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## Agronomic efficiency of polymer-coated triple superphosphate in onion cultivated in contrasting texture soils<sup>1</sup>

Eficiência agrônômica do superfosfato triplo com polímeros na cebola cultivada em solos com diferentes texturas

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**ABSTRACT** - Information related to phosphate fertilization and coated phosphate fertilizer in onion is scarce. Thus, this study was carried out to evaluate agronomic efficiency, production and nutritional characteristics of triple superphosphate coated with polymers in onion cultivated in contrasting texture soils. Two experiments were carried out under protected conditions in pots containing 5 kg soil. The experimental design was completely randomized with treatments arranged in a 2 x 5 factorial: triple superphosphate (TSP) and polymer-coated triple superphosphate (TSP+P) applied in five phosphorus rates: Dystroferic Red Latosol (LVdf) (clayey) = 0; 100; 200; 400; 800 mg P<sub>2</sub>O<sub>5</sub> kg<sup>-1</sup>, and Quartzarenic Neosol (sandy) = 0; 75; 150; 300; 600 mg P<sub>2</sub>O<sub>5</sub> kg<sup>-1</sup>, with three replications. Results indicated that polymer-coated TSP showed no difference for bulb mass and agronomic efficiency for phosphorus fertilization. Agronomic efficiency of phosphorus fertilization decreased with the increase in the amount of phosphorus applied. Phosphorus accumulation for onion bulb cultivated in Dystroferic Red Latosol (LVdf) was higher with the use of polymer-coated triple superphosphate. Growth, production and nutritional characteristics in onion were affected by phosphorus. The highest bulbs mass production and phosphorus accumulation occurred at the doses of 783; 629 mg kg<sup>-1</sup> P<sub>2</sub>O<sub>5</sub> (Dystroferic Red Latosol - LVdf), and of 406; 600 mg kg<sup>-1</sup> P<sub>2</sub>O<sub>5</sub> (Quartzarenic Neosol -RQ).

**Key words:** *Allium cepa* L.. Coated fertilizers. Phosphorus.

**RESUMO** - Devido à escassez de informações relacionadas à adubação fosfatada para a cebola e às tecnologias de revestimento de fertilizantes fosfatados realizou-se esse estudo para avaliar as características nutricionais, produtivas e a eficiência agrônômica do superfosfato triplo revestido com polímeros em cultivos de cebola, em Latossolo Vermelho (argiloso) e Neossolo Quartzarênico (arenoso). Foram conduzidos dois experimentos em casa de vegetação em vasos com capacidade para 5 kg de solo. O delineamento experimental foi inteiramente casualizado com os tratamentos distribuídos em arranjo fatorial 2 x 5: superfosfato triplo (SFT) e superfosfato triplo revestido com polímeros (SFT+P) aplicados em cinco doses de fósforo: Latossolo Vermelho = 0; 100; 200; 400; 800 mg P<sub>2</sub>O<sub>5</sub> kg<sup>-1</sup> e no Neossolo Quartzarênico = 0; 75; 150; 300; 600 mg P<sub>2</sub>O<sub>5</sub> kg<sup>-1</sup>, com três repetições. O revestimento do SFT com polímeros não alterou a massa de bulbos e o índice de eficiência agrônômica da adubação fosfatada. A eficiência agrônômica da adubação fosfatada diminuiu com o aumento na quantidade de fósforo aplicada. O acúmulo de fósforo no bulbo da cebola cultivada no Latossolo Vermelho foi maior com a aplicação do superfosfato triplo revestido com polímeros. As características de crescimento, produtivas e a nutrição da cebola foram influenciadas positivamente pelas doses de fósforo. As maiores produções de massa de bulbos e acúmulos de fósforo ocorreram nas doses de 783; 629 mg kg<sup>-1</sup> de P<sub>2</sub>O<sub>5</sub> (Latossolo Vermelho), e de 406; 600 mg kg<sup>-1</sup> de P<sub>2</sub>O<sub>5</sub> (Neossolo Quartzarênico), respectivamente.

