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Productive characteristics, nutrition and agronomic efficiency of polymer-coated MAP in lettuce crops[1]

Características produtivas, nutrição e eficiência agronômica do MAP revestido com polímeros em cultivos de alface

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ABSTRACT - In contrast to enhanced-efficiency nitrogen fertilisers, principally urea, phosphate fertilisers have been little studied and the available information is limited. The aim of this work therefore was to evaluate the productive and nutritional characteristics and the agronomic efficiency of a polymer-coated MAP fertilizer on two subsequent lettuce crops. The experiment was carried out in a greenhouse, in pots with a capacity of 4 kg, filled with a dystrophic yellow Latosol of a clayey texture. The experimental design was completely randomised and the treatments arranged in a 2 x 5 factorial scheme: two sources of phosphorus (P) (MAP and polymer-coated MAP), applied to the plots in five dosages (0, 100, 200, 400, 800 mg P_2O_5 kg^{-1}) with three replications. The results showed that the polymer-coated MAP increased the efficiency of the phosphate fertilizer in both lettuce crops, improving utilisation of the residual phosphorus. The agronomic efficiency of fertilization decreases with the increases in applied phosphorus. The production and nutritional characteristics of the lettuce were influenced by the levels of P_2O_5 and the use of MAP with polymers. Higher values for dry and fresh weight and for the accumulation of P in the first crop occurred with the use of polymer-coated MAP at dosages of 506.9, 450.1 and 522.8 mg kg^{-1} P_2O_5.

Key words: Phosphate fertilizer. Residual effect. *Lactuca sativa* L.

RESUMO - Contrariamente aos fertilizantes nitrogenados de eficiência aumentada, principalmente a ureia, os fertilizantes fosfatados foram pouco estudados e as informações disponíveis são limitadas. Dessa forma, objetivou-se com o presente trabalho avaliar as características produtivas, nutricionais e a eficiência agronômica da adubação fosfatada com MAP revestido com polímeros em dois cultivos subsequentes de alface. Foi conduzido um experimento em casa de vegetação em vasos com capacidade para 4 kg de solo preenchido com um Latossolo Vermelho distrófico de textura argilosa. O delineamento experimental foi inteiramente casualizado e os tratamentos distribuídos em arranjo fatorial 2 x 5: duas fontes de fósforo (P) (MAP e MAP revestido com polímeros) aplicadas nas parcelas em cinco doses (0; 100; 200; 400; 800 mg P_2O_5 kg^{-1}), com três repetições. Os resultados mostraram que o MAP revestido com polímeros promoveu maior eficiência da adubação fosfatada nos dois cultivos da alface, melhorando o aproveitamento do fósforo residual. A eficiência agronômica da adubação diminui com o aumento na quantidade de fósforo aplicada. As características produtivas e nutricionais da alface foram influenciadas pelas doses de P_2O_5 e com a utilização do MAP + polímeros. A maior massa seca e fresca e acúmulo de P no primeiro cultivo ocorreram com a utilização do MAP revestido por polímeros nas doses de 506,9; 450,1; 522,8 mg kg^{-1} de P_2O_5.

Palavras-chave: Fertilizante fosfatado. Efeito residual. *Lactuca sativa* L.

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INTRODUÇÃO

Lettuce is the main leaf vegetable consumed both in Brazil (OTTO *et al*., 2010) and in the world (SEDIYAMA *et al*., 2009). Among the chemical elements which are essential for nutrition in the lettuce, phosphorus (P) deserves attention due to its effects on productivity (BERTOSSI *et al.*, 2013; JOHNSTONE *et al.*, 2005; KANO; CARDOSO; VILLAS BOAS, 2012; MOTA et al., 2003).

A large part of Brazilian soils are characterised by a high capacity for P adsorption and the low availability of this nutrient in solution (LEITE *et al*., 2009); the low availability of this nutrient occurring even in fertilised soils (OLIVEIRA *et al*., 2004).

The low usage of P from the soil and from fertilizers is also the result of unwanted reactions of the element with such cations as Al and Fe in acid soils of regions with a tropical climate. Some researchers have found various values for the agronomic efficiency of P: 1.2 to 3.4% (DORAHY *et al*., 2008), 17% (TAKASHI; ANWAR, 2007), 0 to 30% (MURPHY; SANDERS, 2007).

There are several strategies for increasing the efficiency of fertilizers, and among them can be highlighted the use of enhanced-efficiency fertilizers, also known as slow-release, controlled or stabilised fertilizers. The global fertilizer industry faces an ongoing challenge to improve the efficiency of its products. This is done by generating technologies which can be incorporated into existing fertilizers in order to increase nutrient usage (TRENKEL, 2010).

According to the AAPFCO (1997) (Association of American Plant Food Control Officials), slow-release and controlled-release fertilizers are those containing nutrients in a form that: a) delays their availability for absorption and use by the plants after application, or b) whose availability to the plants is greater than that seen for “fertilizers with rapid nutrient availability”. In the official legislation of Brazil, there is no definition or differentiation of slow-release and controlled-release fertilizers. However, Vitti and Heirinchs (2007) present definitions which classify these types of fertilizers as:

a) Slow-release fertilizers: products having the property of being dissolved more slowly in the soil, generally achieved by changes in the structure of the chemical compounds, or by coating the fertilizer with materials of low permeability;

b) Controlled-release fertilizers: fertilizers which incorporate products that control the changes in the nutrient which take place in the soil: as the root system does not immediately absorb the amount of nutrients required by the plant, the rapid availability of nutrients seen in conventional fertilizers results in losses since there is no time for the roots to carry out absorption of the nutrient. As a result, the phosphate for example, is subject to reactions with Fe and Al, and the nitrate is liable to leaching. The lower speed in supplying nutrients, seen in slow-release fertilizers, allows the plant to absorb nutrients from these fertilizers as they become available.

