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Effect of different sources of phosphorus with and without PSF on release of phosphorus and different phosphorus fractions in rice (*Oryza sativa* L.)

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Abstract
A field experiment was conducted at AHRS, Kathalagere, during *kharif* 2014, to study the effect of different sources of phosphorus with and without PSF on release of available phosphorus and its influence on growth and yield of rice. The effect of different sources and levels of phosphorus @ 40, 50 and 60 kg ha^{-1} P_2O_5 as rock phosphate applied in the form of nutriphos with or without PSF were tried along with single super phosphate in a randomized complete block design comprising eight treatments replicated thrice. The application of different sources of phosphorus with and without PSF treatment significantly increased the values of saloid – P and Ca – P fraction in soil at harvest stages. Higher values of saloid – P and Ca – P fractions were recorded in treatments involving P levels with PSF treatment compared to application of only P levels. The highest saliod-P (21.23 mg kg^{-1}) was recorded with the treatment where P applied in the form of SSP + PSF. The lowest was recorded in treatment where 40 kg ha^{-1} P_2O_5 through rock phosphate in the form of nutriphos (15.77 mg kg^{-1}). Significant increases in Al - P, Fe – P, red – P, occl – P, organic – P and total - P fractions in soil due to P levels with and without PSF treatment. Higher values of Al - P, Fe – P, red – P, occl – P, organic – P and total - P fractions were recorded in treatments involving P levels without PSF treatment compared to the application of only P levels with PSF treatment. The highest aluminum-P (123.17 mg kg^{-1}) was recorded in the treatment where phosphorus applied in the form of SSP. The lowest aluminum-P was recorded in treatment where40 kg ha^{-1} P_2O_5 through rock phosphate in the form of nutriphos + PSF (106.44 mg kg^{-1}).

Keywords: phosphorus, PSF, *Oryza sativa* L.

Introduction
Genially the paddy growing acid soils are deficient in available P and this constraint limits food production (Chien & Mennon, 1995; Sanchez *et al*., 1997) [3, 13]. Some of the reasons for the low available P in the soils are the low inherent P status of the parent material, intensive weathering of the soil minerals (Sanchez *et al*., 1997; Ssali *et al*., 1986) [13, 18] and also the reversion of soluble P into insoluble forms through reactions with iron and aluminum oxides. Therefore, large amounts of inorganic P fertilizer need to be applied to tropical soils to attain appreciable crop yields and that can be expensive to the farmer. If P supply is not adequate in such soils, crop response to other major nutrients including N would also be limited, hence, the overall fertility and productivity of the soils would be affected (Sahrawat *et al*., 2001) [12]. The rock phosphate replenishment of N through biological fixation, and also in the maintenance or improving soil chemical properties and soil fertility (Sahrawat *et al*., 2001) [13].

The dissolution of RP can be increased through microbial mediation. *Penicillium bilaii* produces citric and oxalic acids to solubilize calcium phosphate, Penicillium variable P16, also produces gluconic acid. Similarly, *Aspergillus niger* produces gluconic, citric and oxalic acids (Manguson & Lasure, 2004), as well as acid and alkaline phosphatases. The dissolution of different types of rock phosphate by *Aspergillus niger* has been well demonstrated. Also, ferric phosphate was best solubilized by *Aspergillus niger* (Naik et al., 2013) [9]. *Aspergillus terreus* solubilizes both organic and inorganic phosphates. Phosphate solubilization by microbes is mediated by several different mechanisms including organic acid production and proton extrusion. It is generally recognized that organic acids solubilize RP through protonation and/or chelation reactions. Besides the acid strength, the type and position of the ligand determine the effectiveness of the organic acid in the solubilization process.

The objectives of the study were
1. To study the effect of different sources of phosphorus and PSF on soil properties under rice.

