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Enhanced-efficiency fertilizers on the growth of coffee plants under weed *(Bidens Pilosa)* competition stress

Fertilizantes de maior eficiência no crescimento inicial de plantas de café sob o stress de concorrência das plantas daninhas *(Bidens Pilosa)*

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Highlights

The study is important because it brings innovation to the fertilization industry.
Slow-release fertilizers are more efficient for coffee competing with *Bidens pilosa.*
More efficient fertilizers provide greater growth of coffee plants in competition.
Enhanced-efficiency fertilizers improve P use by coffee plants in competition.

Abstract

The interference of weeds in coffee cultivation is one of the factors contributing to losses and impairments in crop growth and productivity. Consequently, it becomes necessary to employ strategies aimed at mitigating this stress and facilitating optimal crop development through enhanced nutritional practices. This study aimed to assess the impact of various sources and modes of release of enhanced-efficiency phosphate fertilizers on the initial growth of *Coffea arabica* L. plants in competition with the weed *Bidens pilosa* in a greenhouse. The experiment was conducted at the Federal University of Vales do Jequitinhonha and Mucuri – Diamantina MG, Brazil, employing a block design in a 4 x 6 factorial arrangement with four replications. The factors corresponded to four levels of *B. pilosa* infestation and six phosphorus sources (Super Single, Conventional, MAP, Granulated Organomineral, Pelleted Organomineral, MAP Coated with Polymer, and a control treatment without fertilization). The findings suggest that under the experimental conditions of this research, the escalating density of weed competition from *B. pilosa* negatively

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impacts the initial growth of coffee plants. However, this effect is dependent on the source of phosphate fertilization. Fertilizers with slow-release phosphate sources are recommended for coffee plantations, as they contribute to reduced weed growth in comparison to coffee plants.
Key words: Coffee. Competition. Fertilization. Growth. Plants.

Resumo

A interferência de plantas daninhas no café é um dos fatores de perdas e danos no crescimento e produtividade da cultura, sendo necessária a utilização de estratégias para minimizar este estresse e viabilizar o crescimento da cultura conciliada a uma nutrição adequada. O objetivo foi avaliar o efeito de diferentes fontes e liberação de fertilizantes fosfatados com maior eficiência no crescimento inicial das plantas *Coffea arabica* L. em competição com a planta daninha *Bidens pilosa* em casa de vegetação. O experimento foi realizado na Universidade Federal dos Vales do Jequitinhonha e Mucuri – Diamantina MG, disposto em blocos aleatórios num esquema fatorial 4 x 6, com quatro repetições, referindo-se a quatro níveis de infestação por *B. pilosa* e seis fontes de fósforo (Super Simples, MAP Convencional, Organomineral Granulado, Organomineral Peletizado, MAP Revestido com polímero e tratamento de controle – sem fertilização). Concluindo que nas condições experimentais da pesquisa o aumento na densidade de competição da *B. pilosa,* causa danos no crescimento inicial do cafeeiro, mas o efeito é dependente da fonte de fertilização fosfatada, sendo indicados fertilizantes com fontes de liberação lenta na plantação de café, porque proporciona menor crescimento da planta daninha em relação às plantas de café.
Palavras-chave: Café. Competição. Fertilização. Crescimento. Plantas.

Introduction

Coffee holds significant economic prominence in Brazil, playing a major role in both the domestic market and international trade through grain exports. The extensive territory and diverse climates in the country have created favorable conditions for significant coffee production, establishing it as the world's foremost producer (Navarro et al., 2021). Despite this, Brazil faces challenges related to low productivity, considering its productive potential. Factors contributing to this issue include aging and depleted crops, biennial production, price fluctuations in the global coffee market, biotic and abiotic stresses, nutritional deficiencies, and management problems such as weed interference (Caixeta et al., 2008).

The initial phase of coffee growth, from seedling transplantation to the second year after planting, is considered the most susceptible to weed interference, especially when weeds are present in the crop's planting row (Ronchi et al., 2007).

Bidens pilosa is widespread virtually throughout Brazil, standing as one of the prominent weeds in both annual and perennial crops year-round. Owing to its adaptability and efficiency in resource utilization provided by its hardiness character (Nogueira, 2019), *B. pilosa* can promote increased nutrient extraction, thereby enhancing its competitive potential with the target crop (Santos & Cury, 2011).