**Palavras-chave:** *Allium cepa* L.. Fertilizantes revestidos. Fósforo.

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## INTRODUCTION

Regarding the economic aspects, onion is the third most important vegetable crop grown in Brazil, after potatoes and tomatoes (BETTONI, 2013; MENEZES JÚNIOR; GONÇALVES; KURTZ, 2013). Increase in yield and improvements in health and quality of onion bulbs are influenced by adequate phosphorus supply (AGUIAR NETO *et al.*, 2014). P deficiency causes reduction in the root system growth, in the leaf area, in the bulbs mass, in yield, and delays onion maturation (MENDES *et al.*, 2008; RIZK *et al.*, 2012).

In this context, P has great importance in the management of soil fertility cultivated with vegetables, which in general draw large amounts of this nutrient over the cropping years. This nutrient is also important since the largest part of the Brazilian soils presents high fixation capacity and low P availability (LEITE *et al.*, 2009).

The low utilization of P from the fertilizer by the plants (between 20-60% of the applied amount (Chien *et al.*, 2009)) is due to undesired chemical reactions of P with solid minerals and with cations, such as  $\text{Al}^{3+}$  and  $\text{Fe}^{2+}$ , influenced by the soil pH. Thus, the slow- or controlled-release fertilizer is a possible strategy to act promoting synchronization between the phosphorus absorption curve of the culture and the release of the fertilizer's nutrients for soil solution (DU; ZHOU; SHAVIV, 2006; DAI. *et al.*, 2008; SHI *et al.*, 2009).

Polymer-coated phosphate fertilizers have as a principle the gradual release of nutrients to the soil solution (BANSIWAL *et al.*, 2006; BROCHAT *et al.*, 2008; FAGERIA *et al.*, 2014; ABAT *et al.*, 2014; DEGRYSE; MCLAUGHLIN, 2014), which is in contrast with the full and immediate release observed in soluble phosphate fertilizers, or the too slow release observed in natural phosphates.

Furthermore, granules coating reduces phosphorus contact with iron and aluminum oxides, decreasing the formation of compounds containing unavailable P for the plants (GAZOLA *et al.*, 2013).

The understanding of coating performance is of great important for satisfactory results (VASCONCELOS *et al.*, 2010; KAUNISTO *et al.*, 2011; SILVA *et al.*, 2012;). Among the principal mechanisms of coated phosphate fertilizers, it should be mentioned the reduction of the contact between soluble P with the solid phase of the soil and the reduced precipitation between P and  $\text{Al}^{3+}$  and  $\text{Fe}^{2+}$  present in the soil solution which is in direct contact with the fertilizer.

Fulford and Hernandez (2009) found smaller amounts of phosphorus bonded to aluminum and iron

when using polymer-coated triple superphosphate, which resulted in the increase of P availability in the soil.

According to Tindall (2007), the use of coated monoammonium phosphate (MAP) in maize provided 37.2% fertilizers saving. In cotton, fertilizer saving was 38.9% due to higher efficiency of the fertilizer and to the reduction of the amount applied.

Due to the lack of information related to phosphorus fertilization for onion and new technologies for coated phosphate fertilizers, this study was carried out to evaluate nutritional, production and agronomic efficiency characteristics of polymer-coated triple superphosphate in onion crops in soils with contrasting texture.

## MATERIAL AND METHODS

The experiments were carried out in a greenhouse at the Department of Soil Science of the Federal University of Lavras, Lavras - MG, from September 2013 to December 2013. It was used two soils classified as Dystroferic Red Latosol (LVdf) and Quartzarenic Neosol (RQ) (EMBRAPA, 2013), collected at 0-20 cm depth. Then, the collected soil was air dried, trimmed, sieved in a four millimeters mesh, homogenized and placed in 5kg pots. Concomitantly, soil samples were collected for chemical and textural characterization (Table 1).

