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RAFAEL GONÇALVES VILELA

INTERCROPPING SYSTEMS AND SOIL AMENDMENTS UNDER LONG-TERM NO-TILL ON PHOSPHORUS DYNAMICS

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“Blessed are those who find wisdom,
those who gain understanding.”

Proverbs 3:13
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ABSTRACT

The management of weathered tropical soils, with low availability of phosphorus and the presence of a dry season in winter, is a challenge to favor the levels of organic matter and improve the efficiency of phosphate fertilization. Intercropping maize second crop with cover crops has improved soil quality, enhancing the input of straw in the production system, favoring nutrient cycling and efficient use of natural resources by commercial crops, increasing productivity. The effects of intercropping systems on off-season (autumn-winter) cropping and changes in soil acidity on soil P dynamics were evaluated in a randomized block experiment in split plots. The single or intercropped maize cultivation system with signal grass + sunn hemp were considered as the main plots, and the acidity correction through silicate, limestone or without correction were treated as subdivided plots. Soy is grown as a main crop in the summer seasons. The intercropping of maize in the off-season increases the yield of maize and soybeans by approximately 30 and 9%, respectively. The greater input of plant residues through intercropping temporarily reduces the lability of Po and Pi in the soil at 0-0.05 m depth, but does not limit P uptake by crops. Liming, regardless of the corrective used, increases the pool of Pi in the soil, specifically for labile forms due to the release of P linked to Al and Fe. Intercropping maize second crop with Brachiára and Sunn hemp is a good option for plant diversification in the area, increasing land use efficiency and SP sustainability in tropical agriculture, providing higher yields compared to the monoculture system.

Key words: crop straw inputs; silicate; ruzigrass; maize; soil organic phosphorus.

RESUMO

O manejo de solos tropicais intemperizados, com baixa disponibilidade de fósforo e presença de uma estação seca no inverno, é um desafio para favorecer os índices de matéria orgânica e melhorar a eficiência das adubações fosfatadas. O consórcio do milho segunda safra com plantas de cobertura tem melhorado a qualidade dos solos, potencializando o aporte de palhada no sistema de produção, favorecendo a ciclagem de nutrientes e eficiência no uso dos recursos naturais pelas culturas comerciais, aumentando a produtividade. Os efeitos de sistemas de cultivo consorciados na cultura de entressafra (outono-inverno) e as alterações da acidez do solo sobre a dinâmica de P no solo foram avaliadas em um experimento de blocos ao acaso em parcelas subdivididas. Sendo o sistema de cultivo milho solteiro ou consorciado com capim braquiária + crotalária considerados como as parcelas principais, e a correção de acidez através do silicato, calcário ou sem correção foram tratados como parcelas subdivididas. A soja é cultivada como cultura principal nas estações de verão. O cultivo consorciado de milho na entressafra aumenta em cerca de 30 e 9% o rendimento das culturas de milho e soja respectivamente. O maior aporte de resíduos vegetais através da consorciação reduz temporariamente a labilidade de Po e Pi do solo a 0-0,05 m de profundidade, más não limita a absorção de P pelas culturas. A calagem independente do corretivo utilizado, aumenta o pool de Pi do solo, especificamente para formas lábeis em decorrência a liberação de P ligado a Al e Fe. O consórcio de milho segunda safra com braquiára e crotalária é uma boa opção para diversificação de plantas na área, aumentando a eficiência do uso da terra e a sustentabilidade do SP na agricultura tropical, proporcionando maiores produtividades em comparação com o sistema monocultivo.

Palavras-chave: resíduos vegetais; silicato; braquiária; milho; fósforo orgânico do solo.

SUMMARY

GENERAL INTRODUCTION

Population growth in the world, expected to reach 11 billion people in 2100, puts pressure on agriculture to increase food production with economic efficiency and socio-environmental responsibility, avoiding the depletion of natural resources (FOOD AND AGRICULTURE ORGANIZATION [FAO], 2018; WITHERS et al., 2018). The increase in demand for food in the world has triggered a greater need for the supply of phosphate fertilizers to agriculture, leading to the depletion of its reserves, where projections point to the depletion of 60% of this resource by 2100 (CORDELL; DRANGERT; WHITE, 2009; VAN VUUREN; BOUWMAN; BEUSEN, 2010).

Brazil currently produces 312 million tons of grains, 491% more compared to the 1980s (COMPANHIA NACIONAL DE ABASTECIMENTO [CONAB], 2023). Growing food production simultaneously led to an increase in fertilizer consumption, reaching values above 410% compared to the same period, with consumption of 41 million tons in 2022, with 67% of all P2O5 consumed coming from foreign sources (NATIONAL ASSOCIATION FOR DIFUSION OF FERTILIZERS [ANDA], 2019).