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2. To study the effect of different sources of phosphorus and PSF on growth and yield of rice and

3. To study the effect of different sources of phosphorus and PSF on releasing pattern of Phosphorus in rice.

Material and Methods
A field experiment was conducted to study the effect of different sources of phosphorus and PSF on releasing pattern of phosphorus and its influence on growth and yield of rice during the *kharif* 2014 at Agricultural and Horticultural Research Station (AHRS) Kathalgere, which comes under University of Agricultural and Horticultural Sciences, Shivamogga and belongs to Southern Transitional Zone (zone-7) of Karnataka. It is situated at 12º 45' to 13º 57' north latitude and 76º 45' to 78º 24' east longitude with an altitude of 584.3 meters above mean sea level. A total rainfall of 605.8 mm was received in 82 rainy days during the year of investigation. As against the actual rainfall, the highest rainfall was recorded in the month of August 238.9 mm. The experiment with rice crop (*Oryza sativa,* L) var. JGL-1798 was laid out in Randomized Complete Block Design (RCBD) with three replications which includes T_1: RDF (P applied in the form of SSP), T_2: P applied in the form of SSP + PSF (*Aspergillus awamori*), T_3: 40 kg ha^{-1} P_2O_5 through rock phosphate, T_4: 50 kg ha^{-1} P_2O_5 through rock phosphate, T_5: 60 kg ha^{-1} P_2O_5 through rock phosphate, T_6: T_3 + PSF (*Aspergillus awamori*), T_7: T_4 + PSF (*Aspergillus awamori*) and T_8: T_5 +PSF (*Aspergillus awamori*) with recommended N, K and FYM are common to all the treatments.
Soil analyses Analyses were performed on air-dried soil fractions (< 2 mm). The soil pH was measured potentiometrically in 1:2 (w/v) suspension of water and in 0.01M $CaCl_2$. Organic carbon was determined by the Walkley & Black (1934) [1] method. The growth parameters *viz.,* few plants were randomly selected to recorded the plant height and number of tillers plant^{-1} were recorded on five randomly selected plants from each net plot at tillering, panicle initiation and at harvest stages of the crop. Soil of the experimental site belongs to sandy clay loam with sand content of 72.54 per cent, silt of 9.25 per cent and clay content of 18.21 per cent. The soil is acidic in reaction with a pH of 5.6. The salt concentration as measured by electrical conductivity (EC) was 0.05 dS m^{-1} at 25 ºC (table 1). The organic carbon content was 3.30 g kg^{-1}. The different P fractions in the soils of experimental site are as follows; the saloid P has a value of 10.95 mg kg^{-1}, Al – P: 82.78 mg kg^{-1}, Fe – P: 69.88 mg kg^{-1}, reductant – P: 30.49 mg kg^{-1}, occl – P: 27.13 mg kg^{-1}, Ca – P: 16.93 mg kg^{-1}, organic – P: 43.39 mg kg^{-1} and total – P: 281.58 mg kg^{-1}. Al – P is the major contributor to the total - P pool contributing (29.39%) followed by Fe – P (24.82%).

Results and Discussion
Effect of sources of phosphorus with and without PSF on different phosphorus fractions (mg kg^{-1}) after harvest of the rice crop: The results reveal that application of different sources of phosphorus with and without PSF increased the values of saloid – P fraction in soil at harvest (Table3). Higher values of saloid – P fractions were recorded in treatments involving P levels with PSF seedling treatment compared to application of only Phosphorus. The highest Saliod-P (21.23 mg kg^{-1}) was recorded when P applied in the form of SSP + PSF which is followed by the treatment when applied in the form of SSP which was 18.56 mg kg^{-1} and lowest (15.77 mg