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

It was used a completely randomized design with the treatments distributed in a factorial  $2 \times 5$ : triple superphosphate (TSP) and polymer-coated triple superphosphate (TSP+P) applied at five phosphorus doses: Dystroferic Red Latosol (LVdf) = 0; 100; 200; 400; 800  $\text{mg P}_2\text{O}_5 \text{ kg}^{-1}$ , and Quartzarenic Neosol (RQ) = 0; 75; 150; 300; 600  $\text{mg P}_2\text{O}_5 \text{ kg}^{-1}$ , with three replications. The experimental plot consisted of a 5kg pot containing three onion plants.

**Table 1** - Chemical attributes (1) and texture (2) of Dystroferic Red Latosol (LVdf) and Quartzarenic Neosol (RQ) used in onion crops

Chemical attributes and texture	Dystroferic Red Latosol	Quartzarenic Neosol
pH in water	5.5	5.5
Al <sup>3+</sup> (cmol <sub>c</sub> dm <sup>-3</sup> )	0.0	0.4
H+Al (cmol <sub>c</sub> dm <sup>-3</sup> )	2.1	2.3
Ca <sup>2+</sup> (cmol <sub>c</sub> dm <sup>-3</sup> )	0.4	0.1
Mg <sup>2+</sup> (cmol <sub>c</sub> dm <sup>-3</sup> )	0.1	0.1
K <sup>+</sup> (mg dm <sup>-3</sup> )	8.0	34
Effective CEC (cmol <sub>c</sub> dm <sup>-3</sup> )	0.5	0.7
Potential CEC (cmol <sub>c</sub> dm <sup>-3</sup> )	2.6	2.6
Alumnum saturation (%)	0.0	60
Base saturation percentage (%)	20.0	11.0
P- Mehlich-1 (mg dm <sup>-3</sup> )	0.0	0.0
P-remaining (mg L <sup>-1</sup> )	2.3	20.9
Cu (mg dm <sup>-3</sup> )	2.2	0.1
Zn (mg dm <sup>-3</sup> )	0.5	2.3
Fe (mg dm <sup>-3</sup> )	25.1	17.5
Mn (mg dm <sup>-3</sup> )	4.0	8.0
Organic matter (g kg <sup>-1</sup> )	1.5	0.9
Sand (g kg <sup>-1</sup> )	19	92
Silt (g kg <sup>-1</sup> )	14	2.0
Clay (g kg <sup>-1</sup> )	67	6.0

It was carried out liming in order to increase base saturation to 70% (CFSEMG, 1999), and the limestone used was formed by mixing calcium carbonate and magnesium carbonate (p.a), in a ratio Ca:Mg - 4:1, undergoing a period of 30 days incubation.

Subsequently, basic fertilization was carried out as recommended by Malavolta (1980), with all other nutrients, except P, through pro-analysis salts sources. Macro and micronutrients doses for each pot were 100 mg N; 50 mg K; 40 mg S; 5 mg Zn; 1.5 mg Cu; 3.6 mg Mn; 0.8 mg B; 0.15 mg Mo/dm<sup>3</sup>. Maintenance fertilization was carried out with the reagents (P.A) in all the treatments, with 200 mg dm<sup>-3</sup> N + 130 mg dm<sup>-3</sup> K, using urea and potassium sulfate.

After applying the fertilizers in the pots, it was carried out transplanting of three onion seedlings per plot of the Baia Perifome cultivar, which had previously been produced in polystyrene trays. This cultivar presents the following characteristics: pear-shaped bulb, thin neck, yellow peel and tolerance to long storage periods.

From the limestone incubation to the harvest, soil moisture of the pots was kept constant at 70% (w/w).

At the beginning of bulbification, leaf samples were collected for the evaluation of the nutrient content. Samples considered the young and fully expanded leaves, as recommended by Mendes *et al.* (2008).

Bulbs harvest was carried out in the period in which plants presented more than 70% damping-off (130 days after transplanting). After cure in greenhouse, seven days after harvest, bulbs mass was evaluated.

After the evaluation, bulbs were placed in paper bags and dried at 75 °C in an oven with forced air circulation until constant weight for subsequent determination of the nutrient content. Shoot dry matter was ground in a Wiley mill, and sampled for nitroperchloric digestion, followed by colorimetric phosphorus determination.