Unlike enhanced-efficiency nitrogen fertilizers, phosphate fertilizers have been little studied, and the available information is limited for tropical conditions (DU; ZHOU; SHAVIV, 2006; GAZOLA *et al*., 2013; PAULY; MAHLI; NYBORG, 2002; SILVA *et al*., 2012).

To this effect, an experiment was carried out in a greenhouse to evaluate the productive and nutritional characteristics and the agronomic efficiency of phosphate fertilization in two lettuce crops using MAP coated with polymers.

MATERIAL AND METHODS

An experiment was conducted in a greenhouse of the Department of Soil Science at the Federal University of Lavras, in the state of Minas Gerais, Brazil, from November 2012 to March 2013. Samples of a Red Latosol were collected from the 0-20 cm layer. The collected soil was subsequently air dried and any clumps removed. The soil was then passed through a four-millimetre sieve, homogenised and placed into pots. At the same time, soil samples were collected which were used for the chemical and physical characterisation of the soil in the pots (Table 1).

Table 1 - Chemical attributes[(1)] and texture[(2)] of the soil used in the study

Chemical attributes [(1)]																	
pHwater	P	K^+	S	Zn	Cu	M	B	Fe	Ca^{2+}	Mg^{2+}	Al^{3+}	(H+Al)	t	T	m	V	M.O	P-rem
	mg dm^{-3}								cmol$_c$ dm^{-3}						%		mg L^{-1}
5.0	0.8	8.0	13.1	0.5	2.2	3.9	0.04	25.1	0.4	0.1	0.0	2.1	0.5	2.6	0	20	1.5	2.3

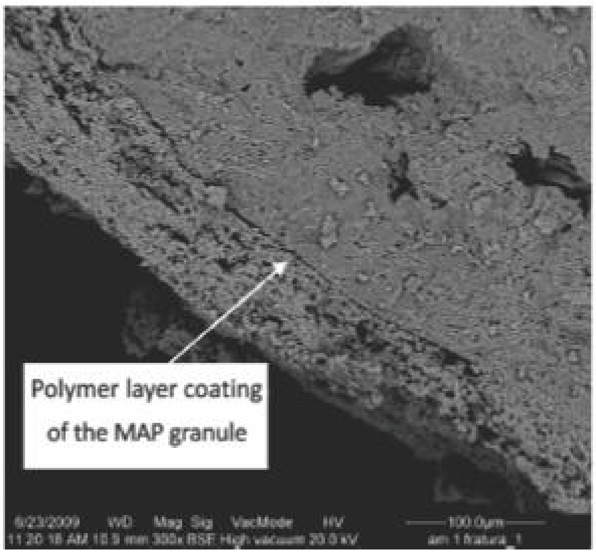
Texture [(2)]		
Sand	Silt	Clay
%		
19	14	67

The pH was determined in water, for a soil to water ratio of 1:2.5; H+Al by the $Ca(OAc)_2$ method at a concentration of 0.5 mol L^{-1} at a pH of 7.0; Ca^{2+}, Mg^{2+} and Al^{3+} were extracted with 1 mol L^{-1} KCl and determined by titration; P and K were extracted by Mehlich-1 and analysed by colorimetry (P) and flame photometry (K); organic carbon was determined by the Walkley-Black method (oxidation with potassium dichromate); Zn, Mn and Cu were extracted by Mehlich-1 and determined by atomic absorption spectrophotometry. Values for effective CEC (t), CEC at a pH of 7.0 (T), percent base saturation (V%) and percent aluminium saturation (m) were obtained indirectly, using the values for potential acidity, exchangeable bases and exchangeable aluminium (CFSEMG, 1999).

The experimental design was completely randomised and the treatments distributed in a 2 x 5 factorial scheme: monoammonium phosphate (MAP), and MAP coated with polymers applied at five levels of phosphorus (0, 100, 200, 400, 800 mg P_2O_5 kg^{-1}), with three replications. Each experimental lot consisted of one pot filled with 4 kg of soil in which three plants were grown.

The product used to coat the MAP granules employed in this study (Figure 1) is composed of soluble anionic polymers, 93.7% biodegradable (CETESB, 1990; OECD, 1992), which reduce the activity of Fe and Al. Such a reduction in activity results in less fixation of phosphorus in the soil, increasing its availability to the plants. The polymer also has the purpose of improving the physical and chemical properties of fertilizers, such as increased hardness, reduced free acidity, reduced hygroscopicity and reduced powder levels (REIS JUNIOR; SILVA, 2013).

Figure 1 - Scanning electron microscope (SEM) image of polymer-coated MAP granules



Liming was carried out to raise the base saturation to 60%; the limestone used (PRNT = 100%), formed from the mixture of calcium carbonate and magnesium carbonate p.a., at a Ca:Mg equivalent of 4:1. Fertilization, when sowing and topdressing, was carried out for each crop using p.a. reagents, as proposed by Malavolta (1980).

After the limestone and fertilizers were added to the pots, three seedlings of lettuce cv. Solaris, previously produced in polystyrene trays, were transplanted per lot, on 10/07/2012 (for the first crop) and 03/09/2012 (for the second crop). For the second crop of lettuce, soil moisture in the pots was kept constant at 70% (w/w), from limestone incubation to harvest.