One of the key characteristics contributing to the success of weeds in their environment is their ruderal nature, signifying their adaptation to conditions of substantial soil disturbance (Bridges, 2000), including low fertility and acidity. Various agricultural practices are employed to counteract these soil characteristics, with the application of fertilizers and amendments being the most notable for enhancing crop productivity. Nevertheless, in recent decades, there has been a notable emphasis on the use of highly soluble mineral fertilizers (Corrêa et al., 2016).

The most commonly used phosphate sources in agriculture are those with high solubility, obtained through acid treatment of rocks. However, these sources generally have low agronomic efficiency (Associação Nacional para Difusão de Adubos [ANDA], 2016). The rapid release of phosphates from these sources may lead to adsorption and precipitation of the nutrient by soil components, especially in clayey soils (Lourenzi et al., 2014). To enhance phosphate fertilization efficiency, the market offers technologies involving the slow release of this nutrient, often in the form of organomineral fertilizers coated or encapsulated with synthetic polymers.

In the context of fertilization and plant growth, phosphorus plays a vital role as a nutrient with low mobility in the soil. A plant with a deeper root system may have an advantage in capturing this essential element (Santos & Cury, 2011). The slow release of nutrients not only minimizes soil losses but also aligns nutrient availability with the growth of the commercial crop, facilitating growth and development even in the presence of weeds.

Various technologies and methods for releasing nutrient sources can serve as alternatives under stress conditions in coffee plants, such as weed competition. The objective of this study was to evaluate the impact of different phosphate fertilizer sources on the initial growth of *Coffea arabica* L. plants in competition with Hairy beggarticks (*Bidens pilosa*).

Material and Methods

Experimental conduct and design

The experiment was conducted under greenhouse conditions, employing a randomized block experimental design in a 4 x 6 factorial arrangement with four replications. *Coffea arabica* L. seedlings of the Rubi MG 1192 cultivar were utilized, along with four levels of competition with *Bidens pilosa* (none - coffee plant free of competition; low - 1 plant pot^{-1}; medium - 2 plants pot^{-1}; and high - 4 plants pot^{-1}). These factors were combined with various sources of P_2O_5 (Super Single, Conventional MAP, Granulated Organomineral, Pelleted Organomineral, Coated MAP with polymer, and a control treatment without fertilization), administered at rates equivalent to 100% of mineral phosphorus fertilization for coffee plantation (Guimarães et al., 1999).

Coffee seedlings, at the stage of five pairs of definitive leaves, were transplanted into polyethylene pots with an 11 L capacity, filled with samples of eutric Red Yellow Latosol (Oxisol) (Table 1), classified according to Empresa Brasileira de Pesquisa Agropecuária [EMBRAPA] (2006). Fertilization at 30 and 60 days after transplanting (DAT) of coffee followed the protocol outlined by Guimarães et al. (1999), observing the predetermined treatments and phosphorus rates.

Table 1
Chemical and physical attributes of the Eutrophic Red Yellow Latosol with a clayey texture used in coffee transplanting

pH	P	K	Al	Ca	Mg	H+Al	SB	t	T	V	M	OM
Water	--- mg dm^{-3} ---		-------------------- cmol$_c$ dm^{-3} --------------------							%	%	dag kg^{-1}
5,97	32,73	262,36	0,02	5,03	2,38	2,81	8,08	8,10	10,89	74	0	3,36
						Textural Analysis						
		Sand				Silt			Clay			
						-- dag Kg^{-1} --						
		25				24			51			

Analyzes carried out at the Laboratory of Physical and Chemical Analysis of Soil, Department of Agronomy, Federal University of Vales do Jequitinhonha e Mucuri. pH water: Water-soil ratio 1:2,5. P e K: Extractor Mehlich-1. Ca, Mg e Al: Extractor KCl 1 mol L^{-1}. SB: sum of bases. T: Cation exchange capacity at pH 7.0. m: Aluminum saturation. V: Base saturation. OM - Organic matter content determined by the Walkey & Black method.

Hairy beggarticks (*Bidens pilosa*) seeds, sourced from the Olericulture sector of UFVJM-Diamantina MG, Brazil, were sown 30 days after transplanting the coffee plants. The target weed density for each infestation level was established through thinning after weed emergence, when they exhibited two pairs of definitive leaves, with four levels of infestation (none, low, medium, and high) determined. Cultivation treatments were carried out manually, and daily irrigation to the pots continued until the conclusion of the experiment, with hand weeding managing other weed species.