Values of P accumulation were determined by multiplying the dry matter and the P content in the bulb of onion plants. After obtaining these data, the agronomic efficiency of the phosphate fertilizer was calculated:

Agronomic efficiency (EAP) = shoot dry matter with phosphorus fertilization (mg) - shoot dry matter without phosphorus fertilization (mg) / P dose (mg); in

mg of shoot dry matter/mg  $P_2O_5$  applied (FAGERIA; SANTOS; MORAES, 2010).

Data were subjected to analysis of variance and regression, using the SISVAR 4.3<sup>®</sup> software (FERREIRA, 2011). Among the linear, quadratic, exponential and logarithmic models, it was chosen the one of most significant regression coefficient at 5% probability by the F test.

## RESULTS AND DISCUSSION

### Clayey Dystroferic Red Latosol (LVdf)

Bulbs mass, P content and agronomic efficiency of phosphorus fertilizer in onion plants were significantly influenced ( $p \leq 0.05$ ) only by phosphorus doses. For P content accumulation in the bulbs, there was significance for the isolated effect of doses, sources and for the interaction between these factors (Table 2).

For all  $P_2O_5$  doses applied in onion plants, regardless of the TSP form, with or without coating, there was an increase in bulbs mass compared to the control (without P application). Bulb mass increased up to the dose of  $783 \text{ mg dm}^{-3} P_2O_5$ , and was equal to  $183.9 \text{ g pot}^{-1}$ , which is an increase of  $161 \text{ g pot}^{-1}$  (702%), compared to the control (Figure 1a).

According to Mendes *et al.* (2008), onion plants deficient in phosphorus showed bulbs with reduced size and with decreased yield.

Tekalign *et al.* (2012) reported that phosphorus fertilization influences onion commercial yield (bulbs mass), and it is of fundamental importance for the production of seed bulbs, since the application of  $40 \text{ kg ha}^{-1} P$  increased onion sprouting in 53%, when compared to control treatment.

Phosphorus content in the leaf ranged between  $0.93 \text{ g kg}^{-1}$  in the control treatment to  $2.1 \text{ g kg}^{-1}$  at a dose of  $408 \text{ mg dm}^{-3} P_2O_5$ , which was the highest P content in onion leaves (Figure 1b). Values of phosphorus content found in this study were below  $3.0 \text{ g kg}^{-1}$ , which is considered ideal by Malavolta (1997) in onion leaves. However, the highest P content ( $2.10 \text{ g kg}^{-1}$ ) was found within the optimal range of 2 to  $4 \text{ g kg}^{-1}$  for onion leaves, according to the Commission of Soil Fertility - RS/SC (2004).

Phosphorus content in the bulb increased with  $P_2O_5$  doses applied where TSP + P had been applied (Figure 1c). The maximum P content in the bulb was  $3.27 \text{ g kg}^{-1}$ , and it occurred at a dose of  $459.1 \text{ mg dm}^{-3} P_2O_5$  with the application of TSP+P, whereas for the

uncoated TSP, the highest P content in the bulb occurred at the dose of  $459.1 \text{ mg dm}^{-3} P_2O_5$ .

The greatest phosphorus accumulation in the bulb ( $629 \text{ mg pot}^{-1} P$ ) occurred at a dose of  $781.43 \text{ mg kg}^{-1} P_2O_5$  using TSP+P. With the application of uncoated TSP, the maximum value of P accumulation was  $294.94 \text{ mg pot}^{-1}$ , and it occurred at a dose of  $772.28 \text{ mg kg}^{-1} P_2O_5$ . Thus, it can be affirmed that TSP+P promoted better phosphorus use since it provided maximum accumulation value 53% higher than the highest value obtained with TSP application.

Agronomic efficiency index in onion cultivation in Clayey Dystroferic Red Latosol (LVdf) decreased with the increase of  $P_2O_5$  doses, and was equal to the application of TSP+P and TSP (Figure 1e).

