction

Global warming has been attributed to the excessive emission of greenhouse gases (GHGs) into the atmosphere, such as carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O). These gases are present in the atmosphere at different concentrations, with CO_2 reaching the highest mark, followed by CH_4 and N_2O, respectively. It is important to emphasize that among the gases with the highest pollution capacity are CH_4 and $_{N2}O$, with pollution capacities 28 and 265 times that of CO_2, respectively [1]. However, the main GHG emitted by Brazil is CO_2 [2].

The production of these gases is optimized in the sectors of energy, agriculture, industrial processes, waste, and land use change, the latter being responsible for 45% of GHG emissions in Brazil [3]. In 2019, in this country the process of land use change accounted for approximately 44% of greenhouse gas (GHG) emissions, followed by agricultural activities with 27% [3].

Land use changes alter the physical, chemical, and biological characteristics of the soil, creating favorable conditions for the intensification of GHG emissions [4, 5]. Moreover, the magnitude of such emissions is influenced by factors such as temperature, humidity, nitrogen and carbon levels, and soil's microbiological patterns [6].

Given the national and global situation, it is evident that it is crucial the existence of research aimed at understanding the dynamics of GHG formation and emissions resulting from land use changes. This research helps determine efficient management techniques that could reduce emissions and promote greater conservation of natural resources, contributing to the achievement of objectives assumed by Brazil in agreements, as the Paris Agreement in 2016, highlighted at COP26 in 2021.

Therefore, this review addresses the anthropogenic actions that intensify the greenhouse effect and, consequently, global warming. It outlines the main pathways of GHG formation, indicating the most important factors that influence the formation and emission of these gasses, and provides an understanding of how land use changes affect emission pathways.

2. Greenhouse effect and global warming: a brief explanation

The greenhouse effect and the presence of GHGs in the atmosphere are natural phenomena. While a portion of the radiation that reaches the Earth is absorbed by oceans, rivers, soil, and plants, another part of the energy is reflected into space, where it is trapped by a layer of gasses in the atmosphere primarily composed of carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O). This phenomenon is known as the greenhouse effect. The retention of part of the incoming solar radiation in the atmosphere is responsible for keeping the planet warm, preventing it from freezing [(7)].

Nevertheless, over the past centuries, there have been significant increases in the intensity of greenhouse gas production and the amount of emissions. Consequently, the layer of GHGs in the atmosphere is becoming gradually thicker, thus retaining more energy and fueling global warming in an unrestrained manner [(8)].

According to the IPCC (Intergovernmental Panel on Climate Change) [(9)], global warming is characterized by a substantial increase in the average temperature of the planet. This influences the speed of polar ice melting, sea level rise, extinction of various living organisms, such as plants and animals, as well as alterations in climatic conditions, which results in negative impacts on agricultural productivity.

GHGs are present in the atmosphere in different concentrations, with the order of magnitude being CO_2 (66%), CH_4 (16%), and N_2O (7%). These gasses are expressed in terms of CO_2 equivalent or Global Warming Potential (GWP) [(1)]. Hence, CO_2 weights 1 GWP, CH_4 weights 28 GWP, and N_2O weights 265 GWP. It is worth noting that, due to the threat of global warming to human survival on planet Earth, numerous nations have mobilized the search for alternatives to mitigate GHG emissions.

In 2016, Brazil signed the Paris Agreement and committed to reducing the amount of greenhouse gas (GHG) emissions of 2005 by 37% by 2025, ratifying goals already established by national Law No. 12,187 of 2009 and national decree No. 9,578 of 2018 [(10, 11-12)]. During COP26 in 2021, the country reaffirmed its objectives stipulating a 50% reduction in GHG emissions when comparing 2030 data to 2005 levels [(13)]. Currently, Brazil has implemented the ABC+ plan, which aims for a low-emission economy in agriculture through activities such as pasture recovery, integrated crop-livestock-forestry systems, agroforestry systems, no-till farming, biological nitrogen fixation, planted forests, animal waste treatment, and climate change adaptation, with validity until 2030 [(14)].