When harvesting the first crop on 25/08/2012 and the second crop on 17/10/2012, the following were evaluated: fresh weight (FW), number of leaves per plant (NLP), length of stem (LS) and plant circumference (PC). After the evaluations, all the shoots were harvested, packed into paper bags and dried at 75 °C to constant weight in a forced air circulation oven so as to determine the shoot dry weight. The dry matter of the shoots was ground in a Wiley mill, and samples, each of two grams, were taken, which were submitted to nitric-perchloric digestion followed by colorimetric determination of the phosphorus, as per Tedesco *et al.* (1995).

The experimental plots were again planted with lettuce to evaluate the residual effect of the phosphate fertilization carried out on the first crop. Management of the second crop cycle was identical to that described above for the first cycle, except for the absence of the use of phosphate fertilizers. After the second harvest, the same variables as in the first crop were evaluated and the soil of the experimental lot was homogenised and samples removed to determine phosphorus availability in the Mehlich-1 extracting solution and the remaining P (CFSEMG, 1999).

The values for P accumulation were determined by the product of the dry weight and P content of the lettuce shoots. After obtaining this data, the agronomic efficiency index of the phosphate fertilization was calculated as follows:

Agronomic efficiency Index (AEI) = shoot dry weight with phosphate fertilization (mg) - shoot dry weight no phosphate fertilization (mg) / P dosage (mg); in mg shoot dry weight / mg applied P_2O_5 (FAGERIA; SANTOS; MORAES, 2010).

The data for each crop was subjected to variance analysis and regression, using the SISVAR® 4.3 software (FERREIRA, 2008). The model with the greatest regression coefficient, significant at 5% probability by F-test, was chosen from among the linear, quadratic, exponential and logarithmic models.

RESULTS AND DISCUSSION

First crop

The growth and production characteristics of the lettuce were significantly influenced by the dosage and form of MAP, and by the interaction between these factors (Table 2); except for dry weight and number of leaves per plant (no significance for the isolated effect of source), plant circumference (no significance for the interaction between form of MAP and P dosage) and plant length (no significance for dosage or for the interaction between source and dosage).

For the first crop, the fresh weight of the lettuce shoots increased with the increase in P_2O_5 dosage, and were higher at dosages up to 651 mg kg^{-1} P_2O_5 with the application of MAP + polymers. Above this dosage of P_2O_5, the uncoated MAP promoted greater fresh weight in the lettuce compared to the coated MAP (Figure 2a).

The maximum value for fresh weight seen with the application of uncoated MAP was equal to 146.7 g pot^{-1}, at a dosage of 693.9 mg kg^{-1} P_2O_5, whereas when using MAP + polymers, the maximum for fresh weight was 154.6 g pot^{-1}, at a dosage of 506.9 mg P_2O_5 kg^{-1} (Figure 2a). These results show that MAP + polymers, applied at a P_2O_5 dosage 27% lower than the uncoated MAP, promoted 5% more fresh weight in the lettuce.

Shoot dry weight increased with the applied dosages of phosphorus (Figure 2b). Lana *et al*. (2004) report that P deficiency causes a reduction in the fresh and dry weight of the shoots and roots, producing a decrease in the circumference of the plant and in the leaf phosphorus content, a fact that highlights the high demand (200 to 400 kg P_2O_5 ha^{-1}) for P by the lettuce (FILGUEIRA, 2003).

When uncoated MAP was the source of the phosphorus, the dry weight of the plants reached a maximum of 14.3 g pot^{-1}, at a dosage of 631.3 mg kg^{-1} P_2O_5. On the other hand, when using coated MAP the maximum dry weight (14.6 g pot^{-1}) was seen at a dosage of 450.1 mg kg^{-1} P_2O_5. The MAP + polymers at a P_2O_5 dosage 29% lower than the uncoated MAP promoted 2% more dry weight.

The difference in growth of the lettuce shoots seen between the MAP with and without coating can be explained by the water-soluble anionic polymer, in combination with the MAP, promoting the complexation of Fe and Al in the region near a fertilizer granule, and discouraging the precipitation of P, leaving it in the available form for plant uptake, unlike the uncoated MAP, where this reaction does not take place.

According to Ghosh, Mohan and Sarkar (1996), phosphate fertilizers have varying solubility in water, and react with the mineral solid phase of the soil, particularly with exchangeable cations such as Al, Fe (acid soil) and Ca (alkaline soil), forming new minerals (variscite = $AlPO_4.2H_2O$; strengite = $FePO_4.2H_2O$) of lower solubility, i.e. more stable. As a result, the P remains in less available forms for uptake by the plants. In this way the aluminium or iron present in the soil solution may cause precipitation of phosphates added to the soil by means of such fertilizers as MAP, as per the following reaction:

$$Al^{3+}_{(soil)} + H_2PO^-_{4\,(fertilizer)} + 2H_2O_{(soil)} \leftrightarrow 2H^+ + Al(OH)_2H_2PO_{4\,(insoluble)}$$

Significance was seen (p<0.01) between dosage and source, as well as the interaction between these factors, for the level and accumulation of phosphorus, and the agronomic efficiency index (Table 3).