Experimental evaluations

On the day of *B. pilosa* sowing and 90 days after weed emergence, assessments of coffee plant height and leaf area were conducted. Height measurements were obtained using a ruler to measure the distance between the stem and the apex of the seedlings, while leaf area was estimated non-destructively using the equation LA = 0.6626 x (LL x LW) 1.0116 (Antunes et al., 2008), where LL and LW represent leaf length and width, respectively. Initial and final growth measurements were utilized to calculate the increments in height, leaf area, and stem diameter of the coffee plants.

Subsequently, at the end of the 90-day coexistence period, coffee plants and weeds were collected, separated into leaves, stems, and roots, and dried in a forced air circulation oven at 65 °C until reaching constant weight to determine the dry matter content.

Following drying, plant material (coffee leaves) and (weed shoots) were ground in a Wiley mill and stored in bags for subsequent determination of phosphorus content in both the coffee plant and *B. pilosa.* The samples underwent nitric digestion (HNO_3) in a closed system using a microwave oven, following the methodology outlined by the Brazilian Agricultural Research Corporation, EMBRAPA (2009), with phosphorus content determined by colorimetry (Malavolta et al., 1997).

Data were subjected to analysis of variance using the F test, and when significant, mean comparisons were conducted using the Scott-Knott test at a 5% probability level.

Results and Discussion

The different fertilization treatments had a significant effect on weed density, and their interaction significantly influenced the plant height, leaf area, shoot dry matter, root system dry matter, and foliar phosphorus content of coffee seedlings. Additionally, significant interaction effects between fertilization strategies and competition densities were observed on phosphorus content in the shoots of *B. pilosa.* Comparing the different fertilization treatments regardless of competition density, statistical significance was detected for all coffee and *B. pilosa* variables.

Coffee growth experienced a reduction with an increase in *B. pilosa* density, dependent on the sources and methods of phosphorus release employed. Regarding coffee plant height without the presence of *B. pilosa,* statistical differences were only observed in the Super Single fertilizer treatment compared to other phosphate fertilizers. In competitions at 90 days of coexistence with low (1 plant pot^{-1}) and medium (2 plants pot^{-1}) weed densities, the Pelleted Organomineral and Coated MAP fertilization treatments exhibited greater increases in coffee plant height. At high density (4 plants pot^{-1}) of competition, the Pelleted Organomineral fertilizer demonstrated a significant height increase in coffee plants, showcasing satisfactory results considering the nutrient protection technology, even in the presence of competition (Table 2).

Plant height serves as an indicator of initial growth conditions and seedling survival capability in the field. However, under weed competition stress, growth can be altered. The reduction in coffee height is directly influenced by competition with *B. pilosa,* given its greater efficiency in utilizing water, light, and nutrients. *Bidens pilosa,* known for its robust root system, is recognized as a significant agricultural weed (Santos & Cury, 2011). The higher initial growth of the weed contributes to decreased growth in coffee seedlings (Ronchi & Silva, 2006). An escalation in *B. pilosa* competition density intensifies the substantial reduction in coffee plant height (Ronchi, 2002).

Table 2
Height increase of young coffee plants (*Coffea arabica* L.) in competition with densities *Bidens pilosa* (0, 1, 2 e 4 plants per pot), after 90 days of coexistence under differentiated release phosphate fertilizers

Fertilizations	Height increment (cm)			
	Bidens pilosa density (plants pot^{-1})			
	0	1	2	4
Control	43,75 cA	34,75 cB	29,82 eC	21,75 eD
Super Simple	47,80 bA	35,47 cB	33,5 dB	27,77 dC
Conventional MAP	50,42 aA	39,82 bB	35,77 cC	29,12 dD
Granulated OM	50,65 aA	40,72 bB	40,1 bB	34,55 cC
Pelleted OM	51,12 aA	49,45 aA	47,3 aB	41,82 aC
Coated MAP	50,80 aA	47,87 aB	46,3 aB	39,32 bC
CV (%)	3,88			

Control: absence of fertilization; Super Simple: single superphophate, Conventional MAP: Monoammonium phosphate, Granulated OM: Granulated organomineral - MAP, Pelleted OM: pelleted organomineral - MAP, Coated MAP: Polymer coated monoammonium phosphate. Means followed by the same lowercase letter in the column and uppercase in the row do not differ from each other by the Scott-Knott test at 5% probability.

