



Developed and Evaluation of Slow Release Phosphorus Fertilizer Using Mono-ammonium Phosphate and Di-ammonium Phosphate

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Authors' contributions

This study was carried out in collaboration among all authors. Authors KR and AG designed the study, performed the experimental process and wrote the first draft of the manuscript. Authors HEM and AM managed the analysis of the experiment and literature searches. All authors read and approved the final manuscript

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ABSTRACT

Phosphorus (P) availability is generally low in Calcareous soils due to its association with soil constituents forming other P compounds that are of low solubility and availability for plant uptake. In particular, phosphorus use efficiency (PUE) in Saudi Arabia agricultural soils is very low. Therefore, there is a growing interest in finding an effective approach to improve PUE. Fertilizer coating with polymers has become a recognized strategy for controlling the release of nutrients and regulating their availability in the soil. In this study, two fertilizers types of phosphate-bound alginate-graft polyacrylamide (P-Alg-g-PAM) were prepared using mono-ammonium phosphate (MAP) and di-ammonium phosphate (DAP). A matrix of sodium alginate (Alg) and poly (vinyl alcohol) (PVA) was phosphorylated using either MAP or DAP, followed by grafting with acrylamide. An incubation study was conducted by using three soils with different CaCO₃ content to evaluated the performance of developed fertilizer (slow-release MAP and slow-release DAP) compared with

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the commercial MAP and DAP fertilizer. The developed fertilizer exhibited P release of 77% for the slow release MAP and 57% for the slow release DAP until the 45 days of the application at pH 7 and 25°C. The results of incubation study, indicated that the available soil-P significantly ($P < 0.05$) varied between the different P fertilizers. In the beginning of the incubation period, the available soil-P into different soil from slow-release MAP and DAP was slightly lower than the commercial MAP and DAP, but with the time proceed, the slow-release MAP and slow-release DAP resultant in more available soil-P than the uncoated MAP and uncoated DAP. The results indicated that, the fertilizers could be classified into two groups: the first "fast release" group showed total P release in the 10 days after incorporation of uncoated MAP and uncoated DAP fertilizers into soil. The second "slow release" group included coated slow-release MAP and coated slow-release DAP fertilizer, released of about 70% during the period of 10-30 days after incubation. The results of P fractionation chemical analysis indicated that, the soluble, exchangeable-P, Ca-occluded-P fraction, was the most dominated P forms distributed among the soils.

Keywords: Fertilizers; mono-ammonium phosphate (MAP); di-ammonium phosphate (DAP); controlled phosphorus release; calcareous soil.

1. INTRODUCTION

The fixation of phosphorus (P) as calcium phosphates in alkaline soils is defined as a historical problem of soil science [1]. This historical problem corresponds to very low phosphorus use efficiency (PUE) of applied P-fertilizer into the soil system even after applied the best cultural practices. Along with low PUE, the deficiency of P in soils across the globe is also wide-spread with 43% of the world soils being P-deficient [2]. In addition, most of P-fertilizers applied to soil system are derived from rock phosphates (RP) which is a finite, non-renewable natural resource with an estimated life-span of 105-470 years [3]. Current levels of food production is not possible without this finite storage and considering long-term food security it is imperative that the use of rock phosphate (RP) in sustainable and equitable manner is not only intra-generation matter but also an inter-generational perspective [4]. Several studies deal with concerns about the longevity of the supply of the mineral phosphate [5]. The finite nature of the RP reserves along with the low use efficiency have triggered many research to improve the PUE from different P sources along with exploiting the low-grade P reserves of poor economic viability to find some alternative source to the costly P-fertilizers.