kg^{-1}) was recorded in the treatment (T_3) 40 kg ha^{-1}P_2O_5 through rock phosphate in the form of nutriphos applied. These results are agreement with the findings of Singaram and Kothandaraman (1993) [17] who reported that application of Phosphorus irrespective of the sources tended to `increase the content of saloid – P. Singaram and Kothandaraman (1992) [16] reported that higher amount of saloid - P in soil was observed with water soluble P source. Incorporation of PSB with DAP and rock phosphate (RP) marginally increased saloid - P value compared to RP and DAP alone. They attributed it to complexation of phosphorus fixing metallic cations with organic acids released from phosphorus solubilizing microorganisms and preventing phosphorus to be adsorbed on soil particles.
Results on changes in Al – P fractions in soil at harvest reveal that application of different sources of P with and without PSF increased the Al – P fractions in soil at harvest (Table3). Higher values of Al – P fractions were recorded in treatments involving only phosphorus without PSF seedling treatment compared to application of Phosphorus sources with PSF seedling treatment. The highest Al – P was recorded when applied in the form of (123.17 mg kg^{-1}) and lowest (106.44 mg kg^{-1}) was recorded in the treatment which received 40 kg ha^{-1}P_2O_5 through rock phosphate in the form of nutriphos + PSF. This may be due to application of phosphorus fertilizers which increased the Al-P content in soil. This suggests that portion of added P was transformed in to Al - P. Treatments comprising application of water soluble P sources like SSP, favored greater formation and accumulation of Al - P content of soil. This may be attributed to dissolution of aluminium of the clay in the acid produced as a result of hydrolysis of SSP in soil. It corroborates with the findings of Sheshagiri Rao *et al.* (1972) [19] and Singaram and Kothandaraman (1992) [16] and Sheela (2006) [15].
Results on changes in Fe-p fractions in soil at harvest reveal that application of different sources of Phosphorus with and without PSF increased the Fe – P fractions in soil at harvest (Table3). Higher values of Fe – P fractions were recorded in the treatments involving only Phosphorus levels without PSF seed treatment compared to application of only P levels with PSF seed treatment. The highest Fe-p (mg kg^{-1}) was recorded in the treatment where Phosphorus applied in the form of SSP (108.85 mg kg^{-1}) followed by (T_2) P applied in the form of SSP + PSF (95.19 mg kg^{-1}) and lowest was recorded in the treatment where (T_6) 40 kg ha^{-1}P_2O_5 through rock phosphate in the form of nutriphos + PSF (80.85 mg kg^{-1}). Chang and Jackson (1957) and Yuan *et al.* (1960) observed that application of phosphatic fertilizers to acid soils increases the fixation and transformation of added phosphate into Fe - P. The reduction of Fe - P with P - solubilizer compared to phosphate fertilizers alone is ascribed to dissolution of iron oxide coatings with organic acids produced by phosphorus solubilizers causing reduction in Fe - P. These results corroborate with the findings of Sheela (2006) [15].
Results on changes in Reductent-P fractions in soil at harvest reveal that application of different sources of P with and without PSF increased the reductent-P fractions in soil at harvest (Table 13). Higher values of red soluble - P fractions were recorded in the treatments involving application of only phosphorus levels compared to phosphorus sources with PSF seed treatment. The highest reductent-P (62.85 mg kg^{-1}) was recorded in the treatment where P applied in the form of SSP followed by the treatment (T_2) when P applied in the form of SSP + PSF (57.96 mg kg^{-1}) and lowest (31.73 mg kg^{-1}) was

recorded in the treatment (T_6) where 40 kg ha^{-1}P_2O_5 through rock phosphate in the form of nutriphos + PSF. Addition of phosphorus fertilizers significantly increased the fixation and transformation of added Phosphorus in the soil. Application of SSP resulted in higher buildup of reductent soluble – P values compared to other treatments. Since, SSP is water soluble, readily reacts with ferric hydroxides, leading to conversion of water soluble form to insoluble form (Singaram and Kothandaraman, 1991) [17]. The reduction of red soluble - P with Phosphorus - solubilizers compared to fertilizers alone is attributed to dissolution of iron oxide coatings with organic acids produced by phosphorus solubilizers. These results are in agreement with the findings of Sheela (2006) [15].

Results on changes in occluded-P fractions in soil at harvest reveal that application of sources of P with and without PSF increased the occluded-P fractions in soil at harvest (Table3). Higher values of occluded– P fractions were recorded in treatments involving only P levels compared to application of P levels with PSF treatment. The highest values (30.75 mg kg^{-1}) were recorded in the treatment (T_1) where P applied in the form of SSP followed by the treatment (T_2) where P applied in the form of SSP + PSF (26.89 mg kg^{-1}) and lowest (22.85 mg kg^{-1}) was recorded in the treatment when 40 kg ha^{-1}P_2O_5 through rock phosphate in the form of nutriphos + PSF. The fixation and transformation of native and added Phosphorus to occluded – P is generally low (Ranjit, 2005) [10]. Treatments involving application of Phosphorus solubilizers recorded lower occluded - P values. This might be due to dissolution of Al - P and Fe - P present in the form of oxides of Fe and Al by the action of organic acids released by Phosphorus solubilizers. These results are in accordance with the findings of Goroji (2000) [5].