The growth of a plant depends on the levels of each essential nutrient, with phosphorus deficiency being common in tropical, highly weathered soils, even with high total P content, which makes it one of the nutrients that most limits plant development (Sanz-Saez et al., 2017). Conventional fertilizers are more susceptible to environmental changes due to their rapid nutrient release into the soil solution. Conversely, polymer-coated fertilizers are protected, exhibiting a decreased release rate (Zavaschi, 2010). The maximum height of coffee seedlings was 23.7% higher when polymer-coated triple superphosphate was applied compared to the uncoated version (Chagas et al., 2016). The synchronism between the slow release of phosphorus and the plant's requirement can provide satisfactory growth for coffee plants despite weed interference in the field.

In the field, factors such as nutrient adsorption to clay, low fertility, inadequate fertilization, or even weeds can influence phosphate nutrition for coffee seedlings. Coating phosphate fertilizer granules with polymers serves as an alternative to minimize losses and reduce the activity of Fe and Al, preventing the formation of less soluble minerals due to the precipitation of these cations with phosphorus (Chagas et al., 2016).

The leaf area of coffee seedlings decreased with an increase in *B. pilosa* density, showing a significant reduction in all fertilization treatments across competition levels. In the absence of competition, phosphate-fertilized treatments exhibited a larger leaf area compared to the control treatment, demonstrating the importance of fertilization and the crop's response to phosphorus in increasing leaf area. For low and medium *B. pilosa* competition densities, the fertilizers with nutrient protection and a slow-release method, Pelleted Organomineral and Coated MAP, produced superior results in increasing leaf area. Even in the presence of competition, a larger leaf area can benefit coffee plant growth and photosynthetic assimilate production. For high density, Pelleted Organomineral demonstrated efficiency and satisfactory results in coffee plants under competition, suggesting that slow release enhances fertilization efficiency under competition, with results for the foliar area of conventional fast-release fertilizers, Super Single and Conventional MAP, being inferior (Table 3).

Table 3

Increase in leaf area of young coffee plants (*Coffea arabica* L.) in competition with *Bidens pilosa* densities (0, 1, 2 and 4 plants per pot), after 90 days of coexistence under phosphate fertilization of differentiated release

Fertilizations	Leaf Area Increment (cm²)			
	Bidens pilosa density (plants pot^{-1})			
	0	1	2	4
Control	4571,79 bA	2594,93 eB	1524,99 dC	1452,99 eC
Super Simple	4862,94 aA	3190,90 dB	2092,32 cC	1997,30 dC
Conventional MAP	5084,90 aA	3600,61 cB	2160,51 cC	2028,06 dC
Granulated OM	5008,89 aA	4516,96 bB	3912,45 bC	2598,69 cD
Pelleted OM	5073,32 aA	4847,97 aA	4547,23 aB	3787,07 aC
Coated MAP	5071,52 aA	4834,27 aA	4272,41 aB	3405,90 bC
CV (%)	6,14			

Control: absence of fertilization; Super Simple: single superphophate, Conventional MAP: Monoammonium phosphate, Granulated OM: Granulated organomineral - MAP, Pelleted OM: pelleted organomineral - MAP, Coated MAP: Polymer coated monoammonium phosphate. Means followed by the same lowercase letter in the column and uppercase in the row do not differ from each other by the Scott-Knott test at 5% probability.

Bidens pilosa has substantial potential for competition with coffee plants, even at low densities, and can reduce the growth of coffee seedlings in the planting row, affecting the formation and reproductive life of the crop (Ronchi, 2002). Phosphate fertilization promotes a greater leaf area in coffee plants, emphasizing the importance of phosphorus in the initial growth of the crop under weed interference conditions, showcasing responsiveness to this nutrient application. Aligning the needs of the crop with fertilizer sources that promote the slow release of phosphorus provides satisfactory development for coffee plants.

The coating of triple superphosphate with polymer potentiated the effect of this fertilizer compared to conventional superphosphate, resulting in a greater leaf area for the coffee plant (Chagas et al., 2016). Coffee plants exhibited a smaller increase in leaf area in the presence of *Mucuna aterrima* and *Urochloa plantaginea* (Fialho et al., 2011) and *Commelina* sp. (Dias et al., 2005), being affected by the plant density present. This indicates that, in addition to phosphate fertilization, the presence of weeds can interfere with this variable. Weed competition causes significant and direct damage to the coffee crop. Minimizing this damage through the slow availability of nutrients is an alternative to enhance coffee plant growth.

