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SOIL ALTERATIONS BY CHRONOSEQUENCE OF PASTURES IN CROP-LIVESTOCK-FORESTRY SYSTEMS

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ABSTRACT - The intensive use of land has accelerated the loss of soil quality, a process that can be avoided by adopting conservationist production systems, such as the Integrated Crop-Livestock-Forest (CLFI system). It is noteworthy that in the Southwest of the State of Maranhão a substantial portion of soils in rural properties are degraded and in distinct stages of erosion, since they have been exploited for decades with non-properly managed pastures. Therefore, the objective of this work was to emphasize the importance of physical and chemical changes in the soil of pastures under crop-livestock-forest integration in general and in the Amazon region of state of Maranhão, Brazil. Therefore, a literature review was conducted through a search for studies in the Google Scholar database, which encompasses multiple other databases, such as Scielo, Elsevier, Scopus, Capes, and others. In face of the conditions of degradation in pastures throughout the state of Maranhão and the broad distribution of native forests such as Babassu forests, the use of technology from CLFI systems could allow for their recovery and sustainable status by means of economically and ecologically feasible productivity. Research on this field is therefore necessary to highlight short- and long-term efficiencies regarding carbon sequestration and quality of organic matter on the soil.

Keywords: organic matter, integrated systems, soil fertility.

ALTERAÇÕES NO SOLO EM FUNÇÃO DA CRONOSSEQUÊNCIA DA PASTAGEM EM INTEGRAÇÃO LAVOURA-PECUÁRIA-FLORESTA

RESUMO - O uso intensivo da terra tem acelerado a perda da qualidade do solo, processo que poderia ser evitado com a adoção de sistemas de produção conservacionistas, como o Sistema Integrado Lavoura-Pecuária-Floresta (ILPF). Ressalta-se que no Sudoeste do Estado do Maranhão uma parcela substancial dos solos das propriedades rurais encontra-se degradada e em distintos estágios de erosão, uma vez que são exploradas há décadas com pastagens mal manejadas. Portanto, o objetivo deste trabalho foi enfatizar a importância das alterações físicas e químicas no solo das pastagens sob integração lavoura-pecuária-floresta em geral e na região amazônica do estado do Maranhão. Para tanto, realizou-se uma revisão bibliográfica por meio de uma busca de estudos na base de dados Google Acadêmico, que engloba diversas outras bases como Scielo, Elsevier, Scopus, Capes e outras. Diante das condições de degradação das pastagens em todo o estado do Maranhão e da ampla distribuição de florestas nativas como as florestas de babaçu, o uso da tecnologia dos sistemas CLFI poderia permitir sua recuperação e status sustentável por meio de produtividade econômica e ecologicamente viável. A pesquisa neste campo é, portanto, necessária para destacar as eficiências de curto e longo prazo em relação ao sequestro de carbono e qualidade da matéria orgânica no solo.

Palavras-chave: matéria orgânica, sistemas integrados, fertilidade do solo.

INTRODUCTION

The Crop-Livestock-Forestry Integration systems or Agro-silvopastoral systems are a set of production strategies that integrates agricultural, livestock, and forestry activities under the modalities of consortium, succession, or rotation that, in synergy, contemplate environmental conservation, valorization of farmers and the economic viability of agricultural activities (BALBINO et al., 2012).

These systems are important tools able to enhance soil quality, which results in higher efficiency on inputs utilization, increase in productivity, and contributes to the improvement of zootechnical indicators (MAGALHÃES et al., 2018). Other contributions may be related to reduction in deforestation, better thermic comfort to animals, reduction in emission of greenhouse gases, and the increase in grain, meat, milk and woody and non-woody products within the same area (LIMA and GAMA, 2018).

Among these advantages, CLFI systems also generates income and good productivity indexes to farmers by improving the usage of inputs, machinery, and workforce, as well as diversifying the production and, consequently, leading to higher income flow that confer

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flexibility towards agricultural risks and system stability. Moreover, fodders planted within these systems improve cycling of nutrients and soil and water conservation, allowing a higher efficiency on the use of environmental resources (CORDEIRO et al., 2015).