The recent advancements in P-fertilizers involves coating of soluble P sources such as mono-ammonium phosphate (MAP) and di-ammonium phosphate (DAP) with hydrophobic or partially hydro-phillic compounds [6] or mixture with superabsorbent [7], nano-sized clay particles [8, 9] or RP mixed with organic acid loaded nano clay polymer composites [10-12]. These

technologies have proved to be promising alternative sources to the costly P-fertilizers as well as improved the PUE but have not yet been adopted at large scale. Besides these, the recent development in smart fertilizer delivery systems or the new generation fertilizers is a good alternative to commercially available P fertilizers to improve the PUE and therefore, enhance resource utilization [13,14].

The control release fertilizer (CRF) is the kind of new generation fertilizer which is designed to release plant nutrients in a steady manner so as to synchronize the release with crop demand [15]. This technology not only helps in improving the nutrient use efficiency but also suggests a suitable mechanism to reduce environmental hazards posed by indiscriminate and excessive use of fertilizers [16,17]. In general, CRF exhibit numerous preferences over the traditional water soluble fertilizers, for example, savings in huge quantities of fertilizers, reducing the rate of release of fertilizer nutrients and thus supplying nutrients to crops for longer period of growth, and increase CRF [18]. In the recent, there is renewed interest to establish this concept for developing new CRF. One of the possible means of applications of CRF is to apply them in association with super-absorbent which is able to release their nutrient in a controlled manner [19]. Also, various coating agents can be employed to regulate the nutrient release. Roy et al., [20] reported that, polymer coating of mono-ammonium phosphate (MAP) granules increased the fertilizer PUE up to 32.6%.

Therefore, attempts by several research groups to overcome such problem have been examined. The use of slow or controlled release fertilizer

(CRF) was used and in this technique, the P fertilizer is generally fixed to a matrix, usually a polymer, and released at a slower rate. However, very limited studies are available on the development and evaluation of CRF in arid and semi-arid soils. In this study, we investigated the assessment and evaluation of phosphorylated alginate controlled release properties in laboratory and incubation experiments compared with conventional water soluble P-fertilizers like mono-ammonium phosphate (MAP) and di-ammonium phosphate (DAP).

2. MATERIALS AND METHODS

2.1 Fertilizers

To improve phosphorus use efficiency, two fertilizers types of phosphate-bound alginate-graft-polyacrylamide (P-Alg-g-PAM) were prepared using mono-ammonium phosphate (MAP) and di-ammonium phosphate (DAP) fertilizer. A matrix of sodium alginate (Alg) and polyvinyl alcohol (PVA) was phosphorylated using either MAP or DAP fertilizer, followed by grafting with acrylamide. Slow-release phosphate-bound alginate-graft-polyacrylamide (P-Alg-g-PAM) using mono-ammonium phosphate (MAP) and di-ammonium phosphate (DAP) were developed and characterized.

2.2 Soil

Three soils were collected from different locations based on CaCO_3 content; the 1st soil was collected from the Experimental and Research Farm at Dirab, 25 km from South Riyadh, while the 2nd and 3rd samples collected from Al Kharj city 80 km from South east of Riyadh.

2.3 Soil Analysis

The collected samples were air-dried, ground and passed through a 2-mm sieve. Total carbonate was estimated according to [21]. Total soluble salts were determined by measuring the electrical conductivity (EC) of saturated soil paste extract as described by [22]. Soil pH was determined through a suspension sample with a soil air-dried to water (w/w) ratio of 1:2.5 and measured with a pH-meter. Soil organic matter was determined by wet oxidation [23]. Available concentrations of N, P and K were extracted and determined as described by [24]. Particle size distribution of soil was carried out using the pipette method as described by [25]. Some

physical and chemical properties of the different soil are presented in (Tables 1a, 1b and 1c).