The changes in Ca-P fractions in soil at harvest reveal that application of different sources of Phosphorus with and without PSF increased the calcium-P fractions in soil at harvest (Table3). Higher values of Ca - P fractions were recorded in treatments involving application of P levels with PSF treatment compared to application of only P sources. The highest values (17.27 mg kg^{-1}) were recorded in the treatment where P applied in the form of SSP + PSF followed by the P applied in the form of SSP (15.10 mg kg^{-1}) and lowest (13.36 mg kg^{-1}) was recorded in the treatment when 40 kg ha^{-1}P_2O_5 through rock phosphate in the form of nutriphos. The buildup of Ca-P compared to rock phosphate in the Phosphorus applied soils as Phosphorus fertilizer alone or with P solubilizers was also observed by Mathan and Biju Joseph (1998) [6].

Results on changes in Organic-P fractions in soil at harvest indicate that application of different sources of phosphorus with and without PSF increased the Organic-P fractions in soil at harvest (Table3) reveal that increased P levels with and without PSF increased the organic - P fractions in soil at harvest. The highest values (35.07 mg kg^{-1}) were recorded in the treatment when P applied in the form of SSP followed by the treatment where P applied in the form of SSP + PSF (30.67 mg kg^{-1}) and lowest (26.04 mg kg^{-1}) was recorded in the treatment where 40 kg ha^{-1}P_2O_5 through rock phosphate in the form of nutriphos + PSF applied. This is due to excess P may be inhibited phosphorylase activity and consequently suppressed the mineralization processes and favored a buildup organic P. Soil microorganisms also play an important role in organic P transformations in soil through excretion of enzymes like phosphatase and dehydrogenase. Phosphatase catalyses the hydrolysis of esters and anhydrides of phosphoric acid and thus its activity indicates the mineralization potential of organic P in soils (Dick and Tabatabai, 1993) [4].

Results on changes in total- P fractions in soil at harvest reveal that application of sources of P with and without PSF increased the Total- P fractions in soil at harvest (Table3) reveal that increased P levels with and without PSF increased the total- P fractions in soil at harvest. The highest values (394.35 mg kg^{-1}) were recorded in the treatment where P applied in the form of SSP followed by the treatment where P applied in the form of SSP + PSF (362.11 mg kg^{-1}) and lowest (297.55 mg kg^{-1}) was recorded in the treatment which receives 40 kg ha^{-1}P_2O_5 through rock phosphate in the form of nutriphos + PSF. There was significant increase in total – P in the soil with application of P fertilizers. These results corroborates with the findings of Sheela (2006) [15] and Ranjit (2005) [10].

Release of available phosphorus at different periods of incubation influenced by different sources of phosphorus and PSF application: Results presented in (Table 4) indicated that after the 30 days of incubation the highest available phosphorus status (44.82 mg kg^{-1}) in soil was recorded in the treatment when P applied in the form of SSP + PSF, which is followed by the treatment which received only SSP (43.13 mg kg^{-1}). The lowest available phosphorus (44.82 mg kg^{-1}) was recorded in T_3 (40 kg ha^{-1}P_2O_5through rock phosphate in the form of nutriphos). Significantly higher available phosphorus was recorded with the application of SSP + with or without PSF over all other treatments at all the periods of incubation. This might be due to combined effect of higher water solubility of super phosphate, hydroxylation and change in soil pH under flooded conditions resulted in more release of available phosphorus in to soil solution than other P-sources and also the available phosphorus content was increased under submerged condition due to transformation of ferric phosphate to highly soluble form under reduced environment prevailing in submerged condition of soil increased the available phosphorus content of soil. These were in agreement with the findings of Sushma (1990), Rastogi et al. (1976) [11] and Mandal and khan (1972) [7]. Less amount of available P in nutriphos treated plots is to its less water soluble nature.

After 60 days (Table4) of incubation highest available phosphorus status in soil (43.92 mg kg^{-1}) was recorded in the treatment when P applied in the form of SSP + PSF followed by (T_1) P applied in the form of SSP (42.27 mg kg^{-1}). The lowest available phosphorus (32.78 mg kg^{-1}) was recorded in T_3 (40 kg ha^{-1}P_2O_5through rock phosphate in the form of nutriphos). The available P content increased consistently up to 60 days irrespective of treatments. There was a slight decrease in available phosphorus contents of water soluble sources due to fixation of phosphorus, in slow relishing phosphorus fertilizers there is increase in available phosphorus compared to 30 days of incubation. The results were in agreement with findings of Channna Keshava et al. (2006) [2].