Leaf area is the most important morphological trait influencing the ability of plants to cover the soil and, importantly, optimize photosynthetic radiation utilization (Fleck et al., 2009), leading to increased production of photoassimilates and subsequent allocation to other plant organs (Ferrari et al., 2015). Enhanced phosphorus availability in the soil can afford coffee plants the ability to utilize the nutrient adequately even under competitive conditions, resulting in a larger leaf area. Therefore, the dynamics of phosphorus assumes a critical role in plant production, and this tends to be compromised in nutrient-deficient systems, necessitating widespread fertilizer adoption (Aleixo et al., 2017). Proper phosphate fertilization management, with an emphasis on the chosen source and nutrient protection due to solubility and reactivity characteristics provided by the different capacities of the soil to adsorb the element, can contribute to increased phosphorus availability (Tiritan et al., 2010).

Coffee plants subjected to higher densities of *B. pilosa* exhibited reduced shoot dry matter, with a significant decrease in all fertilization treatments. When comparing different fertilization methods under no competition conditions, there were no statistically significant differences in shoot dry matter. In low-density competition with *B. pilosa,* phosphate sources like Granulated Organomineral, Pelleted Organomineral, and Coated MAP resulted in higher shoot dry matter, showcasing efficiency in phosphorus supply to the crop despite weed interference. At higher competition densities with two and four weeds per pot, coffee plants with phosphorus supplied through slow fertilization (Pelleted Organomineral and Coated MAP) exhibited increased shoot dry matter compared to other fertilization treatments (Table 4).

Table 4
Dry matter of shoot of young coffee plants (*Coffea arabica* L.) in competition with *Bidens pilosa* densities (0, 1, 2 and 4 plants per pot), after 90 days of coexistence under phosphate fertilization of differentiated release

Fertilizations	Dry Matter of Aerial Part of Coffee Plants (g)			
	Bidens pilosa density (plants pot^{-1})			
	0	1	2	4
Control	29,71 aA	21,30 bB	17,00 bB	16,34 bB
Super Simple	33,73 aA	21,12 bB	16,41 bB	16,00 bB
Conventional MAP	36,56 aA	22,89 bB	17,16 bC	16,29 bC
Granulated OM	32,37 aA	28,09 aA	21,41 bB	18,42 bB
Pelleted OM	36,25 aA	31,56 aB	28,47 aB	27,43 aB
Coated MAP	36,13 aA	29,51 aB	26,15 aB	25,71 aB
CV (%)	14,58			

Control: absence of fertilization; Super Simple: single superphophate, Conventional MAP: Monoammonium phosphate, Granulated OM: Granulated organomineral - MAP, Pelleted OM: pelleted organomineral - MAP, Coated MAP: Polymer coated monoammonium phosphate. Means followed by the same lowercase letter in the column and uppercase in the row do not differ from each other by the Scott-Knott test at 5% probability.

The measurement of shoot dry matter is important for assessing plant growth and development, as it is directly linked to growth and leaf area (Peixoto et al., 2011), i.e., the area available for intercepting light energy and the photosynthetic process (Lima et al., 2012). As observed in height and leaf area variables, fertilizers with nutrient protection allow a greater utilization of phosphorus for coffee plants through slow release, correlating with the accumulation of dry matter in the shoots.

Under competitive stress conditions, fertilizers like Pelleted Organomineral reduced the competition from *B. pilosa*, resulting in higher growth and shoot dry matter values for coffee plants, even at high weed competition levels. This suggests the potential advantages and alternatives of using protected fertilizers as an efficient phosphorus source for commercial crops under competitive stress, addressing the significant losses caused by weeds in coffee plants, as indicated by Ronchi (2002). Evaluating various weed species, these authors concluded that *B. pilosa* was the only species whose increased density caused a reduction in overall coffee plant growth and negatively correlated with growth and nutritional characteristics.

Competition for soil resources and solar radiation is interdependent, with both the plant's root system and shoots engaging in rapid exchanges to allocate photoassimilates (Cahill, 2002). Thus, providing an optimal growth environment conditions the crop for a satisfactory response to competition, primarily related to nutrition (Cahill, 2002).