Phosphorus content and accumulation in the lettuce shoots increased with the P_2O_5 dosage, and were higher with the application of coated MAP (Figures 3a and 3b). In a study carried out by Quadros *et al*. (2011), an increase

Table 2 - Results of the F-test for fresh (FW) and dry weight (DW), number of leaves per plant (NLP), length of stem (LS) and plant circumference (PC) in lettuce, as well as the respective mean values and coefficients of variation, obtained for the first crop by variance analysis

Source of variation	1st crop				
	FW	DW	NLP	LS	PC
Form of MAP	5.09*	2.59^{ns}	0.35^{ns}	7.14**	0.003^{ns}
Dosage	63.1**	31.2**	37.2**	59.0**	31.7**
Source x Dosage	4.79**	6.03**	6.78**	0.84^{ns}	1.43^{ns}
Mean	---------------- g pot^{-1} ----------------		-	cm	cm
	105.5	10.9	13.6	3.5	33.8
CV (%)	10.8	11.9	6.7	9.7	6.1

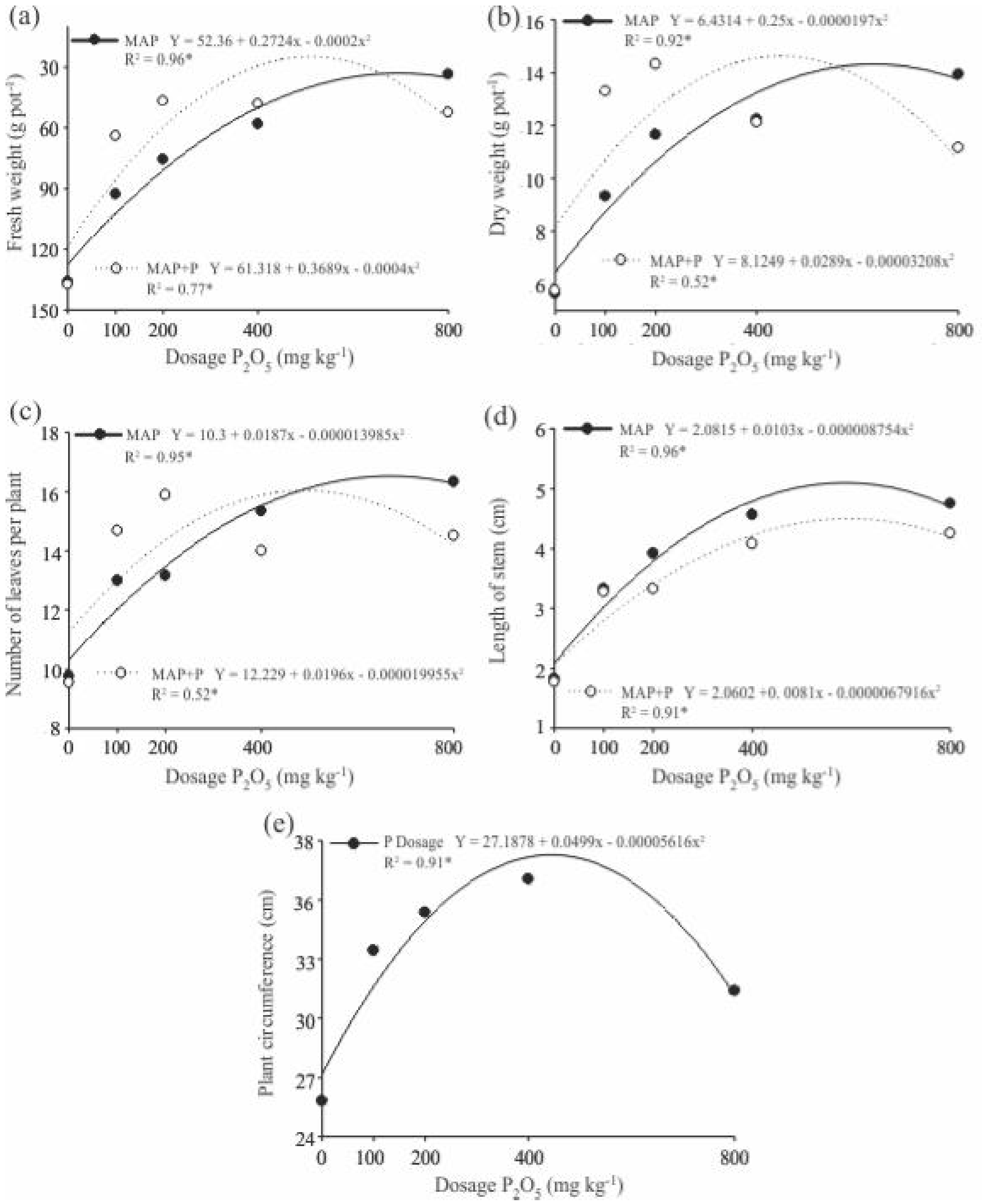
ns - not significant; * p<0.05; ** p<0.01

was also reported in P content and accumulation as a result of the increase in dosages of P when fertilizer was applied to the lettuce.

Phosphorus content of the lettuce shoots ranged from 0.65 g kg^{-1} (with no application of P) to 2.27 g kg^{-1}, at a dosage of 587.5 mg kg^{-1} P_2O_5 for the MAP + polymer treatment.