2.4 Incubation Experiment

An incubation experiment was carried out to evaluate the release of P into soils from MAP-uncoated, DAP-uncoated, MAP-modified Alg-g-PAM (refer to MAP + polymer) and DAP-modified Alg-g-PAM (refer to DAP + polymer) at the Soil Science Department, Faculty of Agriculture and Food Sciences, King Saudi University, Saudi Arabia. The experiments were carried by using 1 g of phosphorylated alginate. The experiment was conducted with 3 soils with different CaCO_3 content (14%, 33% and 43%) and 4 fertilizer types (MAP-uncoated, DAP-uncoated, MAP + polymer and DAP + polymer) in a completely randomized design (CRD) with three replications. In brief, 1 g of fertilizer was mixed with 200 gm air-dried soil in a 250 ml glass beaker. After incorporation of the granules, soil moisture was maintained to 75% of water-holding capacity and was maintained constant during the incubation period with the addition whenever necessary. The samples were incubated at a controlled temperature of 25°C for 1, 5, 15, 20, 25, and 30 days. After each incubation period, destructive soil samples were drawn and extracted by Olsen reagent (0.50 M NaHCO_3 , at pH 8.50) as per the procedure outlined by [26] followed by estimation of P in the extract by ascorbic acid blue colour method [27] using a single beam spectrophotometer (9100 UV-vis Model).

2.5 Sequential P Fractionation

Another experiment was conducted to determine the sequential P fractionation using the same soils. The samples in previous experiment were incubated at 25°C and 70% of soils field capacity. Represented sub-soil samples were collected at 5, 15, and 30 days after incubation and analyzed for P sequential fractionation. A sequential P fractionation method described by [28] with a slight modification, as outlined by [29]. Briefly, (1 g) soil sample was extracted with 25 mL of 0.50 M NaHCO_3 solution and shaken for 16 hours, and then the solution was centrifuged at 4000 rpm for 10 minutes to extract soluble and exchangeable-P and the remaining soil sample was then saved for subsequent extractions. The P bound to Al and Fe hydroxide minerals was extracted by adding 25 mL of 0.10 M NaOH solution to the soil sample from the previous extraction and shaken 16 hours. The solution was then centrifuged at

4000 rpm for five minutes and analyzed for Fe and Al phosphate concentration. The Ca-bound P was extracted by adding 25 mL of 1.0 M HCl to the soil sample and shaken 16 hours. The supernatant was then centrifuged at 4000 rpm for five minutes and analyzed for Ca phosphate concentration. The residual P was digested by adding 10 mL of concentrated HNO₃ to the soil sample according to the EPA method [30].

2.6 Statistical Analysis

The statistical analysis was done using Statistical analytics platform v13.1. The significance of the differences was evaluated by using one-way analysis of variance (ANOVA). Where *P* value <0.05 was considered as statistically significant.

3. RESULTS AND DISCUSSION

3.1 Properties of Slow-release MAP, DAP and Soil

The physical and chemical properties of soil used in this study are listed in Tables 1a, 1b and 1c. The soil texture was sandy loam and sandy clay loam, the soil pH was varied from 7.20 to 8.40 and with EC value ranged from 0.30, 2.17 and 7.20 dS m⁻¹ in soil-1, soil-2 and soil-3, respectively. In addition, results indicated that the percentage of CaCO₃ was relatively high and varied from 14%, 33% and 43% in soils-1, soil-2 and soil-3, respectively, which is considered the most critical factor to fix phosphorus as calcium phosphate, which will not be available for plant uptake. Also the P fractions of original soil at start of the experiment varied among the soil (Tables 1a, 1b and 1c).

3.2 Available Soil-Phosphorus

Influence of addition of uncoated MAP, uncoated DAP, slow-release MAP and slow-release DAP on soil available-P are presented in Table 2, Figs. 1, 2 and 3. Results from laboratory incubation experiments indicated that the available soil-P significantly (*P*<0.05) varied between the different P fertilizers. The available P into different soil from coated slow-release MAP and DAP was lower throughout the incubation period than the commercial MAP and commercial DAP. The results demonstrated that the soil available-P differs widely among the fertilizer type and decreased substantially with time of incubation. The addition of MAP and DAP chemical fertilizers increase the amount of available P in the different soil in the day to 5 days after incubation and then decreases as time

of incubation goes on. The decreases in soil available-P may be attributed to time-dependent reactions involving the sorption and precipitation of added and native P [31-33]. Fig. 4 shows effects of soil type on P availability during the different incubation periods. The results indicated that the soils with different CaCO₃, the available soil-P significantly (*P*<0.05) varied between the different soil in which soil-1 resulted in higher amounts of available soil-P compared with soil-2 and soil-3. The results found a highly negative correlation (*R*² = 0.913) between available soil-P and CaCO₃ content in soil (Fig. 4).