Fageria *et al.* (2014) evaluated the agronomic efficiency of coated phosphate fertilizers in rice and reported that the applied P sources were classified according to the efficient P use in the following descending sequence: polymer-coated simple superphosphate = triple superphosphate > polymer-coated triple superphosphate > polymer-coated ammoniated simple superphosphate > simple superphosphate > MAP > ammoniated simple superphosphate.

### Quartzarenic Neosol with sandy texture

Quartzarenic Neosol in onion cultivation, bulb mass, P accumulation, P content in the leaves and in the bulbs, and agronomic efficiency were significantly influenced ( $p \leq 0.05$ ) by  $P_2O_5$  doses. However, P content in the bulb and P accumulation in the bulb were also significantly influenced by the absence or presence of TSP coating (Table 3).

In all  $P_2O_5$  doses, regardless of the TSP form, there was an increase in bulbs mass when compared to the control (without P application). Bulb mass increased up to a dose of  $406 \text{ mg dm}^{-3} P_2O_5$ , and was equal  $210.2 \text{ g pot}^{-1}$ , which is an increase of  $189.4 \text{ g pot}^{-1}$  (910%), when compared to the control (Figure 2a).

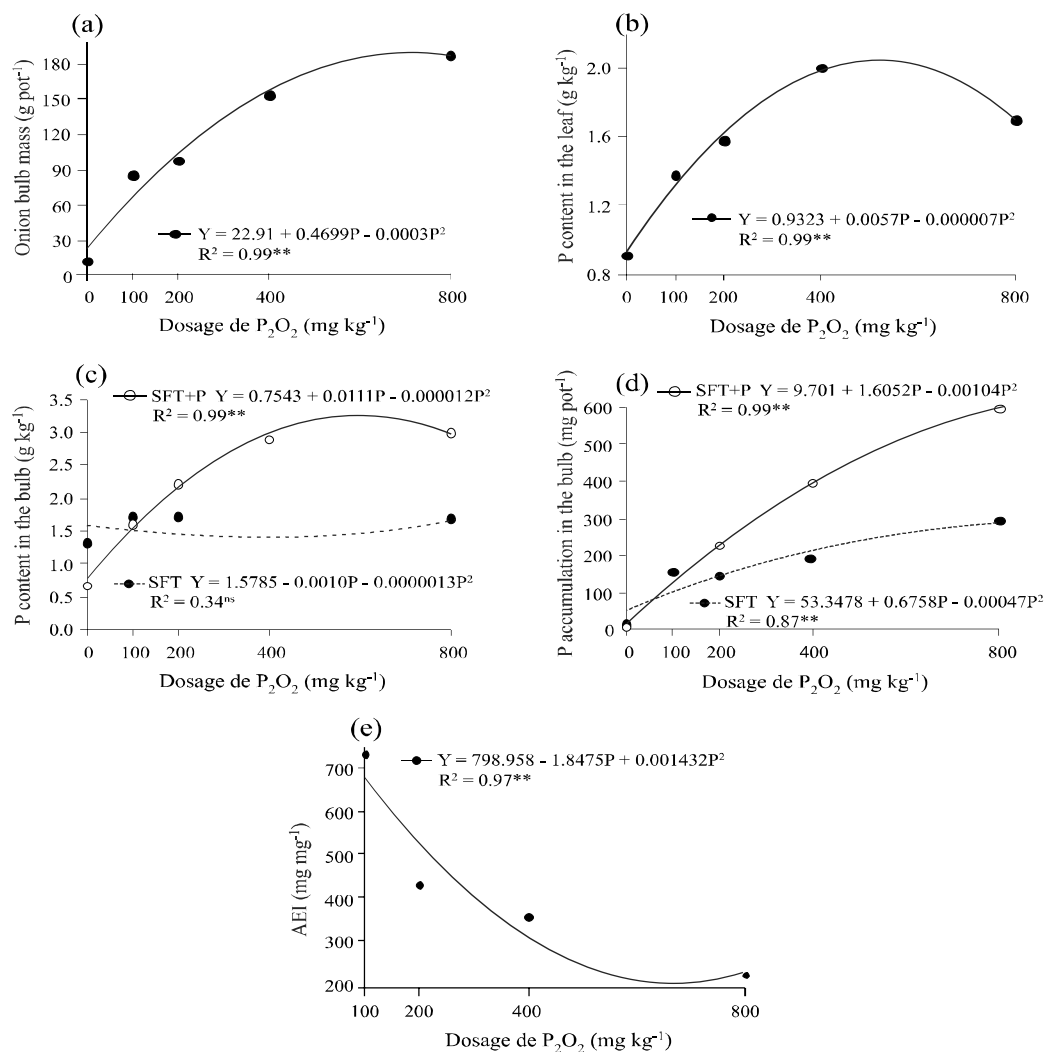
P content in the leaves, in the bulbs, and P accumulation in the bulb of onion plants grown in Quartzarenic Neosol (RQ) increased linearly up to the maximum dose applied ( $600 \text{ mg kg}^{-1} P_2O_5$ ); (Figure 2b, 2c and 2d) and the agronomic efficiency index decreased with the increase in P doses (Figure 2e). For every  $100 \text{ mg } P_2O_5$  applied in onion plants, there was increase of  $0.28 \text{ g kg}^{-1}$ ,  $0.37 \text{ g kg}^{-1}$  and  $95.74 \text{ mg pot}^{-1}$  in P content in the leaves, in the bulbs and in P accumulation, respectively.