Quadros *et al.* (2011) found phosphorus levels in lettuce ranging from 0.91 to 1.65 g kg^{-1} in plants fertilised with organic compost which provided from

Figure 2 - Effect of the application of MAP and MAP + polymers (MAP + P) at different dosages of P_2O_5 on the fresh weight (a) dry weight (b), number of leaves (c) length of stem (d) and plant circumference (e) in the first crop of lettuce *5% level of significance (P<0.05) by F-test



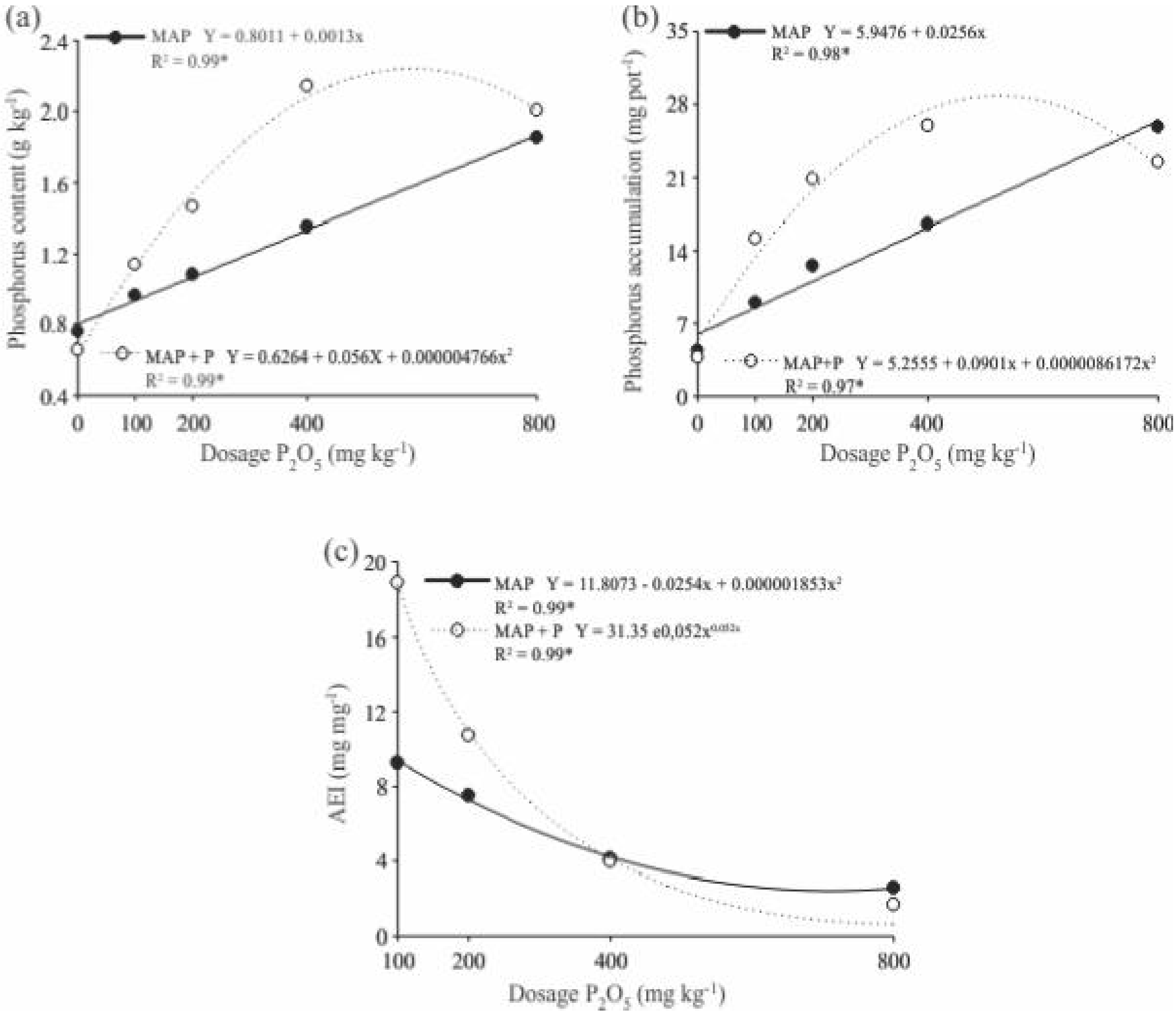
130 to 520 g P_2O_5 pot^{-1}. While Bertossi *et al*. (2013) reported levels of P in lettuce shoots ranging from 0.48 to 1.92 g kg^{-1} with no application of P, up to dosages of 1,145 mg P_2O_5 kg^{-1} respectively.

Table 3 - Results of the F-test for leaf phosphorus content (LP) and phosphorus accumulation (PAc) in lettuce, and the agronomic efficiency index (AEI), as well as the respective mean values and coefficients of variation, obtained for the first crop by variance analysis

Source of variation	1st crop		
	LP	PAc	AEI
Form of MAP	22.6**	18.4**	19.4**
Dosage	58.0**	58.2**	64.0**
Source x Dosage	6.46**	7.4**	12.8**
	---------- g kg^{-1} ----------		
Mean	1.3	15.6	7.3
CV (%)	12.0	16.3	22.3

ns - not significant; * p<0.05; ** p<0.01

Figure 3 - Effect of the application of MAP and MAP + polymers (MAP + P) at different dosages of P_2O_5 on phosphorus content (a), phosphorus accumulation (b) and agronomic efficiency index (c) in the first crop of lettuce *5% level of significance (P<0.05) by F-test



Lana *et al*. (2004) evaluated the effect of soluble phosphate fertilizers and reactive, slowly-soluble fertilizers, and found average values for P in lettuce of: 1.1 g kg^{-1} (control) < 1.2 g kg^{-1} (Arad phosphate) < 1.6 g kg^{-1} (magnesium thermophosphate) < 1.8 g kg^{-1} (single superphosphate) = 1.9 g kg^{-1} (triple superphosphate) = 1.9 g kg^{-1} (Fosmag).