3. Soil CO_2 emissions

The soil is the planet's main carbon reservoir, with soil organic matter (SOM) consisting of 55-60% by mass of carbon (C), considered one of the largest reservoirs in the world, with 1,300 to 1,500 Pg of C in the top meter [(15)]. Soil CO_2 emissions are related to root respiration, microbial activity, and the decomposition of SOM. Regarding land use changes specifically, CO_2 emissions mainly result from alterations in the concentrations of different soil organic matter fractions, influenced by quality, addition or removal of SOM, and fertility [(16)].

Land use changes typically cause alterations in soil chemical parameters, mainly due to differences in management between the new and old systems [(17)]. Additionally, some modifications involve biomass burning [(18)], leading to losses in carbon stocks and driving CO_2

emissions [19]. Land use changes can also influence soil temperature, considered a limiting factor for CO_2 production (R^2 = 55), as it affects soil microbial activity [20, 21].

The soil disturbance result of some activities involved in land use changes can contribute to CO_2 emissions because it causes disruptions in soil aggregates, allowing for greater aeration and even increased water infiltration [4]. This disruption leads to greater exposure of soil organic matter (SOM), enabling increased oxidation of soil organic carbon by microorganisms, resulting in higher CO_2 production (Figure 1) [15, 22, and 23].

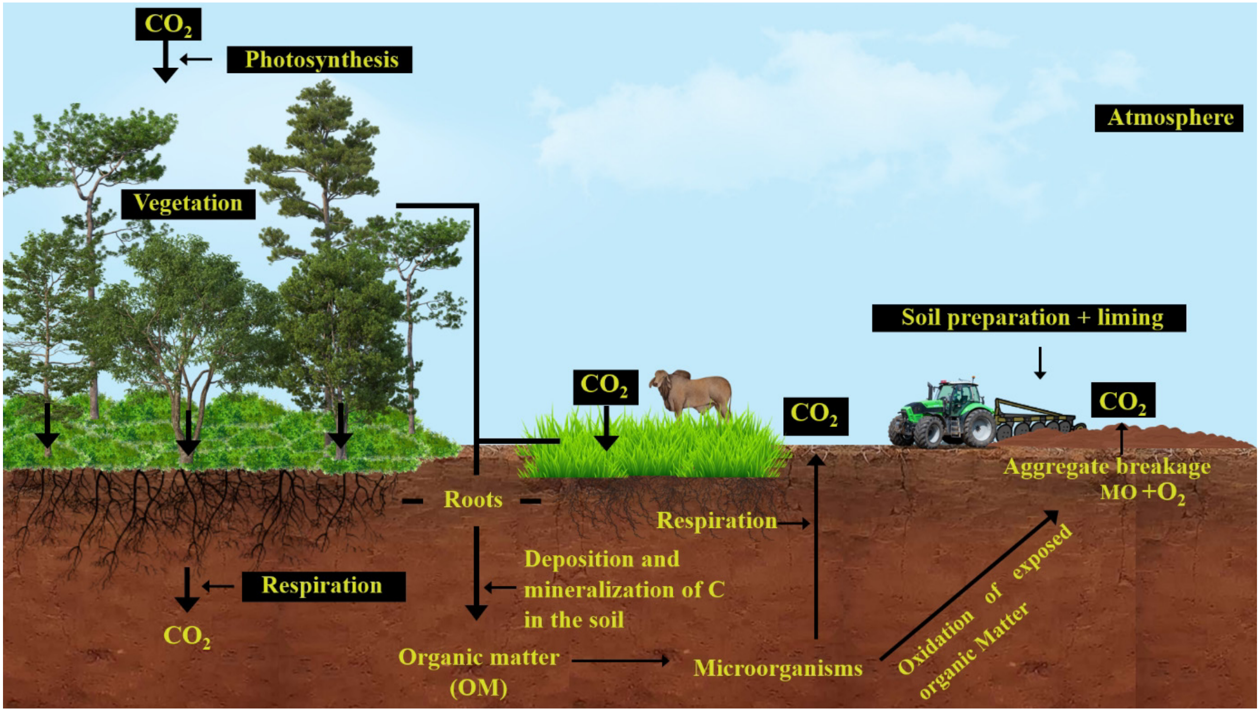

Figure 1: Carbon Cycle (C) in Soil
SOM: soil organic matter, CO_2: carbon dioxide, O_2: Oxygen.
Source: adapted from Jackson et al.[15]; Lavallee et al.[23]; Tavanti et al.[6]; Chang et al.[18].