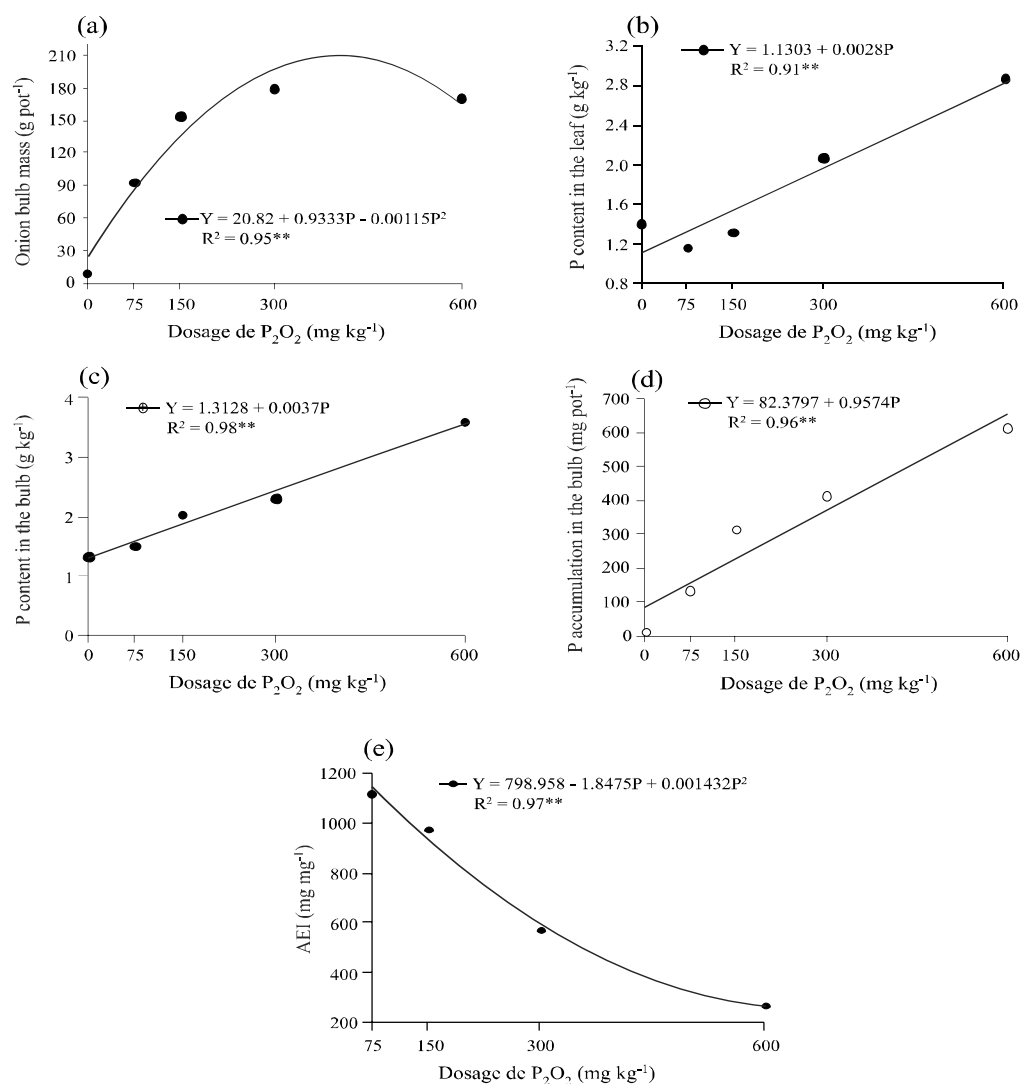
Aguiar-Neto *et al.* (2014) evaluated growth and P accumulation in different onion cultivars and found

