Chemical, physical, and biological attributes of the soil in integrated systems

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Abstract

Integrated systems are conservationist and sustainable systems with great prominence on the national scene for reducing financial and productive risk in the agricultural sector and reducing environmental damage. One of the successes of these systems is to see the cultivation environment in an integrated way, knowing each of its components; soil, plant, and atmosphere. In large-scale field production, the plant and the soil are the components of the production system that are more likely to be modulated, seeking greater productivity. The objective of this work was to survey scientific advances on the chemical, physical and biological attributes of soil in integrated systems. The works show that chemical, physical and biological attributes are influenced by soil management in integrated systems. In general, integrated agricultural systems are more efficient alternatives for Brazil and must meet international commitments to reduce the greenhouse effect for low-carbon agriculture. For the rural producer, the integrated systems are advantageous due to the greater production in a smaller area and the diversification of income.

Keywords: crop-livestock integration, iCLF, soil quality, microbiota.

Atributos químicos, físicos e biológicos do solo em sistemas integrados

Resumo

Os sistemas integrados são sistemas conservacionistas e sustentáveis com grande destaque no cenário nacional, pela redução do risco financeiro e produtivo no setor agropecuário e pela redução dos danos ambientais. Um dos sucessos desses sistemas está em ver o ambiente de cultivo de forma integrada, conhecendo cada um dos seus componentes; solo, planta e atmosfera. Em produção de larga escala a campo, a planta e o solo são os componentes do sistema de produção com maior passividade de serem modulados, buscando maiores produtividades. Objetivou-se este trabalho, levantar os avanços científicos sobre os atributos químicos, físicos e biológicos do solo em sistemas integrados. Os trabalhos evidenciam que os atributos químicos, físicos e biológicos são influenciados pelo manejo do solo nos sistemas integrados. Em geral, sistemas agrícolas integrados são alternativas mais eficientes para Brasil e deve cumprir compromissos internacionais para reduzir o efeito estufa para a agricultura de baixo carbono. Para o produtor rural, os sistemas integrados são vantajosos em função da maior produção em menor unidade de área e pela diversificação de renda.

Palavras-chave: integração lavoura-pecuária, ILPF, qualidade do solo, microbiota.

1. Introduction

The world's human population is projected to reach approximately 9.6 billion inhabitants in 2050. Therefore, it is estimated that the production of primary food will increase by 70% by 2050 to ensure food security for the population (Fao, 2017). This demand for food has caused pressure on agriculture, increasing the intensive use of soils in the Cerrado region, causing its degradation and, consequently, reductions in the productivity of crops.

Thus, there is a need for conservation management, such as the direct planting system, crop rotation and sustainability, such as the crop-livestock-forest integration system (Costa et al., 2015).

Integrated systems, such as crop-livestock integration, crop-forest integration, livestock-forest integration, and crop-livestock-forest integration, are conservationist and sustainable systems with great prominence on the national scene to reduce financial and productive risk agricultural and livestock sector for the reduction of environmental damage (Assis et al., 2019). One of the successes of these systems is to see the cultivation environment in an integrated way, knowing each of its components, soil, plant, and atmosphere. In large-scale field production, the plant and the soil are the components of the production system that are more likely to be modulated, seeking greater productivity.

Due to hundreds of years of improvement, it is already in such an advanced state of improvement that little productivity gains can be achieved from its improvement. However, the soil is still a component with great passivity to be modulated, considering high productivity. In this context, it is essential to highlight that since the beginning of civilization, the concept of soil fertility was based on the integration of the biological, physical, and chemical phases of the soil in continuous renewal through cultivation with appropriate techniques (Gonçalves; Silva, 2018). Given the above, the objective of this work was to raise scientific advances on the chemical, physical and biological attributes of soil in integrated systems.

2. Soil Chemical Attributes

The intensive use associated with inadequate soil management in the Cerrado region has caused its degradation, affecting the productivity of crops. Thus, there is a need for conservation management, such as the direct planting and crop rotation system, and sustainable ones, such as the crop-livestock-forest integration system (Costa et al., 2015).

Integrated systems, such as crop-livestock integration, crop-forest integration, livestock-forest integration, and crop-livestock-forest integration, are conservationist and sustainable systems with great prominence on the national scene for the reduction of financial and productive risk in the agricultural and livestock sector, for the reduction of environmental damage (Assis et al., 2019).