Soil organic matter (SOM) is one of the main factors regulating CO_2 emissions and it is typically divided into two fractions: (1) particulate organic carbon (POC), and (2) mineral-associated organic carbon (MOC). POC has a density lower than 1.6-1.85 g/cm^3 or greater than 1.6-1.85 g/dm^3, but it is associated with particle sizes larger than 50-63 µm, whereas MOC has a density greater than 1.6-1.85 g/dm^3, associated with particle sizes smaller than 50-63 µm [23].

Among the two fractions of soil organic matter, POC stands out as a significant influencer of CO_2 emissions, considered a coarser fraction of carbon in the soil, meanwhile, MOC is a more stable fraction with a lower likelihood of being reduced in the soil, as it holds organomineral associations [23, 24]. Consequently, higher levels of MOC in the soil are associated with lower CO_2 emissions.

The role of soil texture in protecting soil organic matter (SOM) and forming more stable carbon (C) fractions in the soil, leading to a reduction in greenhouse gas (GHG) emissions, remains contradictory. Bruun et al. [25], Miranda et al. [26], and Tavanti et al. [6] demonstrated that clay is capable of protecting soil organic matter, hence preventing the oxidation of carbon into CO_2. In contrast, Midwood et al. [27] stated that soil texture has a low correlation

(R^2 = 0.007 - 0.17) with the process of carbon stabilization and the subsequent formation of SOM fractions, especially mineral-associated organic carbon (MOC). According to these authors, in clayey soils, the higher presence of MOC is due to mineral weathering associated with high humidity, rather than the direct effect of clay.

An alternative for reducing CO_2 emissions concerning land use changes is to decrease mechanical soil tillage practices, as this will result in an accumulation of soil organic matter (SOM). This effect occurs predominantly in the surface layers (0-30 cm), as observed by Riltt et al. (28) when converting pastures to agricultural areas, and by Damian et al. (29) when converting poorly managed pastures into integrated crop-livestock-forestry systems for well-managed pasture areas.

The conversion of certain land uses into pasture systems can lead to reductions in soil carbon (C) levels in the first years following conversion. It is expected that after 10 years of conversion to well-managed pasture systems, soil organic carbon stocks (SOCs) will be similar to or higher than the initial values at system implementation. Much of this result is due to the extensive deposition of plant residues and carbon into the soil through the action of grasses implanted in the system (30, 31). Conversely, the conversion of pasture or native forest areas to agricultural areas can result in a steady decline in SOCs for up to 25 years after the conversion due to soil preparation using machinery and low soil cover in some periods of the year (32).

According to the compiled data (Figure 2), it is possible to observe that the cumulative soil carbon (C) in well-managed pasture systems can offset the CO_2eq emissions from certain animal stocking rates, indicating these types of land use as alternatives to combine economic gain with sustainable production. Based on this research, it is also evident that poorly managed pasture systems contribute to CO_2 emissions into the atmosphere, not only because they emit CO_2, but also because they do not sequester carbon.