The greatest accumulation of phosphorus (28.8 mg pot^{-1}) was seen at a dosage of 522.8 mg kg^{-1} P_2O_5, using MAP + polymers. With application of the uncoated MAP, adjustment of the equation was linear, with an increase in accumulation of 2.56 mg pot^{-1} for each 100 mg P_2O_5 applied; the maximum value being 26.43 mg pot^{-1} at a dosage of 800 mg P_2O_5. It can therefore be seen that the coated MAP resulted in better phosphorus usage, since at a 35% lower dosage, it promoted a greater accumulation of phosphorus compared to conventional MAP.

The agronomic efficiency of the phosphate fertilization in the first crop of lettuce decreased with the increasing dosages of P_2O_5 (Figure 3c), and was greater with the use of coated MAP up to a dosage of 400 mg kg^{-1} P_2O_5 (Figure 3c). With the supply of phosphorus from the coated MAP, the AEI ranged from 18.87 to 1.69 mg dry matter per mg P_2O_5 applied, while for the MAP, values ranged from 9.23 to 2.6 mg dry matter per mg P_2O_5 applied, at dosages of 100 and 800 mg kg^{-1} P_2O_5 respectively.

As explained earlier, coating the granules of the phosphate fertilizer with polymers which reduce the activity of Fe and Al, depending on the acidity of the soil to which the fertilizer is applied, can prevent the formation of new minerals which are less soluble, due to the precipitation of Al and Fe. Non-formation of these new minerals increases lettuce production and the efficiency of the phosphate fertilization.

Fulford and Hernandez (2009), after eight weeks of triple superphosphate (TSP) incubation with and without a coating of water-soluble polymers, found lower levels of Al/Fe bound phosphorus when using TSP + polymer. Less binding of the phosphorus and Fe/Al results in a higher availability of P to the plants.

Murphy and Sanders (2007) state that with the use of a polymer there was a reduction in the availability of Al^{3+}, probably due to sequestration of the cation, thereby reducing its toxicity. This reduction in the availability of Al^{3+} increased the availability of phosphorus to wheat plants.

There has been little research into the efficiency of phosphate fertilization in lettuce crops, despite the high demand for the nutrient by this vegetable (FILGUEIRA, 2003). Strategies which would increase the efficiency of phosphate fertilizers are needed to enable better usage of this nutrient by various crops. For most of the crops grown in Brazil the agronomic efficiency of phosphate fertilization is generally low: wheat (26.7 kg grain / kg P applied); rice (76.2 kg grain / kg P applied); maize (37 kg grain / kg P applied); soybean (20.3 kg grain / kg P applied) (CONAB, 2011; IFA, 2013).

Bertossi *et al*. (2013) report increasing values for phosphorous usage efficiency with increasing dosages of P, varying from 2.98 to 17.11 mg dry matter per g P applied, for dosages in the range of 0 to 500 mg P kg^{-1}. However, most research into N, P and K for various crops (FAGERIA; SANTOS; MORAES, 2010; SILVA *et al.*, 2011; GUELFI-SILVA *et al.*, 2013) show that there is a reduction in P usage with increases in the applied dosage, due to greater losses in the soil-plant-atmosphere system.

Second crop

In the second crop of lettuce, fresh weight, number of leaves per plant and length were significantly influenced by the P_2O_5 dosage only. Dry weight however was significantly influenced by dosage and source, and by the interaction between these factors (Table 4).

For the second lettuce crop, the fresh weight, number of leaves and plant length increased with dosages of up to 534.5, 413.7 and 627.2 mg kg^{-1} P_2O_5 respectively (Figures 1a, 1c, 1d), and the dry weight was higher when using coated MAP (Figure 1b). This differential growth was due to the important role of P in such plants as lettuce, which is to store and transfer energy during photosynthesis, respiration and protein synthesis (MALAVOLTA; VITTI; OLIVEIRA, 1997).

There was significant interaction between source and P_2O_5 dosage for the agronomic efficiency index only. Content, accumulation, $P_{Mehlich-1}$ and AEI were influenced by the isolated effect of the P_2O_5 dosage (Table 5).

The levels of P in the lettuce shoots ranged from 0.98 and 1.45 g kg^{-1}, between the minimum dosage (no application) and the maximum (493.3 mg kg^{-1} P_2O_5). The mean values for P accumulation were higher with the application of the coated MAP (12.95 mg pot^{-1}) compared to the uncoated MAP (4.38 mg pot^{-1}). The dosage giving the maximum accumulation of phosphorus in the lettuce shoots was 460.5 mg kg^{-1} P_2O_5.

There was significant influence from the effect of dosage on the availability of $P_{Mehlich-1}$ in the soil after cultivation of the two lettuce crops, which increased exponentially with increases in the amount of P_2O_5 applied (Figure 4c). There was no significant difference for the isolated effect of source, nor for the interaction between dosage and source (Table 5).

According to CFSEMG (1999), the mean values for $P_{Mehlich-1}$ after the two lettuce crops were classified as: 1.66 (very low); 5.60 (average); 8.45 (good); 14.30