The high consumption of phosphate fertilizers is related to the characteristics of extremely weathered tropical soils, such as low levels of organic matter and high concentrations of iron (Fe) and aluminum (Al) oxides, which provide a high phosphorus adsorption capacity, reducing about 80% the efficiency of phosphorus fertilization (VOLKSWEISS; RAIJ, 1977; SANTOS et al., 2018). Due to these characteristics, it is common to consume high rates of phosphate fertilizers to overcome the processes of immobilization of the element in the soil and supply the nutritional demand of crops. As a result of this process, since the 60s, it is estimated that more than 22 million tons of P have been adsorbed in Brazilian soils, resulting in an increase in the reserve of this element in the soil, but with fractions not available to plants (CUNHA et al., 2014; WITHERS et al., 2018). Due to the important role that P plays in the plant cell, the restriction of its availability impairs the development and productivity of cultures (MARSCHNER, 2011), making it necessary to increase its supply.

However, it is noteworthy that the increase in the recommended doses of P directly impact the production costs of crops, whose nutritional management corresponds to values above 30% in the total cost for the production of commodities such as soybeans and corn (CONAB, 2016; HIRAKURI; ALVES; MONTAGNER, 2018). Considering that 67% of P consumption comes from imports, combined with the fact that it is a finite resource, the increase in demand for P raises concerns about its scarcity and cost of acquisition, making essential improvements in the efficiency of use of this nutrient by plants and obtaining more sustainable alternatives to favor greater P availability (WITHERS et al., 2018). Among the alternatives, one can mention the use of soil acidity correctives and the diversification of crops with species that provide a large amount of straw on the soil.

Among the management methods for chemical correction of the soil, the use of limestone revolutionized agriculture in acid soils, due to the increase of OH- ions in the soil solution, allowing an increase in pH, precipitation of Fe and Al, reducing the complexation and precipitation of anions phosphates and also promoting the deprotonation of hydroxyls in clays, which reduces the adsorption sites and increases the available P content in the solution, in addition to acting as a source of Ca and Mg and reducing problems with toxicity of plants to Al and Mn (NOVAIS; SMYTH, 1999).

In addition to limestone, acidity correction can be performed using calcium and/or magnesium silicates. These silicates are minerals with the structure and composition of wollastonite (CaSiO3), belonging to the pyroxene group, which allow them to be used in agriculture not only to correct acidity, but also as a source of calcium and silicon for plants with low acquisition costs. (MARTINS et al., 2010; CASTRO; CRUSCIOL, 2013).

The solubility and concentration of nutrients in silicates depend on the origin and industrial process to which the mineral is subjected, and the finer the final product, the greater its solubility, reaching up to 6.78 times greater dissolution than limestone, giving in these conditions greater mobility in the soil (ALCARDE; RODELLA, 2003; DATNOFF; RODRIGUES; SEEBOLD, 2007; PEREIRA et al., 2009).

Silicon in the soil solution, in the pH range between 4.0 and 6.5, is found as monosilicic acid [Si (OH)4], which is absorbed by plants (EPSTEIN; BLOOM, 2006). In the soil, transformation to H3SiO4- occurs, competing for the same P adsorption sites in the mineral fraction, with specific adsorption occurring on the Fe oxide surfaces, so that Si can desorb P from colloids into the soil solution, and vice versa. -versa, reducing phosphate fixation and making it more available to plants (OBIHARA; RUSSEL, 1972; CARVALHO et al., 2000; DEMATTÊ et al., 2011). In the work carried out by Castro et al. (2016), silicating provided an increase in the availability of P in the soil and allowed an increase in the foliar P content in the soybean crop. Therefore, although there is evidence of greater availability of P in the soil through the use of silicates, the evaluation of this practice in long-term experiments becomes even more relevant, especially in association with diversified production systems that favor a high supply of straw, such as is the case of the consortium.

In addition to acidity correction, management techniques that contribute to the production of straw allow increases in the levels of organic matter in the soil, which makes the environment less oxidative and decreases the processes of P fixation (COSTA, 2000). In addition, the high production and permanence of straw on the soil surface contribute to the availability of P, due to the increase in the concentration and release of organic acids (AO) of low molecular mass in the soil. These acids participate in several reactions in the soil: Al complexation and reduction of its toxicity, ion adsorption, occupation of phosphate adsorption sites, chemical constitution of the rhizosphere and Ca leaching in the soil (FRANCHINI et al., 2003). The ability of AO to compete with P sources for adsorption sites depends on their composition, concentration, persistence of these anions in the soil and soil pH (STEVENSON, 1967).

For the availability of P through organic matter, by increasing the negative charges in the soil and reducing the sites of phosphate adsorption, the sorption and desorption of P depends on the persistence of organic carbon in the soil, which is governed by microbial activity, metabolic availability of carbon substrate and sorption to soil colloids (PAVINATO; MERLIN; ROSOLEM, 2008). The most active AO are citrus, oxalic, gluconic, lactic and malic, which chelate Fe and Al oxides, increasing P solubility in the soil, a fact that also occurred in the presence of humic and fulvic acids. In addition to these, Ca phosphates in the presence of carbonic acid formed from microbial and root respiration can also be solubilized, making the retained P available (GUPPY et al., 2005). The sorption of simple AO follows the preferential sequence for the adsorption sites: phosphate >>> oxalate > citrate > malate >> acetate (GUPPY et al., 2005).