On the premise that chemical and physical attributes are the main characters in soil quality, studies that aim to clarify the relationship between such attributes and productive components of crops are of fundamental importance at the moment of decision-making for soil management practices (MONTANARI et al., 2015).

That is, a growing agricultural production without the need of converting new areas into agricultural land was what transformed CLFI systems into implementable models for the sustainable expansion of the Brazilian agrobusiness. It is estimated that these systems have already been implemented in over 11.5 million hectares of land in Brazil, demonstrating that this process is under constant growing (TOLEDO et al., 2017; RODRIGUES et al., 2019).

In these terms, the present work aimed to conduct a systematic review on important aspects of CLFI systems regarding their effects on degraded pasture recovery, soil carbon dynamics, impacts on chemical and physical attributes, as well as pointing out its benefits to the Amazonian region in the state of Maranhão, Brazil.

BIBLIOGRAPHICAL REVISION

Maranhão State's Amazonian Region

There is no doubt that the Amazon forest does relevant environmental services to Brazil, and the world, as a regulator of climate and germplasm for present and future interest; however, the current reduction in forested areas in this region has been affecting rain regimes at national level and causing intermittent harm to the agriculture in the country's South and Southeast regions, as well as having a major part on climate changing and loss of potentially unknown biodiversity which all together represent the loss of new foods, medicines, dyes, fragrances, pesticides, and many other products (HOMMA et al., 2020). Rodrigues et al. (2012) considerate the Amazon Forest as the largest reservoir of vegetal and animal diversity in the world, responsible for performing multiple environmental services that, together, have a key role on the conservation of biological diversity, climate regulation, and biogeochemical cycles at a global level.

The Amazonian region of state of Maranhão is in a transitional position among three Brazilian macroregions, corresponding to 80% of the terrestrial surface of the state, West to the 44W Meridian, including 181 of the state's 217 counties, distributed over five mesoregions and twenty-one microregions (MESQUITA et al., 2015). Specifically, the state of Maranhão, Brazil, is found at the transition between the Brazil's Northeast and Amazonian regions, divided into four main biomes: Coastal, Cerrado, Amazonian, and Caatinga. The Maranhão State's Amazonian region (Figure 1) is at the occidental part of the state, at the 0°47'33'' and 5°37'02'' South latitude and the 43°37'54'' and 48°53'05'' West latitude (MARTINS e OLIVEIRA, 2011).

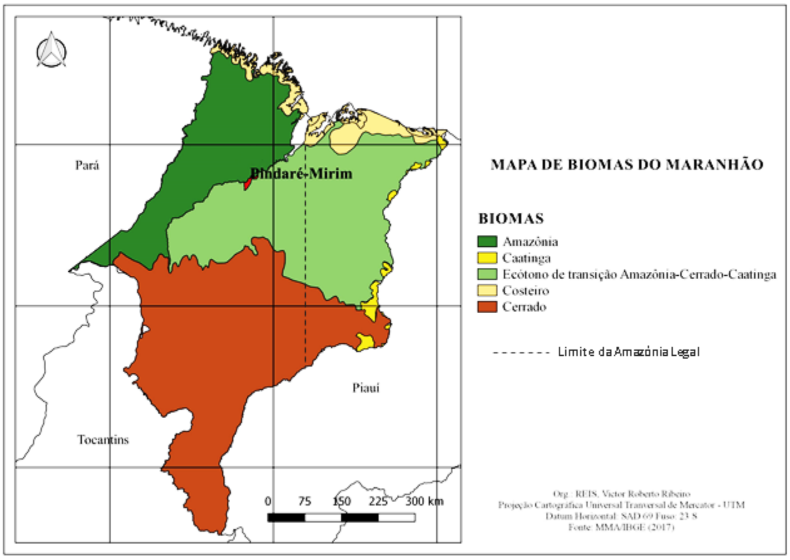

FIGURE 1 - Distribution of biomes located in the state of Maranhão, Brazil. Source: IBGE (2017).