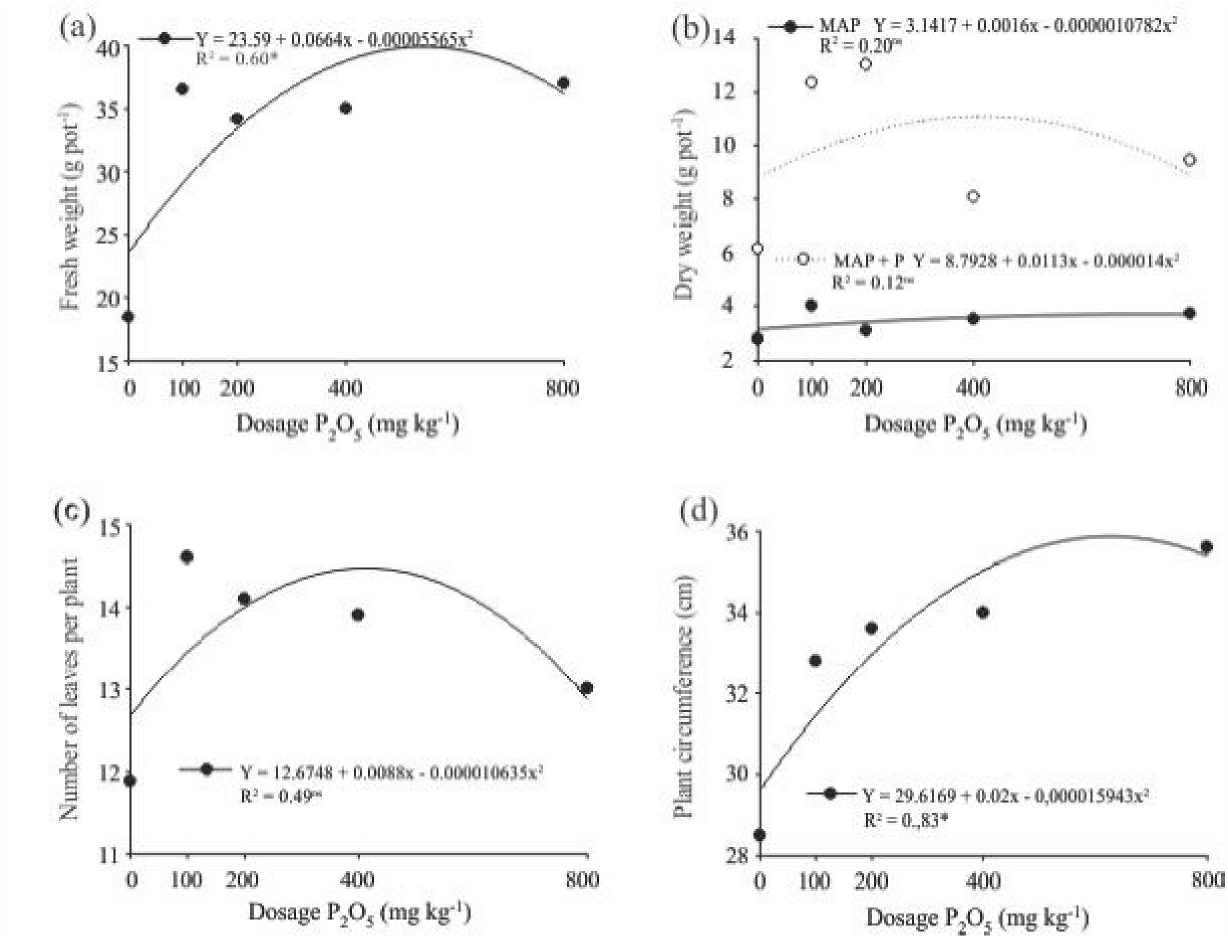
(very good) and 77.50 mg dm^{-3} (very good) for dosages of 0, 100, 200, 400 and 800 mg kg^{-1} P_2O_5 respectively. Thus, as the dosage of phosphorus applied in the fertilizer increased, there was an increase in phosphorus availability after cultivation of the lettuce; however, phosphorus usage efficiency decreased (Figure 3d, 4d).

Table 4 - Results of the F-test for fresh (FW) and dry weight (DW), number of leaves per plant (NLP), length of stem (LS) and plant circumference (PC) in lettuce, as well as the respective mean values and coefficients of variation, obtained for the second crop by variance analysis

Source of variation	2nd crop				
	FW	DW	NLP	LS	PC
Form of MAP	0.00^{ns}	82.7**	0.09^{ns}	12.31**	1.22^{ns}
Dosage	7.05**	3.99*	4.70**	1.14^{ns}	3.07*
Source x Dosage	1.49^{ns}	3.00*	0.78^{ns}	0.76^{ns}	0.78^{ns}
Mean	g pot^{-1}		-	cm	cm
	39.3	6.6	13.5	1.7	32.9
CV (%)	22.5	29.1	9.0	18.4	11.4

ns - not significant; * p<0.05; ** p<0.01

Figure 4 - Effect of the application of MAP and MAP + polymers (MAP + P) at different dosages of P_2O_5 on the fresh weight (a) dry weight (b), number of leaves (c) and plant circumference (d) in the second crop of lettuce *5% level of significance (P<0.05) by F-test



