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Initial growth of coffee tree based on different sources of phosphorus

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ABSTRACT

Coffee farming have a great economic importance to Brazil, especially in the south of Minas Gerais. For cropping, initial care, such as soil corrective practices aimed at the proper establishment of the crop, is necessary. The definition of the best phosphate source for planting is one these practices. Thus, this study seeks to define the best phosphate source to be used in the implementation of a coffee crop aiming at greater vegetative growth of seedlings in the field. For this, an experiment was set up with coffee seedlings grown in pots; the experimental design was randomized blocks with seven treatments (struvite, monoammonium phosphate, reactive natural phosphate, single superphosphate, triple superphosphate, thermophosphate, and control) and five replications. The cultivar Red Catuaí was used at approximately five months of age. The following evaluations were performed: harvest diameter, plant height, root dry mass, stem dry mass, leaf dry mass, total dry mass, foliar phosphorus content, in addition to the Dickson quality index. There was a significant difference for plant height only for simple superphosphate and control; nevertheless, for harvest diameter and stem dry matter, the best results were observed with reactive natural phosphate; and for root dry mass and total dry mass, reactive phosphate rock and monoammonium phosphate stood out. These sources also provided the best Dickson quality indexes, indicating they are the best options when it comes to the initial growth of coffee seedlings. Therefore, for coffee planting, the adoption of reactive phosphate rock and monoammonium phosphate is recommended.

Keywords: Coffee farming; Crop implantation; Phosphate fertilizer.

Introduction

Coffee farming has great economic importance for Brazil, being responsible for a large part of the country's exports. The central and southern regions of Minas Gerais are the main coffee producers, representing 34.38% of the national production, with an average productivity of 24.5 bags ha^{-1} (FAEMG, 2020). Thus, given the importance of coffee farming to the national economy, especially in Minas Gerais, it is essential to define efficient management practices in the implementation of the crop, especially regarding phosphorus sources.

The soils of southern Minas Gerais are predominantly composed of latosols and cambisols (Scolforo, Carvalho, Oliveira, 2008), in which the coffee crops are. The dynamics of phosphorus in these soil classes is influenced by their mineralogy, that is, by the presence of iron and aluminum oxides that strongly fix phosphorus (Pinto *et al*., 2013), affecting its availability. Therefore, management strategies that maximize the availability of this nutrient are necessary to ensure crop sustainability.

Phosphorus is one of the essential nutrients for plant development, making up DNA, RNA, ATP, plasma membranes (phospholipids), and other vital molecules. Moreover, it plays a crucial role in the photosynthesis and energy production of plants (Marschner, 2012). In coffee farming, this nutrient is essential for the development of roots, which are responsible for the efficient absorption of water and nutrients from the soil, ensuring healthy and productive plant growth.

According to Sakiyama *et al*. (2015), phosphorus in coffee farming is required in lower doses compared to nitrogen and potassium; however, it plays a great role at the time of crop implantation, when the seedling needs the nutrient for the full development of the roots, for proper structuring and, later, to obtain satisfactory performance throughout its cycle.

Despite the importance of phosphorus for plant development, its availability in soil is often limited (Santini *et al*., 2020). Therefore, it is common to use phosphate fertilizers to meet the needs of plants. Nevertheless, not all sources of phosphorus are equally efficient in promoting vegetative growth and development. Admittedly, the efficiency of phosphate fertilizers can vary according to the source used (Moreira, Gonçalves, 2022), as well as the origin, solubility, and accessibility of these sources.

Commonly used sources, such as triple superphosphate (TSP) and single superphosphate (SSP), have different degrees of solubility, with SSP being less soluble and fast-acting, while TSP is more soluble and longer-acting. Monoammonium phosphate (MAP), similar to SSP, has high solubility and greater efficiency in absorption by plants (Franco Júnior, Dias, Ribeiro, 2024).

Although SSP has lower phosphorus concentration compared to TSP, it can still be effective for early plant development. The use of SSP has achieved positive results in terms of increasing plant height (Cândido, 2013).

TSP is one of the most concentrated sources of phosphorus available, with high solubility, and its use has also provided positive results in the early development of coffee plants (Chagas *et al*., 2016). However, TSP has acidification capacity, if used in excess, so its use should be carried out with caution.