3.3 Phosphorus Release Behavior

Slow-release of P is the most important property. Phosphorus release behavior of coated slow-release MAP and DAP in different soils. Figs. 5, 6 and 7 show a plot of the released P against incubation period. Results emanated from laboratory incubation experiments indicated that P release into different soil from coated slow-release MAP and DAP was lower throughout the incubation period than the commercial MAP and commercial DAP. About 80% of phosphate was released into soil from the commercial MAP and commercial DAP fertilizer by the 5 days after incubation as presented in. Compared with the uncoated MAP and uncoated DAP fertilizer, the release rate of P from different soil as shown in Figs. 5, 6 and 7 decreased sharply, but still obviously higher than that from the slow-release MAP and slow-release DAP fertilizers. This indicated that the coated slow-release MAP and slow-release DAP had a good slow-release-property, which agreed with the standard of slow-release fertilizers of the committee of European Normalization [34,35]. The results indicated that, the fertilizers could be classified into two groups: the first "fast release" group showed total P release in the 10 days after incorporation of uncoated MAP and uncoated DAP fertilizers into soil (Figs. 5, 6 and 7). The second "slow release" group showed release of around 70% during the incubation periods between 10 and 30 days after incubation and included coated slow-release MAP and coated slow-release DAP fertilizer (Figs. 5, 6 and 7). It is well-known that phosphate would dissolve quickly in the water after being added into the soil, and the P in it released into soil. The slow-release MAP and slow-release DAP would dissolve slowly due to an increase in chain length. The coating superabsorbent MAP and DAP polymers would absorb water slowly in soil and swell after being

added into soil, which would contribute to an increase in the pore size of the three-dimensional network and benefit the diffusion of the fertilizer solution in the hydrogel network. MAP and DAP in the core of coated slow-release MAP and DAP fertilizer would dissolve slowly in water absorbed in the swollen hydrogel network. There exists a dynamic exchange between the free water in the hydrogel and one in soil [36], and then the fertilizer would release slowly into the soil through the grids with dynamic exchange [37,38].

The variation in P release pattern into soil under controlled temperature was observed during the incubation. The release of P from different soil followed in the decreasing order of soil-1 > soil-2 > soil-3. The coating superabsorbent polymers MAP and DAP would absorb slowly the water in soil and swell after being added into soil, which would contribute to an increase in the pore size of the three-dimensional network and benefit the diffusion of the fertilizer solution in the hydrogel network [36, 39]. The results indicated that, the release rate of P from the coated materials into soil was significantly lesser than the commercial DAP under controlled laboratory conditions which establishes the slow-release behavior of the coated slow-release MAP and coated slow-release DAP fertilizer which are likely to reduce P-fixation in soil and maintain a higher amount of bio-available P in soil solution, thus supply P to crops over a long times. The coated slow-release MAP and coated slow-release DAP fertilizer released lesser amounts of P presumably because of reduction of effective surface area available for contact between the core of manufactured products and the soil. This might be the reason for slow-release coating materials to slow down the movement of P into the soil and also reduce the volume of the soil in contact with manufactured coated products. This result is in agreement with the results of [35]. He and Hu [40] synthesized a novel water insoluble slow release fertilizer, biuret poly phosphoramidate using urea, phosphoric acid and ferric oxide, which contain 5.6% N and 11.7% P. Their results indicated that the product not only had good slow release property and excellent water retention capacity but also higher adsorption capacities of cations in saline soil. Throughout the incubation period, the extent of release rate of P varied from different products indicating their differential release pattern which directly or indirectly depends on type of acids, coating agents, coating levels, contact time between soil and applied P sources, temperature and soil moisture content [41]. Irrespective of coating agents, soil-1