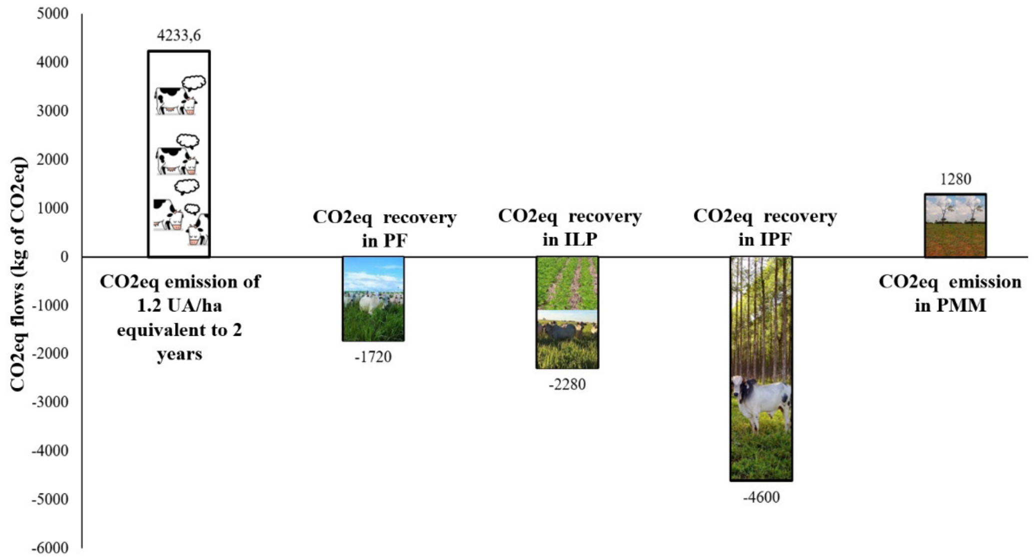

Figure 2: Comparison between enteric CO_2eq emissions by cattle and the exclusively stored recovery of CO_2eq by the soil from different systems, all equivalent to a period of 2 years
Legend: PMM: poorly managed pasture (productivity of 3.7 Mg ha^{-1}); PF: fertilized pasture, ILP: crop-livestock integration, IPF: livestock-forest integration.
Source: adapted from Resende et al.(33) and Damian et al.(29).

In poorly managed pasture systems, the input of carbon into the soil is primarily reduced due to the low efficiency of grass in the system to produce roots and straw, similar to what occurs in agricultural areas. This lower input of carbon into the soil fails to mitigate the emissions that naturally occur in these two land uses [6].

In agricultural conditions, agroforestry systems [34], crop rotation [35], and the use of mulch [36] can positively contribute to carbon sequestration, primarily because these systems can deposit a significant amount of plant residue into the soil. Over time, this residue undergoes carbon cycling processes, ultimately resulting in its immobilization in some fraction of organic matter in the soil.

In general, CO_2 is influenced by soil carbon stocks, as it is the main substrate for microbial production of this gas. However, this C can be found in the soil in forms that are more resistant or susceptible to oxidation, although both are subject to microbial oxidation. Additionally, land use changes influence soil chemical characteristics, which can increase the exposure of C to the effects of microbial oxidation.

4. Soil CH_4 emissions

Methane (CH_4) has an infrared radiation absorption capacity 28 times greater than CO_2 [1]. Its production in the soil depends on anaerobic microorganisms that decompose carbon under flooded conditions, with the ideal temperature range for production being 37°C to 45°C [37].

The production of CH_4 occurs through the action of microorganisms called methanogens, which, under anaerobic conditions, use substrates such as acetate, formate, H_2, CO_2, and methylated compounds [38, 39]. Its oxidation can be carried out by microorganisms called methanotrophs, which use it as the sole food source under aerobic conditions. Additionally, methane can also be oxidized by ammonia oxidants (NH_3), but in both oxidation pathways, CH_4 is converted into CO_2 in the soil [18].

The process of converting CH_4 into CO_2 in the soil can be carried out by Ammonia Oxidizing Archaea (AOA), Ammonia Oxidizing Bacteria (AOB), and methanotrophs, with AOA having a greater affinity for CH_4. Consequently, the higher the number of AOA, the lower the number of AOB in the soil (R^2=0.53) [40]. Moreover, AOA is minimally affected by soil changes, especially with increased temperature and reduced humidity, thus potentially becoming one of the main pathways for CH_4 oxidation in the soil after land use changes [40]. However, the reverse can also be applied since ammonia (NH_4), one of the possible products of nitrogen used as a fertilizer, can also be oxidized by methanotrophs. Therefore, this can be considered a potential competitor with methane for monooxygenase, the enzyme responsible for CH_4 oxidation [41].