Another source that can also be used, but which is not widespread in agriculture, is struvite, as it has great potential as a source of nutrients for plants, since it is a source of slow-release phosphorus and it can be obtained from organic waste (Silva, 2022). In a study conducted by Embrapa (2022), it was observed that struvite promotes significant increases in plant root development and produces higher yields. In addition to being a source of phosphorus, it provides other essential nutrients, making it an interesting option for plant nutrition and for the optimization of agricultural production.

Reactive phosphate rock (RPR), in turn, is a source that has low solubility, although it can be beneficial in soils with adequate pHs (5.5 to 6.5). Its effectiveness may be limited in acidic soils, in which availability is reduced due to adsorption by iron and aluminum oxides. In a study conducted by Silvério *et al*. (2019), the use of this source in coffee farming resulted in satisfactory productivity gains compared to other sources of phosphorus.

In contrast, Moreira and Gonçalves (2022) have shown that MAP has high efficiency in promoting growth, is highly soluble, and provides both phosphorus and nitrogen, being quite effective in the early stages of plant growth, promoting healthier root development. Coffee plants fertilized with MAP tend to grow with more vigor and better leaf development compared to those that have not received phosphorus. Furthermore, its rapid availability can help correct nutritional deficiencies quickly.

Thermophosphate (TP) combines characteristics of natural phosphates with thermal processes to increase solubility. It offers the gradual release of phosphorus over time, being beneficial in acidic soils (Melo *et al.*, 2005).

Given the above, this study seeks to define the best phosphate source to be used in the implantation of a coffee crop aiming at the highest initial vegetative growth of coffee seedlings.

Material and methods

The experiment was carried out from February to May 2023, in plastic pots, in an open-air environment, at Sítio São José, Soledade do Mogi – Inconfidentes, Minas Gerais (22° 19’ 29.08”S, 46° 15' 46.17"W and 896m altitude). The municipality has a historical average (30 years) annual temperature of 17.5°C and accumulated average annual precipitation of 1864mm (Clima Tempo, 2025).

This study used the Red Catuaí cultivar of the species *Coffea arabica* L., approximately four to five months old, containing five to seven pairs of leaves. Horizon B soil of a clayey texture dystrophic red-yellow latosol was used, whose chemical characteristics are presented in Table 1.

The experimental design of randomized blocks was adopted, with seven treatments (Table 2) and five replications, totaling thirty-five plots. Each plot consisted of a pot of 8 dm^3 (20cm base diameter by 23cm height with holes for drainage) with a coffee seedling. The soil analysis was interpreted according to the criteria established by Guimarães *et al*. (1999), and recommendations for the application of fertilizers and correctives were based on these criteria. Thus, to raise the saturation by bases to 60%, 18g pot^{-1} of limestone (CaO = 43.50%, MgO = 8.00%, PRNT= 80%) were added, as well as phosphorus doses, as shown in Table 2.

Phosphate fertilizers, depending on treatments and doses, and earthworm humus (1L pot^{-1}) were mixed into the potting soil moments before planting, which occurred in February 2023. After stabilization of the seedlings, 1.4g pot^{-1} of protected urea (46% N) were applied, corresponding to 5g $plant^{-1}$ N, as well as 2.1g pot^{-1} of potassium chloride (60% K_2O), equivalent to 10g $plant^{-1}$ K_2O; they were applied three times, with an interval of 30 days (Guimarães *et al*., 1999).

All treatments received daily irrigation during the experiment period, except on rainy days.

Table 1. Chemical characterization of the soil used in the experiment.

pH	P	K	Al	Ca	Mg	H+Al	SB	T	V	OM	P-rem
H_2O	mg dm^{-3}		--------------------- cmol$_c$ dm^{-3} ---------------------						%	dag dm^{-3}	mg L^{-1}
5.26	1.6	29.9	0.0	0.6	0.09	6.34	0.79	7.13	11.1	1.14	10.27

pH = active acidity; P = available phosphorus; K = available potassium; Al = exchangeable acidity; Ca = exchangeable calcium; Mg = exchangeable magnesium; H+Al = potential acidity; SB = sum of bases; T = $CTC_{pH\ 7}$; V = saturation by bases; OM = organic matter; P-rem = remaining phosphorus.
Source: IFSULDEMINAS Soil Fertility Laboratory, Inconfidentes *Campus* (2024).