**Table 2** - Results of the F test for bulb mass (BM), phosphorus content in the leaf (PCleaf), phosphorus content in the bulb (PCbulb), phosphorus accumulation in the bulb (PAB), agronomic efficiency index of TSP forms (AEI), and the respective means and coefficients of variation obtained by the analysis of variance for onions cultivation in Clayey Dystroferic Red Latosol (LVdf)

Variation source	Dystroferic Red Latosol (LVdf)				
	BM	PCleaf	PCbulb	PAB	AEI
TSP forms	0.312 <sup>ns</sup>	0.005 <sup>ns</sup>	7.27*	15.68**	0.77 <sup>ns</sup>
Doses	40.76**	3.010*	4.69**	27.07**	18.43**
Forms x Doses	1.111 <sup>ns</sup>	2.112 <sup>ns</sup>	4.59**	5.19**	0.84 <sup>ns</sup>
Mean	g pot <sup>-1</sup>	g kg <sup>-1</sup>	g kg <sup>-1</sup>	mg pot <sup>-1</sup>	mg mg <sup>-1</sup>
	107.50	1.51	1.79	215.34	432.76
CV (%)	24.04	37.70	31.91	35.57	28.63

ns = not significant; \* p≤0,05; \*\* p≤0,01

**Figure 1** - Onion bulb mass (a), phosphorus content in the leaf (b), P content in the bulb (c), P accumulation in the bulb (d), and agronomic efficiency (e) in the cultivation of onion in Clayey Dystroferic Red Latosol (LVdf) with\* 5% significance level ( $p \leq 0.05$ ) by the F test

**Figure 2** - Onion bulbs mass (a), P content in the leaf (b), P content in the bulb (c), P accumulation in the bulb (d), and agronomic efficiency index (e) in onion cultivation in Sandy Quartzarenic Neosol (RQ)\*5% significance level ( $p \leq 0.05$ ) by the F test**Table 3** - Results of the F test for bulb mass (BM), phosphorus content in the leaf (PCleaf), phosphorus content in the bulb (PCbulb), phosphorus accumulation in the bulb (PAB), agronomic efficiency of TSP forms (AEI), and respective means and coefficients of variation obtained by analysis of variance for onion cultivation in Sandy Quartzarenic Neosol (RQ)

Variation source	Quartzarenic Neosol (RQ)				
	BM	PCleaf	PCbulb	AcP	AEI
TSP forms	0.377 <sup>ns</sup>	2.185 <sup>ns</sup>	9.29**	5.35*	5.37 <sup>ns</sup>
Doses	43.713**	10.23**	12.26**	23.65**	24.75**
Forms x Doses	1.336 <sup>ns</sup>	0.93 <sup>ns</sup>	1.745 <sup>ns</sup>	1.537 <sup>ns</sup>	2.84 <sup>ns</sup>
Mean	g vaso <sup>-1</sup>	g kg <sup>-1</sup>	g kg <sup>-1</sup>	mg vaso <sup>-1</sup>	mg mg <sup>-1</sup>
	120.83	1.77	2.16	297.79	732.79
CV (%)	21.91	30.48	29.10	39.97	25.96