In soil under anaerobic conditions, organic matter (OM) is decomposed by microorganisms into smaller fractions through processes of hydrolysis and fermentation. The main products of this process are CO_2 and CH_4. The CH_4 produced diffuses into the upper layer of the soil, where aerobic conditions prevail, allowing for the oxidation of methane by methanotrophic organisms. During the CH_4 diffusion process into the upper layer of the soil, a series of reactions between CH_4 and electron acceptors (n-receptors) can occur. As a result, part of the CH_4 produced from OM decomposition is not emitted into the atmosphere (Figure 3) [42]. The main electron acceptors in the soil include iron and manganese oxides [43].

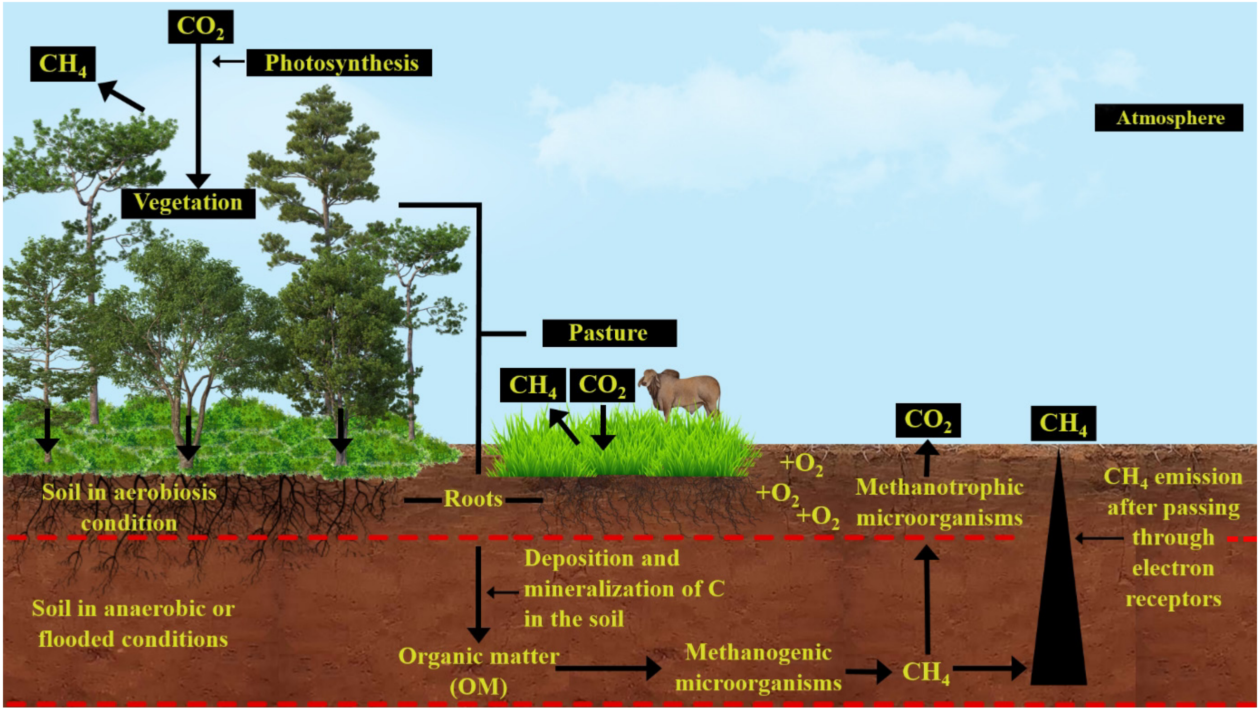

Figure 3: Methane (CH_4) Cycle in Soil
OM: organic matter, CO_2: carbon dioxide, CH_4: methane
Source: adapted from Silva et al.[43]; Keppler et al.[44]; Dean et al.[42]; Chang et al.[18]; Xu et al.[40]

The production of CH_4 from the soil is also related to the decomposition of organic matter under flooded conditions, often observed in agricultural systems such as rice cultivation [43, 45]. This process can also occur in other crops due to high precipitation during certain periods of the year, possibly leading to some areas producing CH_4 due to maximum soil moisture saturation [46]. However, land use changes, such as conversion from one system to agricultural areas, typically result in reduced methane emissions, as these systems experience a decrease in soil organic carbon stocks and soil moisture [47, 48].

