# MAIZE AND BRACHIARIA INTERCROPING SYSTEM EFFICIENCY IN THE USE OF SOIL PHOSPHORUS RESERVES AND FRESH FERTILIZER

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**ABSTRACT**
The potential for using soil P reserves has been evaluated since 2014, in experiments with maize in monoculture and intercropped with brachiaria and in rotation with soybean. In order to evaluate the residual effect of these P reserves in the soil when compared to recent P applications, treatments with rates of P (0, 22 and 44 kg of P $ha^{-1}$) were included as maintenance. Also, the effect of inoculation with arbuscular-mycorrhiza was evaluated. Results showed that, in this specific case and after four years of P "draw down" by the corn grain, legacy P in soil alone (without addition P fertilization) led to a significantly lower cumulative grain yield than with P fertilization, when other nutrients in the soil were at adequate levels. In this research there is no evidence that the use of brachiaria intercropping with corn associated with mycorrhiza can optimize the use of residual phosphorus. In general, the brachiaria intercropped with corn reduced grain yield, due mainly brachiaria management. The potential and the time for utilization of P reserves in the soil is closely related to the bioavailability of P evaluated by extractor (Mehlich1), whose values must be above the critical levels pre-established that provide economic productivity for farmers.
**Key words:** : legacy-P; maintenance-P; mycorrhiza

## INTRODUCTION

Currently, the role of the scientist in increasing the life span of world P reserves lies in increasing the efficiency of use of P in agriculture. This may be P applied in mineral fertilizers, in organic manures (animal manures, composts and biosolids), but also soil P reserves accumulated as residues from past applications of fertilizers and manures (HEFFER et al., 2006). New strategies need to be implemented in order to improve the P efficiency of crop systems, including readjusting fertilizer recommendations, adoption of best management practices, use of crop rotations including P-mobilizing species. Moreover, the reengineering of plant, fertilizer, and microorganism processes are needed, as the development of P-efficient cultivars, novel fertilizers with enhanced efficiency, and stimulating beneficial associations between plants and microorganisms can all extend the root system or mobilize P in the rhizosphere. All these strategies can increase the use of legacy-P from soil and contribute to the reduction of inputs of phosphate fertilizers, therefore leading to a better use of phosphorus in agriculture. The present research is part of a series of experiments conducted in the same area, in the period from 2008 to 2013, and whose partial results obtained previously, were published by Coelho (2014a, 2015b, 2015c). In this context, the objective of this study is to contribute to a more systematic assessment of the effect of soil phosphorus. If the recovery of added P is of interest not only in the year of application but in subsequent years as well, this raises the following questions: (a) can the residual P produce yields that are economically viable for the farmer, (b) what is the effect of the crop system, brachiaria intercropping with corn, in to optimize the use of soil phosphorus reserves and (c) what is the potential of the introduction of mycorrhiza into soil for improving the availability of soil P reserves?