The Amazonian region of state of Maranhão has been suffering from intense deforestation for years, including illegal wood extraction, mining, coal production, excessive hunting to wildlife and, mainly, cattle raising for livestock. In accord to the estimation of deforestation for the year of 2019, published by the National Institute of Spatial Research through the Legal Amazon Deforestation Satellite-Monitored Project, the rate of shallow cuts in the Brazilian Amazon increased by 29.54% compared to 2018 (7,536 km²) (INPE, 2020).

Data from the Terra Class Project (INPE; EMBRAPA, 2020) have indicated that about 62% of the deforested area in the Brazilian Amazon in the year of 2014 was used for pasture. Historically, the increase in pasture areas in the Amazon can be explained by the expansion of beef cattle livestock that developed rapidly around the

1960's decade, impulse by the opening of new highways, such as the BR-010 (from Belem to Brasília), as well as public policies for taxes breaks aiming food production thus turning the Amazon region into Brazil's new agricultural frontier (DIAS-FILHO, 2014).

The conversion of native forests into pasture or agricultural fields is characterized in the state of Maranhão by the opening of glades as consequence of uncontrolled deforestation practices wildfires, known locally as "*coivara*" or "cattle beef agriculture," done mostly by family-owned farms. In larger agricultural areas, the soil is also prepared by means of disc harrowing which incorporates limestones in sufficient amount to elevate base saturation to 50% in the 0-20 cm layer of soil and, subsequently, submitted to less intense harrowing (CARVALHO et al., 2015). In this succession model, fire performs a fundamental short-term role on the expressive increase of potassium, calcium, and magnesium levels due to the addition of ashes to the soil (ARAÚJO et al., 2011).

However, the implementation of unproductive pastures, elevated levels of deforestation, accentuated hunting, emission of greenhouse gases, and wildfires are common and, together, lead to drastic changes in the ecosystem in Brazil's Amazon region (ALMEIDA, 2016). The process of conversion of tropical lands also is one of the major causes for losses of soil microorganisms functionality, which affects agricultural production greatly (FAO, 2020).

Degradation of Pastures and the Crop-Livestock-Forest Integration System

The degradation of pastures is a process characterized by the decline of vigor, production, capacity of financial return and quality of pastures, as well as by the struggling with combating plagues, diseases, and extraneous species, which all together culminate in faster depletion of natural resources that is also associated to inappropriate soil and pasture management. Other causes for degradation are related to inappropriate species and/or pieces of land, pre-abnormities, lack or bad use of soil conservation practices, acidity correction and improper fertilization, unviable cultural burning practices, lack of maintenance fertilization, occurrence of plagues, diseases and extraneous plants, excess of cattle in limited land space, and improper pasturing systems (CRUZ et al., 2022).

Specifically, the causes for pasture degradation rely mostly on the systematic use of occupation rates that exceed the land capacity for carrying bovines and their trampling, no periodic fertilization, and the failing to stablish fodders which has biotical consequences, such as insects/plagues attacks and the *Marandu* fodder death syndrome (DIAS-FILHO, 2011). From such scenario, Balbino et al. (2012) warn about lower offering of fodders, lower zootechnic indexes, and lower productivity of beef and milk per hectare of land, consequently lowering income and the system's efficiency.

In the Brazilian livestock, the productive system has been inserted in an extractive and exploratory way, i.e., this activity aimed for horizontal expansion of the production initially. To Borghi et al. (2018), due to the growing necessity for competitivity and sustainability in this economic sector, cattle farmers chose to substitute this expansion model by another strategy targeted to genetical enhancement by means of crossing European and zebuine cattle species, but that not always was resulted in acceptable earnings given that the feeding strategy was not efficient.

Since then, pasture degradation is the main problem in the productive chain of cattle for beef and milk, occupying 90% of the total pasture are in the Northeast of Brazil, for example (DIAS-FILHO, 2014) and contributing to the increase of greenhouse gases emissions (GEEs), such as methane, nitrous oxide, and carbon dioxide. As consequence, the annual losses from the livestock exploration in Brazilian pastures are estimated to surpass US$ 1 billion (BORGHI et al., 2018).