Soil CH_4 emissions are related to intrinsic cultivation factors, such as planting duration, fallow period, and applied inputs. In a meta-analysis evaluating greenhouse gas emissions in different agricultural systems, Shakoor et al. [49] found that CH_4 emissions increased when poultry manure was applied to soil with pH > 7 and soil moisture saturation > 60%, in rice cultivation areas, and in fallow areas without cover crops. Additionally, higher gas emissions were observed in crops with a duration of less than 320 days. Moreover, CH_4 emissions can also be influenced by the conditions of the soil layer. Cardoso et al. [50] found that higher methane emissions occur in the upper soil layer, as it is mainly influenced by the moisture and temperature of it. The higher the moisture and temperature of the soil fraction, the greater the CH_4 emissions [51].

The methane emission also correlates with nitrogen concentrations applied to the soil. According to Sainju et al. [52], this correlation for monoculture systems is moderate

(R^2=0.56), while the correlation for grass-legume crop rotation systems shows a substantial correlation (R^2=0.91). They concluded that the use of crop rotation with legumes, when combined with reduced nitrogen fertilization, can reduce CH_4 emissions by -1 kg CO_2eq ha^{-1}. However, the study highlighted that there is still no consensus on the influence of fertilization on CH_4 emission.

In addition to the soil and climatic factors that affect CH_4 emissions, recent studies [39, 45, 46, and 53] on methane emissions in pastures indicate the soil methanogenic microbiota as an influential factor in CH_4 release, which can be affected by secondary factors such as soil pH, vegetation, compaction, nutrient input via animal excreta, levels of organic carbon (COS), drainage, sandy texture, total soil nitrogen, soil bulk density, ammonium (NH_4), and soil nitrate (NO_3).

The main factors contributing to methane emissions from the soil identified in the analyzed studies include soil moisture, microbiology, and the availability of organic matter (OM) in the soil. The conversion of wetlands into agricultural areas can reduce methane production, as it decreases soil moisture and carbon stocks in the soil.

5. Soil N_2O emissions

Nitrous oxide (N_2O) is one of the gaseous forms of Nitrogen (N) produced during the nitrification process by certain nitrifying microorganisms (Figure 4A), and it is also produced during the denitrification process by denitrifying microorganisms through nitric oxide reductase, which is commonly associated as the main process of N_2O formation (Figure 4B). There are also other processes of N_2O emissions, such as codenitrification and chemodenitrification, which produce them in smaller proportions [54]. In agricultural areas, its production mainly occurs through the conversion of nitrogenous fertilizers into N_2O. In pasture areas, its production is derived from fertilizer application and from nitrogen deposition in urine by animals [55].