## MATERIAL AND METHODS

The research was conducted at the agronomic research station of the Embrapa, located in Sete Lagoas, MG, Brazil (19° 28' S, 44° 15' W and 732 m above sea level). The soil classified as Red Latosol, very clayey texture. The soil chemical attributes were determined in 2014, getting the following results in the 0-20 cm layer: 40 g $dm^{-3}$ organic matter; 5.95 pH (water); K, Ca, Mg, H + Al and Al = 0.32; 3.45; 0.84; 6.23 and 0.01 $cmol_c$ $dm^{-3}$, respectively; Cu, Fe, Mn, Zn (Mehlich 1) = 1.46; 31.64; 34.77 and 3.18 mg $dm^{-3}$, respectively, and 50% base saturation. The experiments were conducted in the summer seasons of 2014-15, 2016-17, 2018-19 and 2019-20 in the system corn in rotation with soybean. The experiments were in random blocks using a split-split plot design, consisting of three treatments factors, with four replications. The main plots were levels of P (0, 218 and 436 kg $ha^{-1}$) applied in 2003, and classified as low, medium, and high. The split plot factor consisted of crop system (corn and corn intercropping with brachiaria) and the split-split plot factor consisted of doses of P (0, 22 and 44 kg P $ha^{-1}$) as maintenance and, arbuscular-mycorrhiza inoculum, annually applied by hand, banded in the furrows. Corn single hybrids DKB390 (20014-15), AG8088 (2016-17, 2019-20) and SHS4080 (2018-19) were sowed mechanically at 0.70 m between rows and density of five seeds per meter (plant density 70,000 $ha^{-1}$), in the first fortnight of November in each season. The brachiaria brizantha, cv. Xaraes, was sowed intra and inter-row of maize at a rate of 10 kg of seeds $ha^{-1}$ and was used as cover crop. At sowing time N and K were applied at rate of 45 and 75 kg $ha^{-1}$, respectively, as ureia and KCl. Micronutrients, as FTE BR12, at rate of 50 kg $ha^{-1}$ was applied mixed with urea and KCl only in one year. At 35 days after planting (V5-V6 stage with five to six leaves),150 kg of N $ha^{-1}$(70% ureia plus 30% ammonium sulfate) and 75 kg K $ha^{-1}$ (KCl) were applied, spread on the soil surface, following by irrigation. In all growing seasons, except 2018-19, irrigations were provided, as necessary, to supply water during drought periods, a phenomenon of common occurrence in the region. In the growing season of 2018-19, the irrigation was not possible to be provide, and a drought period of 30 days occurred during grain filing stage and the grain yield was very lower, less than 1.50 Mg $ha^{-1}$ and the results will not be considered. At harvest time, number of plants and ears, weight of biomass and grain were determined by hand harvesting four adjacent 4-m long rows. Grain yields were obtained after threshing the ears in a mechanical machine and reported at 130 g $kg^{-1}$ grain moisture. After crop harvest, soil samples of 0 - 20 cm depth, were taken from sub-sub plots in 2014 and 2017. Soil samples were taken between and in the row, collecting five single samples from each sub-subplot. Composted soil samples were mixed, air dry and crushed to pass a 2-mm sieve and analyzed for soil fertility indicator at the Embrapa Maize and Sorghum laboratory of soil analyzes. The biomass of brachiaria was harvest two months after corn has been harvest. The yield of biomass was determined by harvesting two sub-sample of 1 square meter inside of each sub-subplot of the treatments. The weight of biomass was recorded, and subsamples were taken for determination of dry matter (65ºC). All data were analyzed by conventional analysis of variance procedures for split-split plot design (SAS Inst., Cary, NC). When significant factors or interactions were observed ($P \leq 0.10$), Tukey's Studentized Range (HSD) test was used for means separation within each treatment. Statistical significance was assessed at the 0.10 level.

## RESULTS AND DISCUSSIONS

### *Soil phosphorus "bioavailability"*

In the Table 1, are showing the results of "bioavailability" of soil P, extracted by Mehlich1. The applications of high rates of P in 2003, were necessary to reach 20 and 40 mg of P $dm^{-3}$ (Table 1). Thereafter, the balance of phosphorus obtained in the time period of 2003 to 2014 (data not showed), indicated that of total P fertilizer applied in 2003 (218 and 436 kg $ha^{-1}$), the total P removed in the grains of the crops (corn and soybean) were 117 and 136 kg $ha^{-1}$, respectively, representing 53 % and 31 % of the total P fertilizer applied, indicating thus, a positive balance in which significant amounts of P fertilizer (100 and 300 kg $ha^{-1}$) remained as reserves (legacy P) in the soil. However, the results of analyzes of the "bioavailability" of P in soil, measured by extractor Mehlich1, in soil samples taking at 20 cm depth, in 2014 and 2017, represented in the average, only a small fraction of 6.4% and 4.1%, respectively, of these reserves (Table 1).

Table 1. Soil P "bioavailable" analyses (0 - 20 cm depth).

| P-level[1] kg ha$^{-1}$ | P-residual[2] kg ha$^{-1}$ | Crop System | Bioavailable P-Mehlich1 2003[3] | 2014 | 2017 |
|---|---|---|---|---|---|
| | | | mg dm$^{-3}$ soil | | |
| 0 (Low) | 0 (Low) | Corn | 5.33 ± 0.85[4] | 6.31 ± 2.55 | 7.00 ± 4.75 |
| | | Corn+ brachiaria | | 3.97 ± 1.02 | 5.98 ± 3.55 |
| 218 (Medium) | 100 (Medium) | Corn | 20.50 ± 7.87 | 5.54 ± 1.34 | 6.65 ± 3.04 |
| | | Corn + braquiaria | | 6.72 ± 4.13 | 6.77 ± 2.60 |
| 436 (High) | 300 (High) | Corn | 39.70 ± 14.98 | 13.48 ± 3.84 | 10.05 ± 4.58 |
| | | Corn + brachiaria | | 13.64 ± 4.80 | 11.93 ± 6.71 |
| Average | | | 31.84 | 8.28 | 8.06 |
| CV % | | | 20 | 47 | 41 |

[1]Total P added via inorganic P fertilizers (TSP) after 11 years (2003–2014). [2]P fertilizer residual left in soil in 2014. [3]P initial in 2003 determined in soil samples taken four months after triple superphosphate has been applied. [4]Numbers followed by signal ± is the stander deviation.