Due to the high mobility of phosphorus in plants, deficiency symptoms appear first on older leaves, from which the element migrates to younger ones (Malavolta, 2006). Despite various forms of P in the soil, only a small proportion is immediately available to plants (Richardson et al., 2009), requiring widespread fertilizer adoption (Aleixo et al., 2017). Protected fertilizers, as demonstrated in this experiment, are important in providing greater accumulation in shoot dry matter, with values of 27.43 g in Pelleted Organomineral and 25.71 g in Coated MAP at the highest density (4 plants pot^{-1}) of competition with *B. pilosa.* Slow-release fertilizers delay the initial nutrient availability through different mechanisms, extending their availability to crops and optimizing plant uptake, thereby reducing losses (Zavaschi, 2010).

The dry matter of the root system is directly influenced by soil nutrition conditions, with phosphorus playing a major role in initial root growth. The intense competition of coffee seedlings with *B. pilosa* caused a significant reduction in the coffee root system, with smaller accumulations as competition densities increased.

Different fertilization treatments, under no competition with weeds, highlighted the importance of phosphate fertilization in establishing the coffee root system, with higher means that were statistically different from those of control. At a density of one plant per pot, sources like Conventional MAP, Granulated Organomineral, Pelleted Organomineral, and Coated MAP fertilizers provided the highest means. With increased weed competition at a density of two plants per pot, sources with organic matter or nutrient protection (Granulated Organomineral, Pelleted Organomineral, and Coated MAP) provided greater accumulations of root system dry matter. At a density of four weeds per pot, representing the highest competition level, the negative effects of interference were consistent across all fertilization methods, demonstrating the detrimental impact of *B. pilosa* on coffee plant root growth (Table 5).

A relevant factor is the phosphorus-to-root dry matter ratio. Most phosphorus in the soil moves to the roots through diffusion, and since this movement is constrained, diffusion is generally considered a limiting factor in phosphorus absorption by plants (Grant et al., 2001). Phosphorus uptake by plants is directly proportional to root density. Thus, increasing the surface area of the root mass enhances the plant's ability to access and absorb phosphorus from the soil. Phosphate sources with organominerals and/or nutrient protection, particularly under conditions of slow availability, stand out over conventional sources. This distinction is observed in the variable of root dry matter accumulation. The presence of organic matter in the fertilizer not only results in slower nutrient availability but also influences soil properties, especially its structure and water storage capacity (Cavalcante et al., 2009).

Under conditions of stress caused by competition with *B. pilosa,* coffee loses its ability to exploit available resources. This weed is among the most aggressive in water and nutrient utilization from the soil in major agricultural crops in Brazil (Santos & Cury, 2011). The competitive capacity of *B. pilosa* is attributed to its extensive root system volume and high growth rate (Craine, 2006). Coffee plants that coexist with weeds after 60 DAT displayed lower accumulation of root dry matter across all densities (Fialho et al., 2010).

Table 5

Dry matter of the root system of young coffee plants (*Coffea arabica* L.) in competition with *Bidens pilosa* densities (0, 1, 2 and 4 plants per pot), after 90 days of coexistence under phosphate fertilization of differentiated release

Fertilizations	Dry Matter of the Root System of Coffee Plants (g)			
	Bidens pilosa density (plants pot^{-1})			
	0	1	2	4
Control	10,85 bA	6,25 bB	4,93 bB	4,26 aB
Super simple	15,65 aA	8,23 bB	5,48 bC	4,96 aC
Conventional MAP	14,26 aA	10,70 aB	6,36 bC	4,84 aC
Granulated OM	14,35 aA	12,04 aB	10,16 aB	6,02 aC
Pelleted OM	14,78 aA	12,31 aA	9,12 aB	6,33 aB
Coated MAP	15,20 aA	11,18 aB	10,10 aB	6,19 aC
CV (%)	22,55			

Control: absence of fertilization; Super Simple: single superphophate, Conventional MAP: Monoammonium phosphate, Granulated Organomineral: Granulated organomineral - MAP, Pelleted Organomineral: pelleted organomineral - MAP, Coated MAP: Polymer coated monoammonium phosphate. Means followed by the same lowercase letter in the column and uppercase in the row do not differ from each other by the Scott-Knott test at 5% probability.

Various factors in both the developmental environment and the root system itself influence the development and competitive capacity of each plant. The significance of these factors depends on the growing medium, water availability, nutrients, toxicity, deficiencies, soil structure, and diseases (Dunbadin, 2007). Competition with *B. pilosa* and the use of fertilizer sources with nutrient protection and slow release enhance the growth and establishment of the coffee plant's root system. This approach makes phosphorus available even under interference conditions, improving adaptation to stress situations. The importance of phosphorus for plant survival causes it to develop adaptive mechanisms to enhance access to phosphorus stores (Grant et al., 2001). This is a factor of paramount importance, as the element is linked to numerous metabolic processes, including ATP, DNA, and enzyme constitution. The primary role of phosphorus in plant physiology is to provide energy for biosynthetic reactions and plant metabolism (Fabrice et al., 2015).