After 90 days of incubation, the highest available phosphorus status in soil (41.72 mg kg^{-1}) was recorded (Table4) in treatment T_2 (P applied in the form of SSP + PSF) and it was on par with the treatment T_1 where phosphorus applied in the form of SSP (42.27 mg kg^{-1}), while treatment T_8 where 60 kg ha^{-1}P_2O_5 through rock phosphate in the form of nutriphos+ PSF (39.70 mg kg^{-1}). The lowest available phosphorus (36.06

mg kg^{-1}) was recorded in T_3 40 kg ha^{-1}P$_2$O$_5$through rock phosphate in the form of nutriphos). This may be due to quick solubility of SSP released sufficient quantity of phosphorus at the initial period and further steady state was maintained as phosphorus released slowly from the fixed form as the period of submergence proceeds, despite the fixation of phosphorus as AI-P and Fe-P. The more availability of phosphorus in nutriphos applied plots compared to 60 days is due to less fixation compared to conventional sources. Similar results were also obtained by Mandal and Khan (1972) [7] and Sarkar *et al*. (1986) [14].

Relationship (r values) between grain yield and phosphorus fraction of soil after harvest
Simple correlation coefficient (r) observed between grain yield and different phosphorus fractions are presented in Table 5. The grain yield of rice is positively and significantly correlated with saliod-P (r=0.857**), aluminium-P (r= 0.745**), iron-P (r=0.865**), reductent-P (r=0.883**), Occluded-P (r= 0.838**), Calcium-P (r=0.837**), organic-P (r=0.877**) and Total-P (r=0.873**).

Table 1: Effect of different sources of phosphorus with and without PSF on soil properties after harvest of the rice crop

Treatments	pH	EC (dS m^{-1})	OC (g kg^{-1})
T_1: RDF (P applied in the form of SSP)	5.44	0.05	3.20
T_2: P applied in the form of SSP + PSF (*Aspergillus awamori*)	5.57	0.05	3.29
T_3: 40 kg ha^{-1} P$_2$O$_5$ through rock phosphate	5.44	0.04	3.48
T_4: 50 kg ha^{-1} P$_2$O$_5$ through rock phosphate	5.40	0.04	3.52
T_5: 60 kg ha^{-1} P$_2$O$_5$ through rock phosphate	5.38	0.04	3.59
T_6: T_3 + PSF (*Aspergillus awamori*)	5.46	0.05	3.65
T_7: T_4 + PSF (*Aspergillus awamori*)	5.43	0.05	3.83
T_8: T_5 + PSF (*Aspergillus awamori*)	5.38	0.05	3.87
SEm±	0.05	0.002	0.02
CD @ 5%	NS	NS	0.05

NS = Non significant

Table 2: Effect of different sources of phosphorus with and without PSF on yield attributes of grain and straw (q ha^{-1}) yield of rice

Treatments	Grain yield (q ha^{-1})	Straw yield (q ha^{-1})
T_1: RDF (P applied in the form of SSP)	54.49	65.37
T_2: P applied in the form of SSP + PSF (*Aspergillus awamori*)	59.55	73.42
T_3: 40 kg ha^{-1} P$_2$O$_5$ through rock phosphate	50.54	61.49
T_4: 50 kg ha^{-1} P$_2$O$_5$ through rock phosphate	53.71	65.07
T_5: 60 kg ha^{-1} P$_2$O$_5$ through rock phosphate	53.47	67.22
T_6: T_3 + PSF (*Aspergillus awamori*)	53.71	72.46
T_7: T_4 + PSF (*Aspergillus awamori*)	61.27	76.86
T_8: T_5 + PSF (*Aspergillus awamori*)	60.45	75.60
SEm±	1.53	1.49
CD @ 5%	4.67	4.53

Table 3: Effect of different sources of phosphorus with and without PSF on different phosphorus fractions (mg kg^{-1}) after harvest of the rice crop