In the process of solubilization and mineralization of P in the soil, bacteria and fungi are closely linked to these processes, composing the biogeochemical cycle of this nutrient, whose dynamics is dependent on the production system (RICHARDSON, 2001). The way plants acquire P can be modulated by microorganisms, through mycorrhization, release of phytohormones, excretion of AO and protonation, production of siderophores and phosphatase enzymes (CARDOSO; ANDREOTE, 2016). Thus, production systems that promote plant diversification, such as intercropping, can favor soil microbiota and, consequently, greater release of P to crops.

The adoption of vegetation covers in integrated grain production systems enhances the cycling of nutrients, which recover part of the fixed or precipitated P, subsequently making it available to successive crops. As an example, the cultivation of Urochloa ruziziensis favors the availability of P in the soil. In addition, this forage provides an increase in the levels of this element in the humic fraction of the soil, keeping it in organic fractions and reducing adsorption processes (MERLIN; HE; ROSOLEM, 2014). In intensive grain production systems in regions with a dry winter, maintaining the vegetation cover on the ground is a difficulty, which can be overcome by intercropping maize with Urochloa. This practice favors greater accumulation of straw, increased levels of organic matter, pH, P availability and base saturation (CRUSCIOL et al., 2015). In addition to the intense development of the root system of these forages and their ability to solubilize non-labile forms of P, it provides greater accessibility and absorption of this nutrient by plants, favoring cycling and availability for cultures in succession (ALMEIDA; ROSOLEM, 2016).

However, up to 80% of all organic phosphorus (Po) is found in forms not available to plants, such as monoester orthophosphates, formed by inositol phosphates from mono to hexa, including myo-inositol hexaphosphate acid, called of phytic acid (MAGID; TIESSEN; CONDRON, 1996). Inositol phosphates accumulate in the soil due to their adsorption to colloids and the formation of precipitates with insoluble salts, which reduces their biodegradation through enzymes called phytases (OGNALAGA; FROSSARD; THOMAS, 1994; TURNER et al., 2002; TANG et al., 2006). Citrate, followed by oxalate and malate, released from plant roots, are the most efficient for the solubilization of more stable forms of Po, capable of hydrolyzing forms of phytates that are precipitated with Al and Fe, releasing P (TANG et al. ., 2006). Thus, measures that allow the cycling of P retained in phytate forms, such as phytase secretion and AO production, can impact on the management of phosphate fertilization due to the increase of Pi in the soil, enhancing the rate of absorption by plants.

In the soil, P is found in the most varied forms of Po and Pi, grouped in labile, moderately labile and non-labile forms. Therefore, in order to know the influences of the different production systems on the P lability in the soil, the fractionation method proposed by Hedley, Stewart and Chauhan (1982) allows the understanding of this dynamic, considering its different fractions. From a sequential extraction, it is possible to separate Po from Pi, depending on the chemical stability of P in relation to specific reagents (SHARPLEY, 1995). Thus, changes in the dynamics of soil P forms depend on the management system, the amount of P exported at harvest, the replacement rate of P exported from the system, and the ability of plants to utilize P reserves in less labile forms. (TIECHER; SANTOS; CALEGARI, 2012).

The fractionation of P in the soil was studied by Pavinato, Merlin and Rosolem (2008), with the addition of different organic compounds extracted from plant species, allowing to verify that the different compounds led to the accumulation of Pi in the labile and moderately labile fraction, up to 5 cm deep; they also found that plants with a higher concentration of malic acid provided a higher level of P available in the soil. Therefore, it is assumed that the different production systems provide differentiated adsorption and solubility of P, depending on the specificities of crop rotations over time. This will make it possible to infer which systems will reduce the need for phosphorus fertilization due to greater efficiency in the use of P, thus promoting greater sustainability.

Based on the aforementioned reports, it appears that studies on processes involving P dynamics in long-term experiments conducted under conservationist management, in addition to being important, are scarce in Brazil. Understanding the availability of P to plants involving diversity of species for soil cover is still rare, as it involves interactions between production systems and the biogeochemical cycle of this element. Therefore, it is proposed that the study in experiments with long-term production systems can contribute to the understanding of these dynamics involved.

FINAL CONSIDERATIONS

Intercropping maize with Brachiaria and Sunn hemp under long-term no-tillage modifies P reservoirs and its effects are restricted to the soil surface, being accumulated in moderately labile and non-labile forms.

These consortia increase the input of crop residues in the area, favoring grain yield, but temporarily reducing the lability of Po and Pi in the soil in the 0-0.05 m depth layer, due to the increase in the biological stock of P. The increase in biomass production through intercropping contributes slightly to preventing the absorption of inorganic phosphate by soil colloids, increasing the organic P content of the soil without impairing the absorption of this nutrient by crops.

Liming, regardless of the corrective used, increases the pool of Pi in the soil, specifically for labile forms due to the release of P linked to Al and Fe.

Thus, the results indicate that the second crop corn intercropping with Brachiára and sunn hemp is a good option for plant diversification in the area, increasing land use efficiency and NTS sustainability in tropical agriculture, providing higher yields compared to the monoculture system.

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