Since the 1970's decade, the substitution of original pastures for pastures with or without annual cultivation mainly in the Cerrado region has allowed for larger cattle herds, and that reflected positively on the national production of beef and milk at the time by growing 12%, as well as the growing of herds by 115%. However, the majority of pastures were based on marginal lands with acid and poorly fertile soils that lacked mostly phosphorus, calcium, and magnesium, and even improper for other agricultural uses. The degradation process of such lands initiated around 1980's decade and from it emanated the necessity and interest for their restoration with annual cultivations evaluated by means of studies that presented promising results (BORGHI et al., 2018). Such studies were based on CLFI systems – a set of production strategies that integrates agricultural, livestock, and forestry activities under the modalities of consortium, succession, or rotation, synergically contemplating the conservation of the environment, farmer valorization, and the economic viability of the agrobusiness (BALBINO et al., 2012).

Initially, the CLFI systems were developed in Brazil aiming to recover or renew drastically degraded pastures by means of using machinery, inputs, and agricultural techniques more efficiently in areas which extensive cattle farming predominated. This system allows for the recovery of degraded areas as it optimizes the use of land by producing grains and wood within pastures, and that is proven to improve productivity, the use of fertilizers from residual crops, and the provision of nutrients and organic matter. There is also a significant reduction on production costs and pasture renewing, improvement of straw production quality which is mostly used within the non-harvestable part of the CLFI system and diversifies the fodder cultivation (ALVARENGA et al., 2011).

The literature on CLFI systems unitedly divides them into four main modalities: (1) Crop-Livestock Integration (CLI) – integrating agricultural and livestock components in rotation, consortium, or succession, within the same area and year for multiple years; (2) Livestock-Forest Integration (LFI) – integrating livestock (pasture and animal) and forest in consortium; (3) Crop-Forest Integration (CFI) – integrating forest and cropping as a consortium of arboreous species with annual or perennial crops; and (4) Crop-Livestock-Forest Integration (CLFI) – integrating cropping, cattle, and forest in rotation, consortium or succession within the same area. These different modalities of such integrated systems can contribute significantly for the stablishing of agrobusiness within the precepts of sustainability, as they surpass and correct for imbalances imposed by simpler production systems in which management of soils and crops do not prioritize conservationism appropriately (BALBINO et al., 2012).

Multiple environmental benefits at local and global scale have been attributed to these systems, mainly soil and water resources conservation, promotion of carbon sequestration, income flow flexibility throughout the years, and the increase in biodiversity. In other words, the benefits of CLFI systems are related to technical, economic, environmental, and social aspects - specifically, the annual crops, with or without fodders, contribute for cost amortization by implementation of the system and that proportionate enough time for the development of trees prior to the entry of cattle herds; the residual fertilization effect from the crop benefits the forestry and fodder components that consequently promotes well-being of the cattle, water and soil conservation, recycling of nutrients, nutritional value of the fodder, and wood supplying; the livestock component benefits itself from the improved pasture environment conditions and tends to produce more per animal unit; then, the integration of these components propitiates higher efficiency on use of natural resources, inputs, machinery, and workforce, as well as the diversification of products and higher income flows that together confer flexibility towards risks of the activity and better stability of the system. Such technical, economic, environmental, and social benefits were already reported in studies such as those by Figueredo et al. (2014) and Rego et al. (2017) that compare CLFI systems to single systems.

Soil Carbon Dynamics

Carbon is related to global warming given that it is an element constituting gases that forms greenhouse effects, for example, carbon dioxide and CFCs (CUNHA and RODRIGUES, 2019). When they surpass the point of equilibrium, there is a retention of heat that causes multiple environmental disturbs (JUNGES et al., 2018). Carbon is found in five large reservoirs: atmosphere, water, geology, soil, and biota, creating a stock of approximately 46.82 Gt spread throughout landscapes (SIEFERT and SANTOS, 2018).

Cultivation of forest species with longer life cycles offers multiple advantages, such as permanency of vegetation for longer periods compared to annual crops that have shorter life cycles. That is, the higher the time spent on the area the larger will be the stocking of carbon by the vegetation in its biomass, as well as the larger will be its contribution kept on soil (COSTA and STRECK, 2018). The incorporation of atmospheric C on vegetal tissues occurs by means of photosynthesis, and a part of it is converted into chemical energy for plants and posteriorly to animals, rapidly returning to the atmosphere (IBÁ, 2019). The other part may be deposited on soil in the form of leaf litters that are gradually metabolized by microorganisms that form organic compounds with high stability that lasts on soil for longer periods (SIGNOR, 2013).