Treatment	Saliod-P	Aluminium-P	Iron-p	Reductent-P	Occluded-P	Calcium-P	Organic-P	Total- P
T_1: RDF (P applied in the form of SSP)	18.56	123.17	108.85	62.85	30.75	15.10	35.07	394.35
T_2: P applied in the form of SSP + PSF (*Aspergillus awamori*)	21.23	112.90	95.19	57.96	26.89	17.27	30.67	362.11
T_3: 40 kg ha^{-1} P$_2$O$_5$ through rock phosphate	15.77	110.70	84.08	33.00	23.76	13.36	27.09	307.75
T_4: 50 kg ha^{-1} P$_2$O$_5$through rock phosphate	15.93	111.82	84.93	33.33	24.00	12.96	27.36	310.32
T_5: 60 kg ha^{-1} P$_2$O$_5$ through rock phosphate	16.42	114.60	93.27	46.17	26.35	13.36	30.05	340.22
T_6: T_3 + PSF (*Aspergillus awamori*)	16.40	106.44	80.85	31.73	22.85	13.34	26.04	297.65
T_7: T_4 + PSF (*Aspergillus awamori*)	16.56	107.51	81.66	32.05	23.08	13.48	26.31	300.65
T_8: T_5 + PSF (*Aspergillus awamori*)	18.19	110.84	84.19	33.04	23.79	14.80	27.12	311.97
SEm±	0.24	0.47	0.33	0.39	0.47	0.322	0.57	1.56
CD @ 5%	0.72	1.43	1.02	1.20	1.44	0.97	1.74	4.73

Table 4: Available phosphorus at different periods of incubation as influenced by different levels and sources of phosphorus and PSF application

Treatment	Incubation period in days [Available P$_2$O$_5$ (mg kg^{-1})]		
	30	60	90
T_1: control (P applied in the form of SSP)	43.13	42.27	40.15
T_2: control (P applied in the form of SSP) + PSF (*Aspergillus awamori*)	44.82	43.92	41.72
T_3: 40 kg ha^{-1} P$_2$O$_5$ through Nutriphos	29.80	32.78	36.06
T_4: 50 kg ha^{-1} P$_2$O$_5$ through Nutriphos	31.00	34.10	37.51
T_5: 60 kg ha^{-1} P$_2$O$_5$ through Nutriphos	32.13	35.34	38.88
T_6:T_3+PSF(*Aspergillus awamori*)	30.44	33.48	36.83
T_7:T_4 + PSF(*Aspergillus awamori*)	31.66	34.83	38.31
T_8:T_5 +PSF(*Aspergillus awamori*)	32.81	36.10	39.70
SEm±	0.15	0.16	0.17
CD @ 5%	0.45	0.47	2.65

Table 5: Correlation coefficient (r) between grain yield and phosphorus fraction of soil at harvest

Phosphorus fraction	r value
Saliod-p	0.857**
Aluminium-P	0.745**
Iron-p	0.865**
Reductent-p	0.883**
Occluded-P	0.838**
Calcium-P	0.837**
Organic-P	0.877**
Total- P	0.873**

Note: *-significant @ 5 percent: **-significant @ 1 percent

Conclusion
Effect of different sources of phosphorus with and without PSF on release of phosphorus and different phosphorus fractions in rice (*Oryza sativa* L.). The application of different sources of phosphorus with and without PSF treatment significantly increased the values of saloid – P and Ca – P fraction in soil at harvest stages. Higher values of saloid – P and Ca – P fractions were recorded in treatments involving P levels with PSF treatment compared to application of only P levels. The highest saliod-P (21.23 mg kg^{-1}) was recorded with the treatment where P applied in the form of SSP + PSF. The lowest was recorded in treatment where 40 kg ha^{-1} P$_2$0$_5$ through rock phosphate in the form of nutriphos (15.77 mg kg^{-1}). Significant increases in Al - P, Fe – P, red – P, occl – P, organic – P and total - P fractions in soil due to P levels with and without PSF treatment. Higher values of Al - P, Fe – P, red – P, occl – P, organic – P and total - P fractions were recorded in treatments involving P levels without PSF treatment compared to the application of only P levels with PSF treatment. The highest aluminum-P (123.17 mg kg^{-1}) was recorded in the treatment where phosphorus applied in the form of SSP. The lowest aluminum-P was recorded in treatment where40 kg ha^{-1} P$_2$0$_5$ through rock phosphate in the form of nutriphos + PSF (106.44 mg kg^{-1}).

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