The success of these production systems in producing regions is because of the straw accumulated by cover crops or pastures and the cultural remains of crops (Costa et al., 2015). Straw in integrated production systems has been observed with improvements in chemical attributes, Phosphorus and Potassium content (Crusciol et al., 2010; Ferreira et al., 2018), Calcium and Magnesium (Falleiro et al., 2003) and micronutrients such as Zinc, Manganese, Iron and Copper (Franzluebbers & Hons, 1996), in addition to improvements in cation exchange capacity, organic matter (Crusciol et al., 2010; Ferreira et al., 2018) and pH increase (Cunha et al., 2011).

However, the inefficient use and management of the soil, in addition to contributing to the emission of greenhouse gases, harming the environment (Carvalho et al., 2010), still bring numerous problems related to its sustainability due to the degradation of the soil's organic matter, negatively altering its chemical attributes, as well as its biodiversity (Costa et al., 2015). Thus, incorrect soil management can lead to a decline in crop production in general, with degradation of nutrient exports and depletion of soil reserves (Bonini et al., 2016).

They developed numerous works related to integrated systems, mainly focused on the production of forage to constitute straw, the search for conservation practices for better use of resources and soil quality. Thus, it is necessary to adopt these soil and crop management practices, mainly to improve chemical attributes and create favourable conditions (Costa et al., 2015).

Associated with the no-tillage system, an excellent alternative in these production systems, where the presence of plant residues on the soil surface can increase the pH, exchangeable Ca and Mg contents of deeper soil layers, depending on the content of Exchangeable Al, in addition to an increase in organic C (Carbon), O. M. (organic matter) and P contents of the most superficial layers of the soil (Silveira & Stone, 2001; Lourente et al., 2010; Anghinoni et al., 2013; Costa et al., 2015).

According to Santos et al. (2011) and Costa et al. (2015), the positive results of the integrated systems obtained become valid from the second year of cultivation. In the first year of cultivation, added to the corresponding increase in plant residues from grasses cultivated in the off-season, it will provide increments in attributes chemicals and significantly increase higher crop productivity in the current crop subsequent years (Loss et al., 2011).

According to Silva et al. (2011a), integrated production systems show more significant amounts of soil carbon due to greater amounts due to the entry and accumulation of organic residues, where alternating crops of different families tend to increase their exploitation and increase soil improvements. In the work of Soares et al. (2020), with eight years of management, the corn consortia with *Brachiaria ruziziensis* and *Stylosanthes spp.* and Bieluczyk et al. (2020), corn and piatã (*Urochloa brizantha*) intercropping provide improvement in soil chemical attributes, especially with increased soil Carbon.

In work proposed by Costa et al. (2015), when evaluating intercropping and succession involving corn, sorghum and forage, the chemical attributes of the soil had the highest values of P, O. M., pH, K, Ca, Mg, SB, S, cation exchenge capacity (CEC) and V% in the area where it had been cultivated corn, regardless of the forage species used in the production system. When grasses were implanted in corn and sorghum, they presented the highest values for O.M., Ca, Mg, SB, CEC and V%.

Bonini et al. (2016) observed in integrated agricultural production systems that the levels of O.M., Ca, Mg and P, in the 0-0.20 m layer, after two years of implementation of the systems, increased, compared to the initial analysis, being the result of the accumulation of straw on the surface, which after decomposing, becomes a supply of nutrients and an increase in organic matter (Costa et al., 2015).

For the rural producer, it is advantageous to produce using the integrated system due to greater productivity and the diversification of income over the years and the environmental benefits promoted by the system (Reis et al., 2018). In general, integrated agricultural systems are more efficient alternatives for Brazil and must meet international commitments to reduce the greenhouse effect for low-carbon agriculture and, consequently, contribute to improving global food and energy security (Bieluczyk et al., 2020).

3. Physical Attributes of the Soil

Soil quality is benefited by agricultural systems, with little tillage and crop diversification. With this, the soil's physical structure increases its complexity when the quantity, quality, foliar input, and the diversity of species of the phytomass produced in the installed system are increased (Assis et al., 2015).

With this, the integrated systems and the no-tillage system aim to mitigate environmental impacts and promote the system's sustainability and efficiency in land use (Magalhães et al., 2018). One of the benefits of the production of integrated systems is the development of an edaphic environment favourable to the development and growth of roots due to the soil's physical qualities (Santos et al., 2008; Mendonça et al., 2013; Costa et al., 2015).

The integrated agricultural production systems are based on the agricultural development of single crops and intercropped with forage as a food source for the production of cattle in the off-season and straw production in the 1st harvest crop, with the recent addition of the forestry component, all in the exact location, through crop rotation or succession (Balbino et al., 2011; Vilela et al., 2012).