In this context, the atmospheric concentration of CO_2 is then greatly influenced by the equilibrium between the entering and outing of organic carbon in soil, thus the use of lands or human activities can be the main responsible for any carbon imbalance. In other words, the soil is an open system in which energy and matter are traded with the environment so that the deposition of C is directly associated to the decomposition of organic matter (PRIMIERI et al., 2017). The circulation of organic matter in a natural or transformed environment may result in specific flows of nutrients and energy that internally regulates each ecosystem and generates a dynamic equilibrium as response. That is, the quality of the system is put to its capacity of performing it functions within its limits, as well as its guarantee of maintaining biological activity and keeping or correcting the environment quality in its entirety (MIRANDA and AVELAR, 2018).

Losses of C occur mainly from the microbial respiration during the decomposition of residues incorporated to the system, also from those still in conversion process. Other forms of loss of C may be related to lixiviation and soil erosion (DADALTO et al., 2015). In accord to Baldotto et al. (2015), the mobility of carbon is associated to fractions of organic matter found in the soil, being more soluble or less humid, offering a potential for lixiviation. By evaluating the stock and fractions of organic carbon in forest soil, crops, and livestock areas, Baldotto and colleagues found that native forests provide more favorable conditions for humification and that these systems support higher amounts of sequestered carbon compared to others. That is, maintenance of soil quality is one of the key factors to reach sustainability in a production system, highlighting management as the main action for preservation of organic matter (CAETANO et al., 2013).

In this context, more diversified systems are important for reposition and maintenance of organic matter in the soil (ASSIS et al., 2019). Thus, CLFI systems have greater chances of concentrating organic carbon in the soil due to the continuous growth of vegetal matter on the area and the multiple sources of organic content, which also can be used as an indicator of soil quality (LOSS et al., 2012). That is, the organic matter promotes better structured soils which favors for higher infiltration rates and the penetration of roots in the soil profile (NETO et al., 2014). Reported results also demonstrate that the type of management and consortium of cultivars with rotation directly influence the occurrence of fauna communities in the soil in these integrated systems, also indicating that CLFI, CLI, and systems of direct plantation offer the best conditions for development of organisms (FERREIRA, 2016).

Physical Attributes of Soils and the Alterations by Integrated Systems

The soil is one of the main supports for crop production and its behavior is ruled by a complex set of physical, chemical, and biological factors subjected to effects of climate that interact and tend to equilibrium (KLEIN et al., 2015). The maintenance of soil quality is essential for the sustainability of agroecosystems, since it performs a fundamental role by being a vital parameter of production (MOREIRA et al., 2018).

It is fundamental to monitor soil quality, especially the physical attributes, as they affect important processes for the success of the entire system. That is, physical attributes have been used to quantify changes provoked by distinct types of soil management, such as vegetal layer, surface residues, and content of organic matter (WENDLING et al., 2012), which can be mentioned the density and total porosity of the soil, directly associated to crop productivity (OLIVEIRA et al., 2018). There is a high variability in such attributes due to the dynamics caused by diverse factors that composes integrated systems, such as: machinery, animals, trees, among other, that integrates themselves in different temporal-spatial scales (MORAES et al., 2014). Part of these alterations in soil physical attributes are consequent from a set of factors such as soil texture, height, and grazing intensity, the amount of vegetal residues from fodders, and soil humidity, which altogether may maximize the effect of animal trampling (MOREIRA et al., 2012). Multiple attributes must then be measured in order to evaluate how the soil management influences on soil characteristics, as well as its relationship with plants (LOSS et al., 2017), being the most common ones: granulometric composition, density, porosity, stability of aggregates, resistance to penetration, infiltration, capacity for water retention, and hydraulic conductivity (ARAÚJO et al., 2012).