As far as the critical level is concerned, the bioavailability of P extracted by Mehlich1, previously established for this soil, under conventional tillage, is in the range of 8.0 to 10.0 mg of P dm$^{-3}$ of soil (COELHO & ALVES, 2004). However, as verified by Ciotta et al. (2002), for a Latossolo clayey texture, managed under no-tillage for several years (>20 years), the "bioavailability" of P, in the layer of 0-20 cm, measured by Mehlich1 extractor was higher (10,85 mg kg$^{-1}$) as compared with the same soil under conventional management (4,04 mg kg$^{-1}$), and the recommended critical level is lower, with value of 6.0 mg dm$^{-3}$ of P in the soil (SOUZA et al., 2016). Thus, as showed in the Table 1, in the period of time analyzed, only the application of a high dose of P (436 kg ha$^{-1}$) in 2003, maintain in the soil, values of "bioavailability" of P above the critical level. For the control and application of a medium dose of P (218 kg ha$^{-1}$) in 2003, the values of "bioavailability" of P are similar and close or below of the critical level considered for soils managed under no till system (Table 1).

Although the bioavailability of P increases with increasing levels of residual P, the values are similar within cropping systems, except for the soil samples taking in 2014, when the bioavailability of P was lower for the treatment with low P residual and the crop system was corn intercropped with brachiaria (Table 1). Almeida et al. (2019), in experiment with bachiaria ruziziensis, cultivated as cover crop in the soybean off-season, observed decreases in the soil P bioavailability by fundamentally to reduce P mobility and P resupply from soil solid phase into soil solution.

*Grain yield potential and corn responses to P-reserves, P-fresh and mycorrhiza*

Independent of applied treatments (level of P residual and maintenance, mycorrhiza, and crop system), the annual corn grain yields to three cultivated crops, range from 5.50 to 11.10 Mg ha$^{-1}$ with average of 8.64 Mg ha$^{-1}$ (data not shown). In irrigated corn, the yield potential obtained by farmers in the region, range from 8.0 to 10.0 Mg ha$^{-1}$ against 4.50 to 6.50 Mg ha$^{-1}$ in rainfed corn conditions.

In the Table 2, are presented the grain yield of corn in each growing season. For all experiments the isolated effect of levels of P residual (legacy P) and maintenance (fresh P) were statistic significant ($p \leq 0.10$), with the higher yields obtained with the high level of P residual associated to P maintenance (Table 2). If we take in count only the effect of P residual, without P maintenance or mycorrhiza application, it was obtained gain of 30 % (2.15 Mg ha$^{-1}$), 27 % (2.07 Mg ha$^{-1}$) and 3.2 % (0.26 Mg ha$^{-1}$) in the grain yield in the plots with high P residual (300 kg ha$^{-1}$) as compared with control, indicating that is important to maintain in the soil values of "bioavailability" of P above the critical level (Table 1), to reach economic yields of corn.

Table 2. Effect of P residual (legacy), P maintenance, mycorrhizae, and crop system in the grain yield of corn cultivated in rotation with soybean in four growing seasons.