ns = not significant; \*  $p \leq 0.05$ ; \*\*  $p \leq 0.01$

adjustment to the linear model for P accumulation in the bulb. The authors also reported maximum values of P accumulation in the bulb of 37.29 mg plant<sup>-1</sup> in plants cultivated in a Haplic Cambisol with loam sandy texture, located in the municipality of Petrolina. In other crop cultivated in a Eutrophic Red-Yellow Argisol in the municipality of Baraúna, P accumulation values were 11.30 mg plant<sup>-1</sup>.

The maximum values of P content in the leaf (2.90 g kg<sup>-1</sup>) and in the onion bulb (3.60 g kg<sup>-1</sup>) occurred at a dose of 600 mg kg<sup>-1</sup> P<sub>2</sub>O<sub>5</sub>. These values were 28% (leaf) and 9% (bulb) higher compared to the maximum values found in cultivation in Clayey Dystroferic Red Latosol (LVdf) (Figures 1b and 1c). This is due to higher buffering capacity of clayey soils when compared to sandy soils.

The capacity factor of clayey soils is high. Thus, it can only be achieved minor changes in P content of the soil solution with the application of higher P doses, which may not be economically interesting. This fact occurs due to higher adsorption in clayey soils (MACHADO *et al.*, 2011; NOVAIS *et al.*, 2007).

Machado and Souza (2012) reported that the use of P sources of gradual release makes its availability in the soil increase over time, and the most pronounced effect was observed in the following soil texture sequence: clay > intermediate texture > sandy texture.

For P accumulation in onion plants cultivated in Quartzarenic Neosol (RQ), there was no significance ( $p \leq 0.05$ ) for the interaction between P and doses forms (Table 3), unlike what occurred in the Clayey Dystroferic Red Latosol (LVdf) (Table 2), where doses higher than 80 mg dm<sup>-3</sup> TSP+P resulted in higher values of P accumulation in onion plants. Mean value of P accumulation in the application of TSP+P was 348.08 mg pot<sup>-1</sup>, and mean values of P accumulation in the application of TSP was 247.50 mg pot<sup>-1</sup>, with no significant difference ( $p \leq 0.05$ ) between means.

Similarly to the Dystroferic Red Latosol (LVdf), the agronomic efficiency index in onion plants cultivated in Sandy Quartzarenic Neosol (RQ) decreased with the increase in P doses. Values of agronomic efficiency of phosphate fertilizer in Quartzarenic Neosol (RQ) ranged between 1.117.8 and 269.5 mg mg<sup>-1</sup> (Figure 3e), and in the Dystroferic Red Latosol (LVdf), variation ranged between 731.7 and 219.0 mg mg<sup>-1</sup> (Figure 1e).

Results obtained in onion plants cultivated in Quartzarenic Neosol (RQ) presented no significant differences between TSP forms for the variables quantified and analyzed in this study.

## CONCLUSIONS

1. Polymer-coated TSP did not increase bulbs mass and agronomic efficiency index of the phosphorus fertilization;
2. In both soils, agronomic efficiency of phosphate fertilizer decreased with the increase in the amount of phosphorus applied to the onion plants;
3. Phosphorus accumulation in onion bulbs cultivated in Clayey Dystroferic Red Latosol (LVdf) is higher with the application of polymer-coated triple superphosphate;
4. Regardless of the coated TSP, growth, production and nutritional characteristics in onion increased in function of phosphorus doses;
5. The highest bulbs mass production and phosphorus accumulation in onions cultivated in Dystroferic Red Latosol (LVdf) occurred at the doses of 783; 629 mg kg<sup>-1</sup> P<sub>2</sub>O<sub>5</sub>, and in Quartzarenic Neosol (RQ), at doses of 406; 600 mg kg<sup>-1</sup> P<sub>2</sub>O<sub>5</sub>, respectively.

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