had released significantly higher amount of P than the other soil-2 and soil-3 during each interval of sampling. Between the two coating agents, there was distinct variation in release of P during incubation experiments. As presented in Figs. 5, 6 and 7, it observed that MAP coated polymer released higher amount of P over the DAP coated polymer at different incubation period. The data in tables and figures shows that after 10 days from the incubation, the P release rate of MAP coated polymer and DAP coated polymer was higher than the commercial MAP and DAP. The fast releasing P-fertilizers supports better root establishment, but this might be depended on the concentration of solution P instead of total P present in soil. Commercial MAP and DAP fertilizers released its entire active-P into soil too early compared to the establishment time of root and formed insoluble inert initial reaction products in soil. However, the controlled release fertilizer (CRF) are able to release their nutrient contents gradually which coincide with the nutrient requirement of the plants [19]. Timothy et al. [42] reported that release rates of P from CRF products were slower than those for $\text{NH}_4^+\text{-N}$, $\text{NO}_3^-\text{-N}$. Improved growth and yield with CRF compared with soluble MAP and DAP fertilizers have been documented in potato [43].

3.4 Soil-Phosphorus Fractions

Tables 3a, 3b and 3c present the effects of fertilizers types and incubation periods on P fractions, which include the soluble and exchangeable-P, Al and Fe-bound- P, Ca-bound- P, and residual- P as discussed below. The results indicated that soluble, exchangeable-P, Al and Fe-bound- P, Ca-bound- P, and residual- P varied among different soils and fertilizers type. In soil-1, 2 and 3 and 5 days after incubation, the uncoated MAP fertilizer exhibited the highest concentration of soluble and exchangeable-P and Ca-bound- P compared with other P fertilizers. Similar trend were observed at 15 and 30 days of incubation. The results indicated that the amount of the Al-Fe P fraction was very low compared to other P fractions. This caused by the high original concentration of Ca in studied soil which ranged from 14% to 43%, which was responsible for determining the ion speciation in the soil solution [44]. The results indicated that, Ca-occluded P fraction is the main P fraction in the studied soil and ranged from 50.0% to 60% from the total P concentration. This supports the earlier observations that most Saudi soils are dominated by the Ca-P fraction [45,46].

Table 1a. Physico-chemical properties and P fractionation of original (Soil 1) at the start of experiment

pH	Ec (dS m ⁻¹)	OM	CaCO ₃	Cations				Anions				Available nutrients						Particle size distribution			Texture class	
				Ca ⁺²	Mg ⁺²	Na ⁺¹	K ⁺¹	Cl ⁻¹	HCO ₃ ⁻¹	CO ₃ ⁻²	SO ₄ ⁻²	N	P	K	Fe	Zn	Cu	Mn	Sand	Silt		Clay
7.50	0.3		%	(meq L ⁻¹)								(mg kg ⁻¹)						%			Sandy loam	
		0.22	14	4	3	11.36	13.65	3.4	3.6	0.00	10.3	2.70	3.12	66.8	2.24	0.42	0.12	1.02	76	8	16	
Phosphorous fractionation (mg kg ⁻¹)																						
NaHCO ₃ -P (Soluble and exchangeable – P)						NaOH-P (Fe & Al -P)				HCl-P (Ca –P)				Residual - P						Total- P		
8.69						6.00				227.7				31.35						273.7		