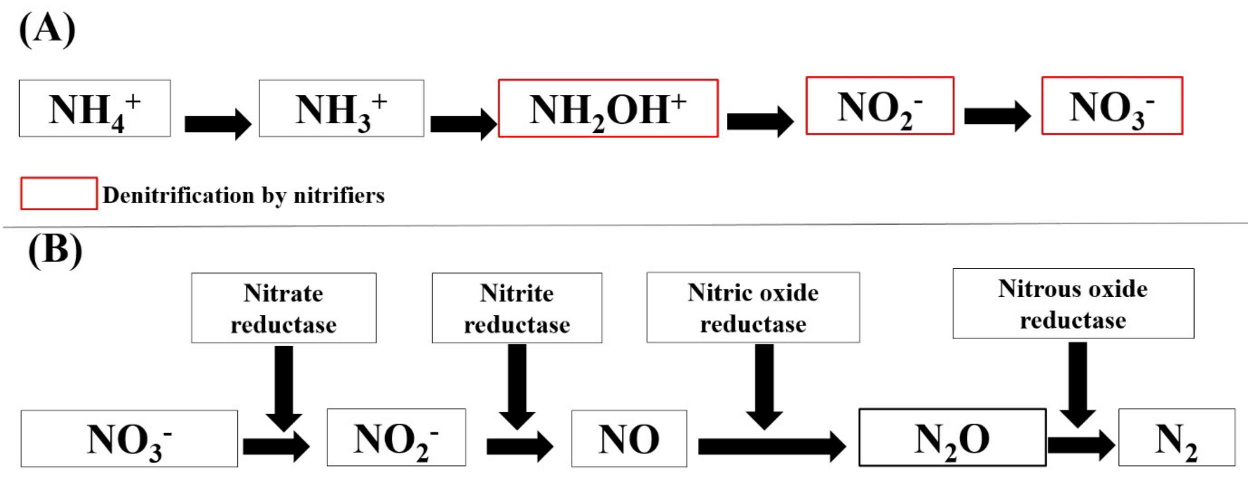

Figure 4: Nitrification (A), and Denitrification (B) Processes involved in N_2O production
NH_4^+: Ammonium; NH_3^+: Ammonia; NH_2OH: Hydroxylamine; NO_2^-: Nitrite; NO_3^-: Nitrate; NO: Nitric oxide, N_2: Dinitrogen; N_2O: Nitrous oxide
Source: adapted from Vieira [54].

The production of this gas in the soil depends on the action of bacteria, fungi, and Archaea that use ammonium (NH_4^+) and nitrate (NO_3^-) produced by fertilizers, animal urine, or soil organic matter as the main substrate during one of the phases of the nitrogen (N) cycle (56). Ammonia-oxidizing Archaea (AOA) dominates in soils with low NH_4^+ concentration and produces less N_2O compared to ammonia-oxidizing bacteria (AOB) (57). Fungi, on the other hand, can perform the denitrification process, preferring to use NO_3^- and NO_2^- to form N_2O, as they are unable to form N_2 since they lack the N_2O reductase enzyme (58).

Nitrogen fertilization can interact with soil moisture and the availability of organic carbon, leading to a higher proportion of nitrate, which is one of the main substrates for the N denitrification process, and the consequent emission of N_2O as one of the products. This effect can be enhanced by the availability of carbon in the soil since it is also an essential element for most microbial processes (59, 60). Peaks in soil's N_2O emissions typically occur a few days after the application of nitrogen fertilizers (61).

Within the first 24-48 hours after nitrogen fertilizers, mainly urea, are added to the soil, they undergo the action of the enzyme urease, which hydrolyzes urea into ammonium (NH_4^+) and carbonate ions (CO_3^{2-}). The carbonate is subsequently hydrolyzed into bicarbonate (HCO_3-) and OH ions, drastically increasing the soil pH (pH > 8). This elevated pH can cause soil organic matter to release NH_3^- because OH affects the NH_4^+/NH_3^- ratio, with the nitrogen from urea tending to remain in the form of ammonia at higher pH levels. Ultimately, this increased availability of NH_3^- can be oxidized by ammonia-oxidizing bacteria (AOB), potentially generating N_2O (55).

Yuttitham et al. (62) corroborated that N_2O emissions can be intensified by fertilizer application, and Silva et al. (43) observed that N_2O emissions may be associated with microbial carbon (C) and nitrogen (N) contents. Data from the IPCC (9) demonstrated that under ideal environmental conditions, nitrogenous agricultural fertilizers can account for up to 1% of N_2O emissions. Agricultural areas that use nitrogenous fertilization are subject to the highest N_2O emissions (9; 63), especially those using urea, as the reaction of this fertilizer with soil water leads to the formation of ammonium, which can subsequently be utilized in the denitrification process by nitrifiers (54). The use of fertilization with animal residues can also stimulate N_2O and NO_x emissions as there may be inhibition of enzymes that reduce nitrate and nitrite (64).

In livestock farming, N_2O emissions are related to the combination of urine and dung deposition on the soil, with urine releasing N into the soil and feces providing C (60). However, although this is a favorable combination for N_2O production, the release of N from dung is slow, which may favor the formation of low levels of NH_4^+ in the soil, promoting the presence of AOA and consequently lower N_2O emissions (55).