The foliar phosphorus content of coffee plants is significantly affected by increasing weed densities. Competition-free coffee plants exhibited higher phosphorus levels in leaves than the control across all phosphate sources. In the early growth stage, phosphorus increases the root system of newly planted plants. As weed density rises, coffee plants exhibit a negative response, resulting in reduced foliar phosphorus levels, particularly in the most soluble sources. Nonetheless, the Granulated Organomineral, Pelleted Organomineral, and Coated MAP show higher means in plants at different levels of competition with *B. pilosa* (Table 6).

Among other factors, plant density plays a key role in competition. The greater the weed density, the more individuals compete for the same resources, intensifying competition with the crop of interest (Jakelaitis et al., 2006). The notable reduction in species growth, both in intra- and interspecific competition, results from competition for space and resources such as phosphorus, among plants occupying the same location for a certain period (Guilherme, 2000). The relative content of macro- and micronutrients in the shoots of coffee plants is significantly reduced due to *B. pilosa* interference, further decreasing with increasing weed density. The relative phosphorus content in coffee drops from 72% at a density of one plant per pot to 39% at a density of five plants per pot (Ronchi et al., 2003).

Table 6
Foliar phosphorus content of young coffee plants (*Coffea arabica* L.) in competition with *Bidens pilosa* densities (0, 1, 2 and 4 plants per pot), after 90 days of coexistence under phosphate fertilization of differentiated release

Fertilizations	Foliar Phosphorus Content in Coffee Plants (g kg^{-1})			
	Bidens pilosa density (plants pot^{-1})			
	0	1	2	4
Control	1,42 bA	1,37 bA	1,03 bB	0,82 cB
Super Simple	2,11 aA	1,44 bB	1,29 bB	0,83 cC
Conventional MAP	2,08 aA	1,36 bB	1,32 bB	1,20 bB
Granuleted OM	2,24 aA	1,85 aB	1,83 aB	1,58 aB
Pelleted OM	2,35 aA	2,08 aA	1,84 aB	1,49 aC
Coated MAP	2,15 aA	1,95 aA	1,80 aB	1,58 aB
CV (%)	12,6			

Control: absence of fertilization; Super Simple: single superphophate, Conventional MAP: Monoammonium phosphate, Granulated OM: organomineral Farelado - MAP, Pelleted OM: pelleted organomineral - MAP, Coated MAP: Polymer coated monoammonium phosphate. Means followed by the same lowercase letter in the column and uppercase in the row do not differ from each other by the Scott-Knott test at 5% probability.

Phosphorus is crucial in the young phase of the crop, significantly increasing the root system of newly planted plants (Malavolta, 2006). Critical ranges of phosphorus content in coffee leaves in the first year after planting are from 1.14 to 1.21 g. kg^{-1} (Clemente et al., 2008). Increasing *B. pilosa* density decreases foliar phosphorus content. However, weed competition combined with the addition of organomineral fertilizers and/or slower-release fertilizers increased coffee plant phosphorus content compared to other fertilizers. This is important for potential plant adaptation to stress conditions, with better utilization of protected fertilization. The application of polymer-coated triple superphosphate resulted in a 49.4% higher accumulation of phosphorus in coffee leaves compared to uncoated fertilizer (Chagas et al., 2016). Notably, the use of protected fertilizers is more prevalent, as rapid release in conventional fertilizers may promote nutrient adsorption and precipitation by soil components, particularly pronounced in clayey soils (Lourenzi et al., 2014). Reis et al. (2013) evaluated the nutritional status and phosphorus fractions in the coffee plant to relate it to crop productivity and concluded that the phosphorus reserve in coffee leaves ensures increased metabolic activity in plants, allowing for greater productivity.

In addition to competition for space with the coffee plant, intraspecific competition also occurs between individuals of the same weed species, especially at higher densities (Ronchi et al., 2007). The use of protected fertilizers can minimize weeds' competitive advantage over coffee plant growth.

At present, the indiscriminate use of fertilizers promotes weed growth in agricultural areas. Thus, the proper application of essential nutrients, besides being economically and environmentally sound, is a necessary cultivation practice for maintaining infestation balance (Santos & Cury, 2011).