In this context, the utilization of integrated systems of production is seen as an alternative that brings multiple benefits from the point of view of physical, chemical, and biological conditions of the soil, increasing the cycling and efficiency of use of nutrients, as well as the viability of recovering areas with degraded pastures (BONINI et al., 2016). The benefits promoted by such integrated systems are related to the layering and enrichment of soils, by means of the deposition of a dense organic matter layer continuously stablished by the falling of leaves and branches that changes the cycling of nutrients (NETO et al., 2018). In other words, the physical quality of the soil is associated to its capacity of allowing the development of plants with degrading itself (LLANILLO et al., 2013).

Carvalho et al. (2016) claim that integrated systems improve physical quality of the soil by increasing macroporosity in pastures and the microporosity in all areas and profundities, also decreasing soil density at its surface layer. By evaluating soils under CLI system and soils under monoculture of crops and pasture, Bono et al. (2012) found out that the integrated management presented basic and accumulated infiltration speed in soil closer to that observed from native forests. Other studies, such as those by Assis et al. (2015) and Silva et al. (2016), have found results that corroborates with Bono and colleagues' findings, further explaining that soils under a system of crop-livestock integration improved density and porosity, as well as the content of organic carbon, compared to native forest and eucalypt monoculture, which had the authors claiming to be a great strategy for soil management during recovery of degraded areas.

Sales et al. (2016) have also observed that compression of the soil in systems of crop-livestock integration after 2 to 4 years of implementation did not reach limit values for the development of cultivars. Similarly, Assis et al. (2015) observed that integrated systems of crop-livestock-forest promoted the improvement of soil physical conditions. It is worthy mentioning that such observations about the effects on soil quality in integrated systems may take years compared to conventional systems, which is a disadvantage from the point of view of management (CARVALHO et al., 2016). Moreover, studies have also demonstrated the negative effects of such integrated systems to the soil, highlighting as the main one the animal trampling, which causes surface compression and reduces infiltration. However, the intensity of compression strictly depends on the type of soil, the humidity content, animal filling rate, and level/species of fodder mass (MORAES et al., 2014).

Chemical Attributes of Soils and the Alterations by Integrated Systems

Chemical attributes of soils have been universally adopted for inferences related to sustainability in different systems of use and management, given that such attributes present potential for detection of changes promoted by the quality of soils (CARVALHO et al., 2015). These alterations in chemical indicators are resultant from the development of systems and occur in function of time and of the conduction of each system of use and management of soils (MILINDRO et al., 2016).

Among the chemical indicators for quality of soils are organic matter and pH, which the former may be highly sensible to alterations towards management practices, and the other refers to the capacity of exchanging cations, content of phosphorus, potassium, magnesium, aluminum saturation, base saturations, among others (SILVA et al., 2020). In a general manner, the chemical attributes of soils are grouped into variables related to the content of organic matter, soil acidity, content of nutrients, phytotoxic elements, and determined relationships such as base and aluminum saturations (ARAÚJO et al., 2012). As claimed by Carvalho et al. (2015), one must also observe edaphoclimatic conditions and the species used, because they influence on nutrient dynamics significantly and may present diverging results compared to soils under integrated systems.

Multiple studies have demonstrated increments on the contents of nutrients in integrated systems in different regions and types of soil, mostly because of the following reasons: fast cycling of nutrients in the soil that are available in mineral form from feces and urine, and the efficiency in the use of fertilizers as a function of the different necessities that crops have when in rotation (KICHEL et al., 2019). Additionally, as claimed by Costa et al. (2015), the greater deposition of vegetal residues on surface soils under such systems and posterior decomposition favor the accumulation of nutrients in the system and that generates higher biological activity in the environment. Other studies have also shown increases of P and K contents, as well as organic matter, on the first 10 cm of profundity also relating to reductions in pH (FREIRE et al., 2012).

Iwata et al. (2012) verified that the CLFI system promoted improvements on chemical indicators of soils, such as the increase in pH, reduction in aluminum saturation, increase in contents of nutrients, and greater stability on the chemical quality of the soil under effect of seasonality. On the other hand, in a study conducted by Diel et al. (2014), in systems of exclusive cultivation and those where CLFI was integrated, there was constated that CLFI did not lead to significant changes in chemical attributes of the studied soil, probably because of the brief period of 2 years since the system was implemented, which is known to take much longer to cause any significant changes.