The concentration of organic matter (OM) in the soil can also influence N_2O production, as a large amount of OM in the soil acts as a buffer for pH, reducing the concentration of NH_4^+ in the soil solution in response to this phenomenon. Subsequent concentrations of NH_3, NO_x^-, and N_2O are also reduced (65).

Another inherent soil factor capable of influencing N_2O emissions is soil texture. According to Carmo et al. [66], soil texture, when associated with moisture, can influence N_2O emissions because it is directly related to water retention capacity shortly after micro and macropores are filled. With water saturation, anaerobic conditions occur, sufficient for some microorganisms to produce N_2O. Thus, clayey soils tend to emit more N_2O [67]. It is important to note that N_2O production can also occur under aerobic conditions due to the action of aerobic microorganisms. Therefore, aerobic conditions are not a limiting factor for N_2O production and should not be disregarded when justifying gas quantification [68].

Soil pH can also influence N_2O emissions by inhibiting or enhancing the enzymes involved in the nitrification and denitrification processes, as well as influencing the microbial population present in the soil [69]. pH between 5.4 and 5.9 enhances N_2O emissions due to increased denitrification processes [70]. However, lower pH values also reduce nitrous oxide reductase (Figure 4B), which ultimately increases N_2O emissions [71]. When comparing pasture systems with and without liming management over long periods, differences in N_2O emissions were observed. Pasture soils that were corrected through liming showed an increase in pH and a reduction in N_2O emissions [61].

Emissions of N_2O are influenced by land use changes, especially in areas where native forests are replaced by agriculture or pastures [72]. In these areas, there are microbial changes in the soil that favor the processes of nitrification and denitrification, while natural forests are considered sinks for N_2O [56].

To attempt to reduce N_2O emissions from nitrogen fertilizers, biological nitrogen fixation (BNF), crop rotation, and the use of cover crops (from legumes) can be an option [34, 35, and 36]. According to Sant'Anna et al. [36], who evaluated three legumes used in green manure systems, N_2O emissions from plant residues were confirmed. However, the emission concentrations were lower than those stipulated by the IPCC which demonstrated that the use of crops capable of BNF is advantageous as it reduces the need for nitrogen fertilizers, consequently reducing CO_2 emissions produced during the manufacturing, distribution, and application processes. Furthermore, the use of legumes can compensate for the need for nitrogen fertilization in pasture systems [73], thus highlighting management alternatives for mitigating this greenhouse gas in pasture conditions.

6. Conclusion

Land use changes interfere with the chemical, physical, and biological parameters of the soil, influencing the emission of greenhouse gasses (GHG) into the atmosphere. CO_2 is naturally produced in the soil by the action of microorganisms, and its emission mainly depends on soil organic carbon (SOC). The production of CH_4 also depends on SOC; however, it is produced under anaerobic conditions, meaning that well-drained soils or those with low SOC have difficulty producing this gas. On the other hand, N_2O emissions depend on the availability of substrates (NH_4^+ or NO_3^-). Agricultural soils are generally associated with higher emissions of this gas, but this is a consequence of the greater nitrogen input in this land use system.

Conflict of Interest Statement

We have no conflicts of interest to declare.

Author Contributions

Conceptualization: N. L. Abreu, C. Faturi, A. C. Rêgo, T. C. Silva. Investigation: N. L. Abreu, C. E. S. Sousa, L. M. Moraes, J. V. C. Oliveira, L. A. Faria . Methodology: E. S. C. Ribeiro. Supervision: T. C. Silva, A. C. Ruggieri, A. S. Cardoso. Visualization: N. L. Abreu, E. S. C. Ribeiro, C. E. S. Sousa, L. M. Moraes, J. V. C. Oliveira, L. A. Faria. Writing – original draft: N. L. Abreu, C. E. S. Sousa, L. M. Moraes, L. A. Faria. Writing – review & editing: N. L. Abreu, A. C. Rêgo.

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