Table 2. Concentration of P_2O_5 and dose of the sources used in the study.

Source	Dose*	Concentration (%)**						
	g pot^{-1}	N	P_2O_5	K_2O	Ca	Mg	S	Si
Struvite***	46	--	22	--	1	8	--	--
Monoammonium Phosphate	21	9	48	--	--	--	--	--
Reactive phosphate rock	37	--	27	--	28	--	--	--
Simple Superphosphate	56	--	18	--	16	--	10	--
Triple Superphosphate	25	--	41	--	10	--	--	--
Thermophosphate	59	--	17	--	16	4	--	8
Control	--	--	--	--	--	--	--	--

* Dose corresponding to 80g pot^{-1} P_2O_5 (64 dm^3) or 10g pot^{-1} P_2O_5 (8 dm^3)
** Brasil (2018)
*** Valle *et al*. (2021)
Source: authors (2025).

Phytosanitary control was carried out manually; however, in cases of occurrence of weeds, pests, and diseases that could cause damage to plants, additional measures would be taken with the use of products registered for the crop.

Harvest diameter and plant height were evaluated on the day of implementation of the experiment and, later, at the end of the experiment. Plant height was measured using a graduated scale, and for the harvest diameter, a digital caliper was used.

From these measurements, the following quality variables were determined:

a) plant height and harvest diameter ratio (HDR);

$$HDR = \frac{PlantHeight}{HarvestDiameter} \qquad \text{Eq. (1)}$$

b) Shoot root ratio (SRR), obtained by the equation:

$$SRR = \frac{ShootDryMass}{RootDryMass} \qquad \text{Eq. (2)}$$

c) DQI: Dickson quality index (Dickson, Leaf, Hosner, 1960), obtained by the equation:

$$DQI = \frac{TotalDryMass}{(HDR+SRR)} \qquad \text{Eq. (3)}$$

At the end of the experiment, the leaves, shoot, and root system were separated. The harvested root material was placed in a 2mm mesh sieve and subjected to hydraulic separation with the aid of a hose to loosen the soil from the roots.

To determine the dry matter, the material was packed separately in paper bags and dried in an oven with forced air circulation at 60°C for 72 hours or until it reached a constant mass. Subsequently, the material was weighed on an analytical balance. Leaf samples were sent to the IBRA megalab laboratory for the determination of foliar phosphorus content (Malavolta, Vitti, Oliveira, 1997).

To verify the normality and homogeneity of variance, the data were submitted to the Shapiro-Wilk and Bartlett tests and then to the analysis of variance ($p<0.05$). When significant, the mean grouping test (Scott-Knott) was performed, using the “ExpDes.pt” package in the RStudio compiler (R TEAM, 2022).

Results and discussion

Table 3 shows the results of the mean test for the variables studied based on the different phosphorus sources used in the initial development of coffee seedlings. Low CV values were observed (Pimentel-Gomes, 2022), indicating low variability of the data, being a low dispersion signal.

For the variable plant height (PH), among the different phosphorus sources tested, the best results were obtained with the use of struvite, monoammonium phosphate, reactive natural phosphate, triple superphosphate, and thermophosphate. In contrast, the single superphosphate (SSP) source was the only one that resulted in lower values, being superior only to the control. This lower performance in the use of SSP should be attributed to the fact that when this source is used after the use of limestone, without waiting for the reaction time, incompatibility may occur (Bonfim-Silva *et al*., 2021).

For stem diameter (SD), the results can be classified into two distinct groups. In the first group, the sources that stood out the most were: monoammonium phosphate, RPR, triple superphosphate, and thermophosphate. RPR, due to its gradual solubility, provides the continuous release of phosphorus, favoring stem growth. Thermophosphate, as it is a thermal fertilizer, offers efficient phosphorus release, favoring more vigorous growth (Table 3).

Still in the first group, there are TSP and MAP. These fertilizers quickly provide phosphorus, resulting in moderate stem growth. The rapid availability of phosphorus may have

Table 3. Plant height (PH), stem diameter (SD), and foliar phosphorus (P_Foliar) in coffee plants subjected to different sources of phosphorus. Inconfidentes, MG, 2025.