Thus, the maintenance of soil quality is a primordial factor for sustainable agriculture (SALTON et al., 2015) and the evaluation of its quality allows for the determination of proper measures of management that aims conservation and improvement of yields during harvesting (TADINI et al., 2019), from which great versatility can be obtained for the utilization of such systems in the construction of soil fertility and cycling of nutrients (FERREIRA et al., 2018) and the increment of C stocks in the soils, as well as the mitigation of greenhouse gases emissions (SÁ et al., 2017).

Overview of Studies of Soils in CLFI Systems

Evaluation of soil quality can be hard because of the soil-plant system complexity. Observing physical and chemical attributes in soils is considered by researchers as the most adequate form of measuring and monitoring state of conservation or any other degradation process that may be occurring in the soil (HAVLICEK, 2012). From this perspective, there was conducted a systematic review on the Google Academic portal in order to check and quantify publications regarding CLFI systems and analogous studies about physical and chemical analyses, as well as organic carbon, between the years of 2015 and 2019.

Within the analyzed range of years, there was observed an increasing advance in the number of publications regarding chemical analysis of soils as it went from 258 publications in 2015 to 373 in 2019. In comparison, studies regarding chemical parameters of soils in CLFI systems had more publications than studies reporting physical attributes of soils presenting a difference of 129 articles between 2015 and 2019 (Figure 2). Chemical attributes are good indicators for the level of degradation in pastures. Attributes such as pH, Ca, Mg, and H + Al present a close relationship with soil management (JUNIOR et al., 2011). In accord to studies conducted by Carvalho et al. (2015), systems of management and use by means of the crop-livestock and crop-livestock-forest integrations provide better contributions for the improvement of soil fertility when compared to native vegetation in the Cerrado region, for example.

It is worthy mentioning that there are various physical parameters that can be studied and considered as indicators of pasture degradation, such as density, macroporosity, microporosity, total porosity, resistance to penetration, among others, which data from such parameters can used further on the process of recovery of these areas (ASSIS et al., 2015). In general, published data has shown that physical attributes is the second most studied in research on CLFI soil performance. In the year of 2019 there were published 315 studies and that has shown an increase in the number of publications compared to the previous years (Figure 2). The year with the lowest number of publications was 2015 when there were reported 223 studies, but that served as reference for the increase observed during the years following, which means that research in this field is expanding in order to bring suitable and sustainable solutions for farmers.

Additionally, studies on organic carbon content in such systems have been increasing considerably by surpassing the mark of 187 studies in 2015 to 207 in 2019 (Figure 2). The utilization of diversified production systems helps on reinsertion and maintenance of organic matter in the soil (ASSIS et al., 2019). As claimed by Silva et al. (2019), organic matter favors infiltration of water in the soil and higher and better penetration of roots. Mascarenhas et al. (2017) suggest that higher contents of organic carbon in the soil are observed in the surface layer as a function of the greater deposition of organic matter consequent of the decomposition of crop residues. These alterations in organic matter can be measured from changes in C stocks in soils and its chemical and physical fractions, as well as their combination. Brady and Well (2013) affirm that organic matter is the main reservoir of C in soils, justifying the increasing number of publications in this field.