| **Mycorrhizae (M)/ P-Maintenance (kg ha$^{-1}$)** | **P - Residual (kg ha$^{-1}$)** | | | **Average** | **Crop system** | |
|---|---|---|---|---|---|---|
| | **0 (Low)** | **100 (Medium)** | **300 (High)** | | **Corn** | **Corn + Brachiaria** |
| | | | *Growing Season 2014-15, Grain Yield (Mg ha$^{-1}$)* | | | |
| M | 7.17b | 7.00c | 9.52b | 7.90c | 8.87b | 6.92c |
| 0 | 7.07b | 6.63c | 9.22b | 7.64c | 7.81c | 7.44c |
| 22 | 7.78b | 7.89b | 10.05ab | 8.57b | 9.05b | 8.10b |
| 44 | 8.90a | 9.54a | 10.39a | 9.60a | 9.79a | 9.42a |
| Average | 7.72B | 7.77B | 9.80A | | 8.88A | 7.98B |
| | | | *Growing Season 2016-17, Grain Yield (Mg ha$^{-1}$)* | | | |
| M | 6.88b | 6.81c | 9.90ab | 7.86c | 8.58bc | 7.14c |
| 0 | 7.58b | 6.82c | 9.65b | 8.02c | 7.96c | 8.08b |
| 22 | 8.90a | 8.53b | 10.56a | 9.33b | 9.28b | 9.38a |
| 44 | 9.41a | 9.95a | 10.73a | 10.03a | 10.09a | 9.97a |
| Average | 8.19B | 8.02B | 10.21A | | 8.98A | 8.64A |
| | | | *Growing Season 2019-20, Grain Yield (Mg ha$^{-1}$)* | | | |
| M | 8.12 | 6.88 | 8.76 | 7.92b | 8.88b | 6.96b |
| 0 | 8.06 | 7.66 | 8.32 | 8.01b | 8.35b | 7.67b |
| 22 | 9.35 | 8.88 | 9.86 | 9.36a | 9.70a | 9.03a |
| 44 | 9.25 | 9.14 | 9.78 | 9.39a | 9.96a | 8.83a |
| Average | 8.69A | 8.14B | 9.18A | | 9.22A | 8.12B |

Medias in the same column following by same letters are not statistically different by tukey test at 0.10 level. Small letters compare effect of P levels maintenance and capital letters compare P levels residual and crop system.

On the other hand, independent of crop system used, the grain yields obtained in the control treatment (Table 2) during the period analyzed (6.0 to 8.0 Mg ha$^{-1}$), were an indicator to the potential of this soil to supply P for the crop, although the "bioavailability" of P (Mehlich1) is around the critic level

(Table 1), an indicator that other sources of P in soil are releasing P for corn. As mentioned by Soltangheisi et al. (2020), without P fertilization, organic P contribution to supply P for plant uptake is higher than inorganic P. These actors, verifying in long-term field experiment, that under nil-P, the organic fractions of P (Po labile and moderate labile), was depleted by 31% (from 51% in 2009 to 20% in 2017), which indicates that these organic P fractions are acting as a source of available P over the time. Another aspect to be considered is that the Melich1 extractor do not measure the potential of P bioavailability of soil. As verified by Gatiboni et al. (2002), a single Mehlich1 extraction, extracted only 29% of the potentially available phosphorus and to extract the potentially available phosphorus, four successive extractions were necessary.

The effect of crop system in the corn grain yield was not consistent, with variations among the growing seasons (Table 2). Only in the growing season of 2016-17, the corn grain yield was similar between the crop system, in the others growing season, the system brachiaria intercrop with corn reduced corn grain yield. Apparently, this effect could be not attributed to soil P bioavailability and probably due to the management of development of brachiaria. Lower yields of cash crops have been observed after growing ruzigrass compared with those in fallowed soil. Almeida et al. (2019) observed a lower soybean [*Glycine* max (L.) Merrill] grain yield and leaf P concentration after ruzigrass than fallow in four consecutive years.

Although, the soil used in the present research has a high reserve of phosphorus in the soil, from natural and the addition of phosphate fertilizer over the period (Table 1), corn responded to doses of this nutrient applied as maintenance (Table 2), especially when the “bioavailability” of soil revealed by the Mehlich1 extractor was below the critical level (6.0 mg $dm^{-3}$). However, as reported by Owen et al. (2015), the exploitation of soil P reserves is hindered by the fact that the forms, distribution, and accessibility of legacy P are complex and diverse, and often not in a form that is readily available for plant uptake. Thus, in the absence of a pool of readily-available P provide by inorganic fertilizers, plant must utilize numerous strategies to acquire soil inorganic (Pi) and organic (Po) quickly and efficiently to ensure an adequate supply of P during the growing seasons.

## CONCLUSIONS

Results showed that, in this specific case and after four years of P “draw down” by the corn grain, legacy P in soil alone (without addition P fertilization) led to a significantly lower cumulative grain yield than with P fertilization, when other nutrients in the soil were at adequate levels. In general, the cultivation of brachiaria intercropped with corn reduced the productivity of corn grains when compared to corn cultivated alone. However, this reduction was not associated with the availability of P in the soil, but probably with an inadequate management of the brachiaria, resulting in a marked competitive effect. Thus, in this research, there was no evidence that the use of brachiaria intercropped with corn associated with mycorrhiza can optimize the use of soil P reserves. The potential and time for utilization of P reserves in the soil is closely related to the bioavailability of P, evaluated by extractor (Mehlich1), whose values must be above the pre-established critical levels, that provide economic productivity for farmers.

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