According to Silva et al. (2011b), annual pastures followed by annual grain crops make the soil's physical structure and chemical properties efficient, thus increasing plant growth. Thus, integrated systems are an excellent alternative because they can diversify agricultural environments and associate crop-livestock-forest integration systems in a balanced way; therefore, they preserve the structure of the soil, increasing organic matter and nutrients (Loss et al., 2012).

According to Assis et al. (2015), the integration systems promote an improvement in the physical quality of the soil concerning the degraded pasture. Macedo (2009) reported that the integrated systems increased the stability of aggregates and the rate of water infiltration and decreased soil density and compaction, which despite the concentration of animals, in some cases, compromise the physical properties, to Carvalho et al. (2005), there is a chemical compensation, due to greater availability of nutrients due to more significant deposition of urine and faeces.

The management of integrated systems has to take into account the sustainability of soil attributes, to Bonetti et al. (2019), moderate grazing with forage of 30 cm in height favours an increase in the rate of water infiltration in soybeans due to improvements in the physical properties of the soil (apparent density and macroporosity). Moderate grazing can maintain a good relationship between macro and microporosity in the soil structure, therefore, it can promote good soil aeration, water infiltration and water retention in the soil profile (Liebig et al., 2011).

For Batista et al. (2019), the physical attributes of the soil were modified after grazing in integrated systems with animals, which increased penetration resistance and soil density and reduced hydraulic conductivity and total porosity. However, grazing does not affect the physical quality of the soil in continuous or alternative stocking systems, as long stocking rate and forage mass are the results of controlled management (Fidalski et al., 2008).

In general, the compaction caused by animal grazing alters physical attributes through the repetitive and cumulative effects of trampling (Capurro et al., 2014); thus, the amount of water infiltration tends to decrease as soil density and penetration resistance increase (Frolla et al., 2018). Such factors can delay the development of plant roots (Ortigara et al., 2014) by reducing water infiltration (Miguel et al., 2009) with lower production of pastures (Bonetti et al., 2015). In the work of Assis et al. (2015), evaluating the changes in physical attributes because of the implementation of crop-livestock-forest integration systems, they observed that the integrated systems, with three or four years of implementation, contributed to improving the physical quality of the soil. In the same way, Costa et al. (2015) did not observe the physical degradation of the soil, including the improvement of the attributes, after the five periods of testing; in addition, there was a sufficient amount of straw, leaving the soil covered.

Fidalski et al. (2008), when evaluating physical attributes of the intercropping of forage peanut with grass in a pasture under continuous grazing, they observed that grazing in a continuous stocking system, with control of animal stocking rate and maintenance of forage mass, intercropped or not with forage peanut and fertilized with nitrogen, does not compromise the physical quality of the soil.

Silva et al. (2011b) observed in their work that the best soil structuring was verified in the crop-livestock integration system, in the more superficial layers of the soil compared to conventional cultivation, continuous pasture and native vegetation. The authors also reinforce that crop-livestock integration is a promising strategy to develop sustainable production systems, and the two-year management period is adequate for crop-livestock rotation.

The increase in production due to integrated systems improves physical conditions, diversifies, and stabilizes producer income and enables the recovery of areas with degraded pastures and their conversion to productive and profitable areas (Alvarenga et al., 2010). Thus, the improvement of physical quality associated with soil fertility demonstrates the potential of this system, with superior advantages over areas with monocultures (Loss et al., 2012; Assis et al., 2015).

4. Biological Attributes of the Soil

Several paradigms have been changed in the face of pressure from agriculture regarding the ever-increasing demand for food (Fao, 2017). The cultivation system, as technologies such as genetic improvement, which were very important in the 70s to increase the yield per area of crops, alone, is not so efficient.

Therefore, to guarantee the food security of the world population, it is necessary to see the cultivation system in an integrated way, knowing each of its components: soil, plant, and atmosphere. In large-scale production, the plant and the soil are the components of the production system that are more likely to be modulated, seeking greater productivity.

In this context, it is essential to highlight that since the beginning of civilization, the concept of soil fertility was based on the integration of the biological, physical, and chemical phases of the soil in continuous renewal through cultivation with appropriate techniques (Gonçalves; Silva, 2018). However, for many years, research has focused on knowing better about soils, their colours, their natural fertility, physical conditions, and agricultural productivity, neglecting biological processes and their ecological interactions (Lepsch, 2002).

This was characterized as an error, as the soil is a complex, dynamic and multifunctional system that houses a vast diversity of communities with millions of species, from microorganisms (archaea, bacteria, and fungi) to larger organisms such as mites, ants, earthworms, nematodes, protozoa among others, and therefore deserves great attention (Bardgett; Van der Putten, 2014; Batista et al., 2018).