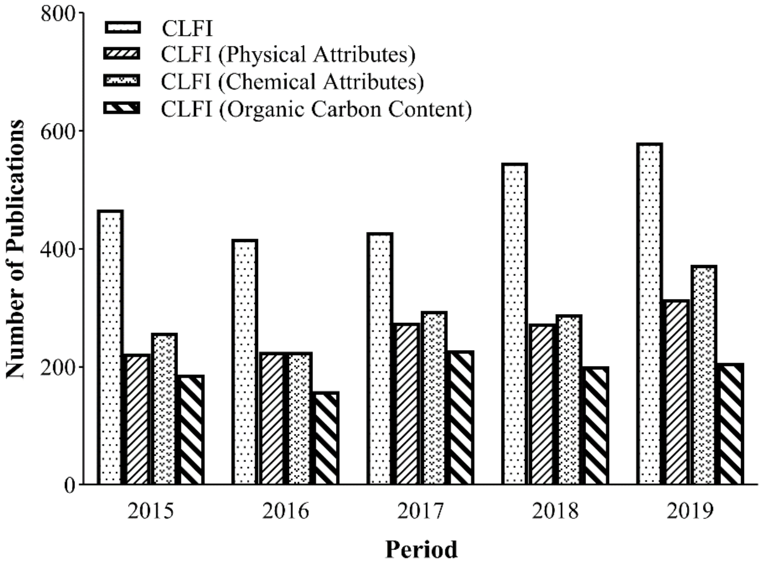

FIGURE 1 - Evolution of the number of publications on CLFI systems regarding physical and chemical attributes of soils, as well as their organic carbon content on Google Scholar.

Studies reporting evaluations on organic carbon content are less occurrent compared to studies regarding physical and chemical attributes, totalizing only 982 publication within the compilation of years searched, presenting an average of approximately 196 publications per year. This could be justified by the fact the analyses of organic carbon and organic matter sometimes is comprehended as chemical analysis/attributes (Figure 3).

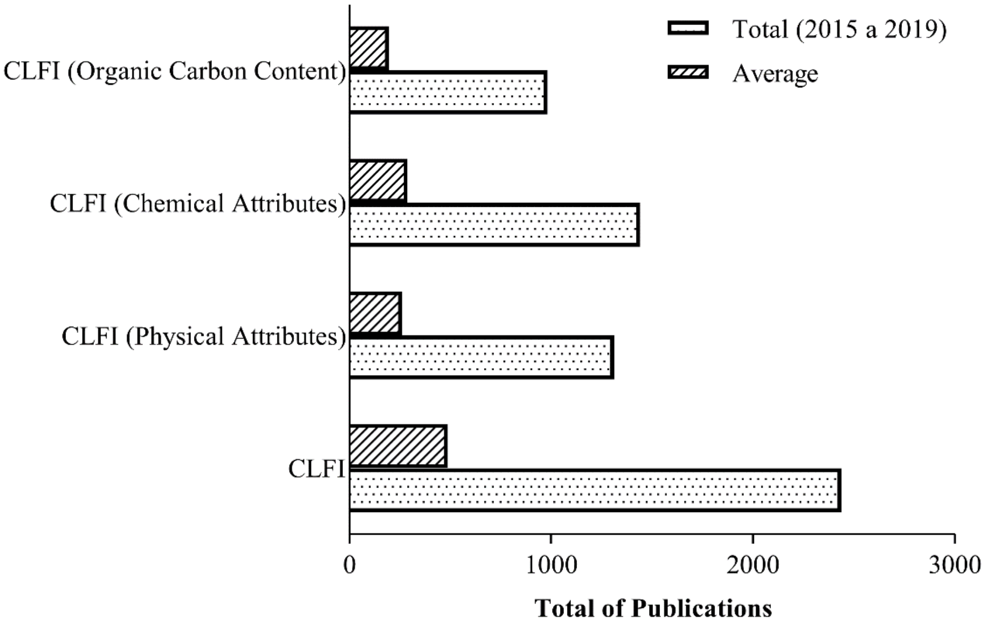

FIGURE 3 - Total and average number of publications about CLFI systems and their physical, chemical, and organic carbon content on Google Scholar

Chemical attributes are more searched and published than physical attributes, totalizing 1441 studies about soil chemistry compared to 1312 about soil physics in CLFI systems. Data on organic carbon were not much expressive compared to chemical and physical attributes as they may be included in the generality of chemical studies. There was an evolution in the number of publications related to CLFI which shows a growing interest among scientists as it went from 223 publications in 2015 to 315 in 2019.

CONCLUSION

The review process for this study intended for the comprehension of CLFI systems as viable alternative for agrobusiness, as it brings valuable benefits for the soil, for farmers, for livestock, and, on top of that, the reduction in emission of GEEs. In face of the conditions of degradation in pastures throughout the state of Maranhão and the broad distribution of native forests such as Babassu forests, the use of technology from CLFI systems could allow for their recovery and sustainable status by means of economically and ecologically feasible productivity. Research on this field is therefore necessary to highlight short- and long-term efficiencies regarding carbon sequestration and quality of organic matter on the soil.

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