The phosphorus content of *B. pilosa* decreases with increasing competition density. The competition-free weed exhibits higher phosphorus content in Granulated Organomineral, Super Single, and Conventional MAP fertilizers. Comparing fertilization treatments with increasing densities, it is statistically observed that the highest means of *B. pilosa's* phosphorus content occur with Super Single and Conventional MAP fertilizers at a competition density of one plant per pot, Super Single fertilizer at a competition density of two plants per pot, and Super Single, Conventional MAP, and Granulated Organomineral fertilizers at the highest competition density of four plants per pot. These results demonstrate that fertilizers with nutrient protection technology result in lower plant usage. However, when compared to the phosphorus content of the coffee plant, Coated MAP and Pelleted Organomineral fertilizers yield higher means in coffee leaves. This suggests that the slow release of phosphorus enhances the coffee plant by preventing immediate soil nutrient absorption by weeds (Table 7).

Table 7
Phosphorus content of a *Bidens pilosa* weed in competition with densities of (0, 1, 2 and 4 plants per pot), after 90 days of coexistence under phosphate fertilization of differentiated release

Fertilizations	Foliar Phosphorus Content of *Bidens pilosa* (g kg^{-1})			
	Bidens pilosa density (plants pot^{-1})			
	0	1	2	4
Control	4,04 bA	4,22 bB	3,64 cC	2,62 bD
Super simple	5,10 aA	4,79 aA	4,36 aB	4,07 aB
Conventional MAP	5,02 aA	4,91 aA	3,89 bB	3,79 aB
Granulated OM	5,10 aA	4,41 bB	3,97 bC	3,88 Ac
Pelleted OM	4,05 bA	3,77 cB	3,50 cB	2,93 bC
Coated MAP	3,94 bA	3,61 cB	3,34 cB	2,75 bC
CV (%)	6,75			

Control: absence of fertilization; Super Simple: single superphophate, Conventional MAP: Monoammonium phosphate, Granulated OM: Granulated organomineral - MAP, Pelleted OM: pelleted Organomineral - MAP, Coated MAP: Polymer coated monoammonium phosphate. Means followed by the same lowercase letter in the column and uppercase in the row do not differ from each other by the Scott-Knott test at 5% probability.

The species *B. pilosa* can extract a significant amount of nutrients, and the greater the extraction, the higher the competitive potential with the crop of interest (Santos & Cury, 2011). Ronchi et al. (2003) observed in competition studies that the relative macro- and micronutrient content in *B. pilosa* was extremely high. At a density of only one plant per pot, the accumulation of phosphorus in *B. pilosa* exceeded the value observed in coffee plants grown without *B. pilosa* interference. Fialho et al. (2012) found similar results in leaves of competition-free coffee plants, with a phosphorus concentration 19.5% higher than that of coffee plants subjected to a density of six weeds per pot, regardless of the competing species.

As phosphorus is considered a nutrient with low mobility in the soil, plants with a larger root system have advantages in capturing this element (Santos & Cury, 2011). In the present experiment, the phosphorus absorption capacity by *B. pilosa* is greater than that of coffee plants. However, regardless of competition density, the coffee plant's capacity to absorb phosphorus in the face of competition is greater with the presence of slow-release nutrients, either through fertilizer with polymer protection technology or organomineral pelleting. This is important, as phosphorus is essential for plant growth, having a major function in plant cell compounds, respiration, and photosynthesis (Taiz et al., 2017). In conditions of weed interference, balanced competition can benefit commercial crops, such as coffee, because competition for soil resources and solar radiation is interdependent, and both the root system and the shoots of the plants undergo rapid exchanges. Concerning the allocation of photoassimilates, when one fraction is more required to face the competition (Cahill, 2002), the trend and the new technology of sources of slow-release protected fertilizers, as observed in the results, allow for a balance of competition for nutrients between the commercial crop and weeds.

Conclusions

Competition with the weed species *Bidens pilosa* has a negative impact on the initial growth and foliar phosphorus content of coffee plants (*Coffea arabica* L.). However, under greenhouse conditions, this effect is dependent on phosphate fertilization. The use of more efficient phosphate fertilizers, such as organomineral technology and polymer-coated MAP, provides coffee plants with balance in the presence of intense competition from *Bidens pilosa.* This is achieved by supplying a slow release of nutrients according to the growth and requirements of the plant. This factor proves crucial in the face of competition, field-related stresses, and the pursuit of quality fertilization.

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