In this sense, crops in integrated crop-livestock forest systems have promoted significant advances because, in this system, there is a concern with the fertility and functional ecology of the soil, which can be measured through bioindicators (Batista et al., 2018; Soares et al., 2019). Among the leading, microbiological and biochemical indicators are functional microbial groups (ammonifiers, cellulolytic, denitrifiers, N-fixers, nitrifiers, proteolytic and phosphate solubilizers), C and nutrients contained in the microbial biomass of the soil, the respiratory rate of the soil (CO evolution) and the activity of key enzymes involved in the cycling of C and nutrients (arylsulfatase, β-glucosidase, phosphatase, urease and the hydrolysis of fluorescein diacetate) (Batista et al., 2018).

Soares et al. (2019), evaluating the impact of different agricultural systems under long-term no-tillage management on the biological properties of the *Cerrado*, observed that long-term soil management practices, with the introduction of plant residues in different quantities and chemical composition variables, affect the microbiological attributes of soil differently. Therefore, they found that the system with an annual succession of soybean with corn intercropped with *U. brizantha* grazed in the off-season Livestock Crop Integration (LCI) stands out with greater potential for improving these attributes in long-term deployments compared to others.

In this study, Soares et al. (2019) observed that in LCI in the layers of 0.10-0.20 and 0.20-0.30 m, the CLS system presented greater basal respiration, differing from the others. The authors also highlighted that the long-term integrated agricultural system promoted an increase in the activity of microorganisms in depth. In addition, the higher microbial activity in this system may also result from the duration of no-tillage, started in 1991, associated with the continuous supply of organic residues that accumulate on the soil surface, which stimulate the microbial activity of the same.

Soares et al. (2020) also observed the carbon from microbial biomass (BMC) in the 0.00-0.10 m layer, and they found that this was higher in the LCI system, possibly due to carbon accumulation through the greater input of different types of crop residues, the implantation time, the inclusion of animals in grazing and the leguminous/grassroots succession system over 26 years. Similar results were also found for the soil microbial quotient (*q*MIC), which in the 0.00-0.10 m layer presented higher LCI system values than the others (1.83%).

In a study in which the objective was to investigate the influence of the introduction of Eucalyptus on the community and microbial activity of the soil in an integrated tropical system of cultivation, livestock and forestry, Sarto et al. (2020) verified that the β-glucosidase (bG) activity of the soil was higher in the ILPF than in the monoculture and cerrado pastures at a depth of 0-5 cm from the soil. Furthermore, they observed that the introduction of eucalyptus into the pasture increased the soil bG activity by 51% in the row, 131% at 2 m, 95% at 4 m and 99% at 6 m from the tree line compared to the pasture at a depth of 0-5 cm. The increase in bG was also observed at depths from 5 to 10 and 10 to 20 cm. The bG activity was higher in ILPF at 2, 4 and 6 m from the eucalyptus line when compared to pasture and cerrado. They also found that integration of Crops, Livestock, and Forestry (iCLF) increased the AP acid phosphatase activity by 48.5% in the row (0 m), 55.5% in 2.4% in 4 and 42.5% in 6 m of eucalyptus the pasture of monoculture from 0 to 5 cm. The PA activity was similar in iCLF and *Cerrado* from 0 to 5 cm.

Ventura et al. (2020) observed that the intercropping of corn with *B. ruziziensis* showed greater fungal diversity at both depths, greater bacterial diversity in the 0-10 cm layer and greater total microbial diversity 0-10 cm layer. Corn with *B. ruziziensis* showed superiority when there was no inoculation at both depths, and corn with *B. brizantha*, *P. maximum* and Campo Grande estilosante when there was inoculation with *A. brasilense* the 10-20 cm layer.

5. Final Considerations

The works show that chemical, physical and biological attributes are influenced by soil management in integrated systems. In general, integrated agricultural systems are more efficient alternatives for Brazil and must meet international commitments to reduce the greenhouse effect for low-carbon agriculture. For the rural producer, the integrated systems are advantageous due to the greater production in a smaller area and the diversification of income.

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7. Auhors' Contributions

Matheus Vinicius Abadia Ventura: article writing, grammatical and scientific corrections. *Antonio Carlos Pereira de Menezes Filho*: article writing, grammatical and scientific corrections. *Hellen Regina Feranndes Batista-Ventura*: article writing, grammatical and scientific corrections, article submission.

8. Conflicts of Interest

No conflicts of interest.

9. Ethics Approval

Not applicable.

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