Treatment	PH	SD	P_Foliar
	cm	mm	g kg^{-1}
Struvite	33.3 a	5.51 b	1.67
Monoammonium Phosphate	33.8 a	6.27 a	1.61
Reactive Natural Phosphate	35.6 a	6.67 a	1.53
Simple Superphosphate	30.5 b	5.71 b	1.68
Triple Superphosphate	34.0 a	6.17 a	1.72
Thermophosphate	32.9 a	6.29 a	1.47
Control	28.3 b	5.27 b	1.64
Overall mean	32.6	4.51	1.64
MSD	3.82	0.87	0.21
p-value	0.013*	0.030*	0.249^{ns}
CV	8.97	10.96	10.21

Means followed by equal letters in the columns did not differ from each other by the Scott-Knott test ($p<0.05$).
MSD = minimum significant difference; F for treatments; CV = coefficient of variation (%).
*significant effect <0.05%; ns = not significant.
Source: authors (2025).

been sufficient for proper development, although not as efficient to highlight these fertilizers.

Finally, in the second group, with the smallest diameters observed, one can find struvite, simple superphosphate, and control. Struvite and simple superphosphate, due to limited solubility, restrict phosphorus availability, resulting in smaller stem diameter. These sources, with the control without added phosphorus, had the lowest development, highlighting the importance of this nutrient for the growth of the coffee tree (Table 3).

Similar results for PH and SD, in coffee farming, were obtained by Candida *et al*. (2013). In this sense, the use of RPR for the implantation of coffee crops is important for the growth, establishment, and maintenance of seedlings in the early stage.

No significant difference was observed in foliar phosphorus content, and all results were within the limits considered adequate, between 1.2 and 1.6g kg^{-1} (Martinez *et al*., 2004; Guimarães *et al*., 1999), indicating that all sources provided phosphorus and that the nutrient was transported (Table 3). The phosphorus content in the control is explained by the residual effect of this element and the addition of humus in the preparation of the substrate for seedling production.

For the dry mass of the root system (Table 4), the best results were obtained with the use of MAP and RPR, without significant differences between them. Similar results were observed for the total dry mass. However, for stem dry mass, the source that provided the best indices was RPR. Considering that dry matter is a direct indicator of quality in plant development, it is noted that phosphorus sources RPR and MAP help in the best development of plants.

For leaf dry mass, no statistical difference between the sources tested was found. All sources were administered at the recommended dosage and adequately met the nutritional needs of the coffee plant (Table 4).

Vaz and Souza (2021) observed that the use of different phosphorus sources did not result in significant differences in shoot dry mass, root dry mass, plant height, and stem diameter; these authors attribute the variations to doses and not to the sources used. In contrast, in this study, all phosphorus sources were administered at the same dose of P_2O_5, and the differences observed were due to the different phosphorus sources used.

Silvério *et al.*. (2019) have shown that triple superphosphate, multiphosphate, thermophosphate, and Araxá phosphate contributed to the increase in stem diameter and the number of leaves, evidencing the importance of defining the best source to be used in coffee planting.

In general, the sources tested were sufficient to provide phosphorus for plant development; however, the importance in determining the best source in the initial phase of plants is evidenced (Tables 3 and 4). Given the above, it was possible to conclude that the use of RPR was the best option among all the variables studied. This result corroborates the recommendation to use natural phosphate in coffee farming (Guimarães *et al.*, 1999).

Table 5 presents the mean values of the quality parameters of coffee seedlings based on the different phosphorus sources used in the initial development of the plants. High reliability can be observed in the results (measured by CV), since, according to Pimentel-Gomes (2022), values lower than 10% are classified with high precision, and the average can represent the population.

It was possible to organize the RPAR values into two groups, those with higher values for struvite, PT and control treatments. the second group with other sources (Table 5). As phosphorus is intrinsically linked to root development, lower SRR values indicate greater root growth, so the treatments of the second group provided a larger root system and, on the other hand, lower shoot growth. According to Marana *et al*. (2008), results lower than 4.7 are indicative of adequate root system development.

Table 4. Root Dry Mass (RDM), Stem Dry Mass (SDM), Leaf Dry Mass (LDM), and Total Dry Mass (TDM) in coffee plants subjected to different sources of phosphorus. Inconfidentes, MG, 2025.