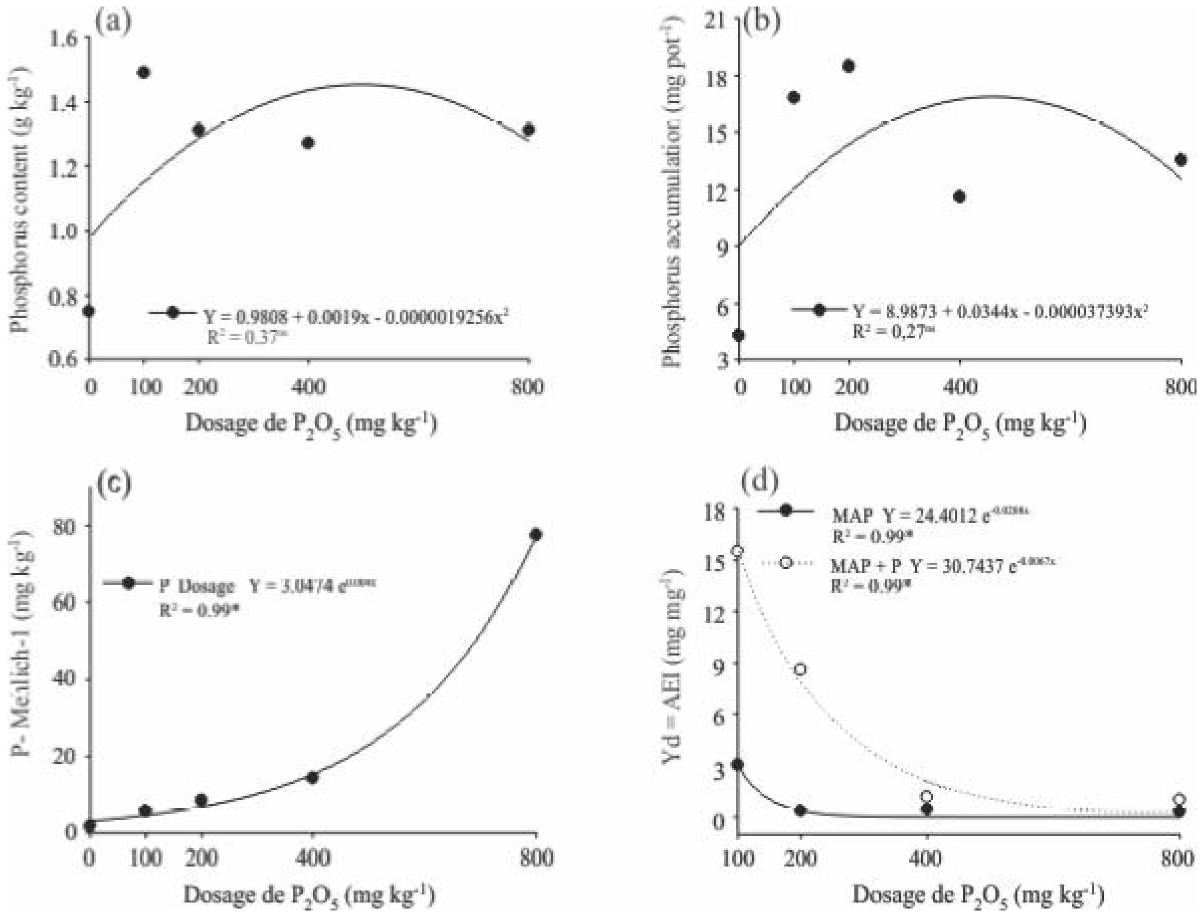
The agronomic efficiency index for the second crop of lettuce decreased exponentially with the increase in dosage, and was greater with the application of coated MAP. The difference in agronomic efficiency between the coated and the uncoated MAP was significant at dosages of 100 and 200 mg kg^{-1} P_2O_5. At a dosage of 100 mg kg^{-1} P_2O_5 the average AEI for the coated MAP was equal to 15.33 mg dry matter mg^{-1} P_2O_5, while for the uncoated

Table 5 - Results of the F-test for leaf phosphorus content (LP), phosphorus accumulation (PAc), $P_{Mehlich}$, remaining P, agronomic efficiency index (AEI) and recovery of applied phosphorus in lettuce, as well as the respective mean values and coefficients of variation, obtained for the second crop by variance analysis

Source of variation	2nd crop				
	LP	PAc	$P_{Mehlich}$	P-rem	AEI
Form of MAP	0.08^{ns}	27.3**	2.07^{ns}	0.71^{ns}	15.77**
Dosage	5.26**	3.44*	8.67**	2.07^{ns}	9.41**
Source x Dosage	1.17^{ns}	1.47^{ns}	1.94^{ns}	1.03^{ns}	4.33*
Mean	----------------- g kg^{-1} -----------------		---- mg pot^{-1} ----	--------------- mg dm^{-3} ----------------	
	1.2	8.7	21.5	4.9	3.8
CV (%)	24.1	51.9	122.3	34.8	89.7

ns - not significant; * p<0.05; ** p<0.01

Figure 5 - Effect of the application of MAP and MAP + polymers (MAP + P) at different dosages of P_2O_5 on phosphorus content (a), phosphorus accumulation (b), phosphorus availability (Mehlich-1) (c) and agronomic efficiency index (d) in the second crop of lettuce



*5% level of significance (P<0.05) by F-test

MAP, this value was 3.05 mg dry matter mg^{-1} P_2O_5. At a dosage of 200 mg kg^{-1} P_2O_5 the AEI was 8.61 and 0.36 mg dry matter mg^{-1} P_2O_5 respectively.

The results for the AEI (Figure 4d), together with those for the lettuce dry weight in the second crop (Figure 3b), show that even in the second crop, the polymer-coated MAP promoted greater response in dry weight per unit of P_2O_5.

CONCLUSIONS

1. Coating the MAP with polymers increased the efficiency of phosphate fertilization in both lettuce crops, improving the usage of residual phosphorus in a clay soil;
2. The agronomic efficiency of phosphate fertilization decreases with the increase in the amount of phosphorus applied to the lettuce crop;
3. The characteristics of growth, production and nutrition in the lettuce were positively influenced by phosphorus dosage and the use of polymer-coated MAP;
4. The greater production of fresh and dry matter and of phosphorus accumulation in the first crop of lettuce occurred with the use of polymer-coated MAP at dosages of 506.9, 450.1 and 522.8 mg kg^{-1} P_2O_5 respectively.

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