Treatment	RDM	SDM	LDM	TDM
	---------- g	----------	----------	----------
Struvite	16.17 c	36.59 b	34.97 a	87.73 b
Monoammonium Phosphate	21.05 a	37.49 b	34.86 a	93.40 a
Reactive Natural Phosphate	20.31 a	40.51 a	33.68 a	94.50 a
Simple Superphosphate	17.50 c	37.32 b	31.67 a	86.49 b
Triple Superphosphate	18.47 b	37.13 b	33.40 a	88.99 b
Thermophosphate	16.90 c	38.50 b	33.56 a	88.96 b
Control	14.06 d	33.98 c	28.30 b	76.34 c
Overall mean	17.50	37.32	33.56	88.96
MSD	1.39	1.95	2.26	3.45
p-value	< 0.001	< 0.001	< 0.001	< 0.001
CV	6.02	4.00	5.26	3.00

Means followed by equal letters in the columns did not differ from each other by the Scott-Knott test ($p<0.05$).
MSD = minimum significant difference; F for treatments; CV = coefficient of variation (%).
**significant effect <0.01%; ns = not significant.
Source: authors (2025).

Table 5. Growth and quality parameters of coffee seedlings: shoot root ratio (SRR), plant height and harvest diameter ratio (HDR), and Dickson quality index (DQI) based on different phosphorus sources. Inconfidentes, MG, 2025

Treatment	SRR	HDR	DQI
Struvite	4.45 a	6.09	8.34 c
Monoammonium Phosphate	3.45 b	5.40	10.58 a
Reactive Natural Phosphate	3.66 b	5.40	10.49 a
Simple Superphosphate	3.95 b	5.35	9.30 b
Triple Superphosphate	3.83 b	5.51	9.53 b
Thermophosphate	4.23 a	5.25	9.36 b
Control	4.46 a	5.40	7.77 c
Mean	4.00	5.48	9.33
MSD	0.39	0.52	0.73
p-value	< 0.001	< 0.001	< 0.001
CV	7.55	7.31	6.01

Means followed by equal letters in the columns did not differ from each other by the Scott-Knott test ($p<0.05$).
MSD = minimum significant difference; F for treatments; CV = coefficient of variation (%).
**significant effect <0.01%; ns = not significant.
Source: authors (2025).

Thus, plants with more developed roots have greater tolerance to climatic inclement weather, such as lack of rainfall, because they can explore a greater volume of soil, and these seedlings are also not affected by strong winds due to their better fixation to the ground.

The HDR analysis, depending on the different phosphorus sources, did not result in significant differences between treatments (Table 5). This indicates that there was no effect for this variable for any source used, not impacting the ratio. Therefore, there is uniformity between the treatments, and, according to Rudek (2013), the results are considered acceptable.

In this study, it was possible to observe DQI values (Dickson, Leaf, Hosner 1960) higher than eight, except for control. However, significant differences were observed between the sources, with the highest values observed for MAP and RPR treatments, followed by SSP, TSP, and TP; in turn, struvite and control were not different from each other. According to Marana *et al*. (2008), values greater than 0.2 correspond to adequate plant development. These results are in line with those presented in Tables 3 and 4, in which the use of MAP and RPR sources followed the same trend.

In general, the growth and quality parameters of coffee seedlings provide information that can be applied agronomically, that is, the non-use of phosphorus in planting the seedlings or the use of struvite as a phosphate source are not good options, since it was for these treatments that the highest SRR values were obtained, indicating greater shoot growth and lower root development.

On the other hand, the use of MAP and RPR is the best option to optimize the quality of plants in the field at the initial stage of development. However, practices that precede the definition of the source, such as good sampling, soil correction at the correct time, appropriate soil management, and choice of quality seedlings should also be considered.

Conclusions

Reactive phosphate rock and monoammonium phosphate were the sources that achieved the best Dickson quality index.

Monoammonium phosphate and reactive phosphate rock provided greater growth of the root system and shoot of the plants, offering greater resistance to seedlings in the first months after planting.

For planting coffee seedlings, it is recommend the use of reactive phosphate rock or monoammonium phosphate as a priority.

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