Table 1b. Physico-chemical properties and P fractionation of original (Soil 2) at the start of experiment

pH	Ec (dS m ⁻¹)	OM	CaCO ₃	Cations				Anions				Available nutrients						Particle size distribution			Texture class	
				Ca ⁺²	Mg ⁺²	Na ⁺¹	K ⁺¹	Cl ⁻¹	HCO ₃ ⁻¹	CO ₃ ⁻²	SO ₄ ⁻²	N	P	K	Fe	Zn	Cu	Mn	Sand	Silt		Clay
7.20	2.17		%	(meq L ⁻¹)								(mg kg ⁻¹)						%			Clay loam	
		3.4	33	21.4	4.6	14.76	60.45	4.6	5.20	0.00	14.3	6.23	2.60	89.3	1.9	0.41	0.12	1.2	60	16	24	
Phosphorous fractionation (mg kg ⁻¹)																						
NaHCO ₃ -P (Soluble and exchangeable – P)						NaOH-P (Fe & Al -P)				HCl-P (Ca –P)				Residual - P						Total- P		
5.94						5.08				317.9				71.65						400.6		

Table 1c. Physico-chemical properties and P fractionation of original (Soil 3) at the start of experiment

pH	Ec (dS m ⁻¹)	OM	CaCO ₃	Cations				Anions				Available nutrients						Particle size distribution			Texture class	
				Ca ⁺²	Mg ⁺²	Na ⁺¹	K ⁺¹	Cl ⁻¹	HCO ₃ ⁻¹	CO ₃ ⁻²	SO ₄ ⁻²	N	P	K	Fe	Zn	Cu	Mn	Sand	Silt		Clay
8.40	3.50		%	(meq L ⁻¹)								(mg kg ⁻¹)						%			Sandy loam	
		0.27	43	19.7	11.0	3.20	0.44	11.4	0.50	0.00	23.1	4.80	2.60	56.5	2.78	0.32	0.17	1.15	70.3	16.0	13.7	
Phosphorous fractionation (mg kg ⁻¹)																						
NaHCO ₃ -P (Soluble and exchangeable – P)						NaOH-P (Fe & Al -P)				HCl-P (Ca –P)				Residual - P						Total- P		
3.68						7.13				198.2				62.0						271.0		

Table 2. The soil available-P from the prepared phosphorus fertilizer compared with uncoated MAP and DAP in different soil at different time of incubation

Treatments		Available phosphorus (mg kg ⁻¹)						Mean LSD _{0.05} = 12.0	Mean LSD _{0.05} =6.6
		1 Day	5 Days	10 Days	15 Days	20 Days	30 Days		
Soil- 1	DAP- uncoated	176.7	146.8	58.9	18.2	37.1	25.6	77.2 c	92.3 a
	MAP-uncoated	239.7	268.7	79.9	25.5	30.3	26.3	111.7 a	
	DAP + Polymer	48.9	29.6	48.9	129.2	157.7	159.5	95.6 b	
	MAP + Polymer	44.6	38.0	44.6	116.8	114.5	120.0	79.8 c	
Soil -2	DAP- uncoated	194.4	125.8	59.9	14.6	27.7	19.3	73.6 c	88.4 ab
	MAP-uncoated	221.7	213.8	73.9	21.6	30.6	28.6	98.4 b	
	DAP + Polymer	60.8	52.6	60.8	130.3	150.0	155.6	101.7 ab	
	MAP + Polymer	59.7	46.7	71.3	140.8	122.0	125.5	94.3 b	
Soil- 3	DAP- uncoated	184.9	131.8	66.5	16.9	29.8	27.3	76.2 c	82.4 b
	MAP-uncoated	219.8	204.5	77.9	26.5	41.2	32.3	100.4 ab	
	DAP + Polymer	44.8	32.9	54.7	108.0	138.8	140.5	76.9 c	
	MAP + Polymer	54.0	71.9	62.0	41.5	81.5	102.3	79.7 c	
Mean LSD _{0.05} = 8.5		129.2 a	1113.6 b	63.3 e	70.9 de	80.5 c	75.3 cd		

*Soil 1, CaCO₃=14%; Soil 2, CaCO₃=33% and Soil 3, CaCO₃ =43%

Table 3a. P fractions as influenced by different fertilizers type at 5 days after incubation

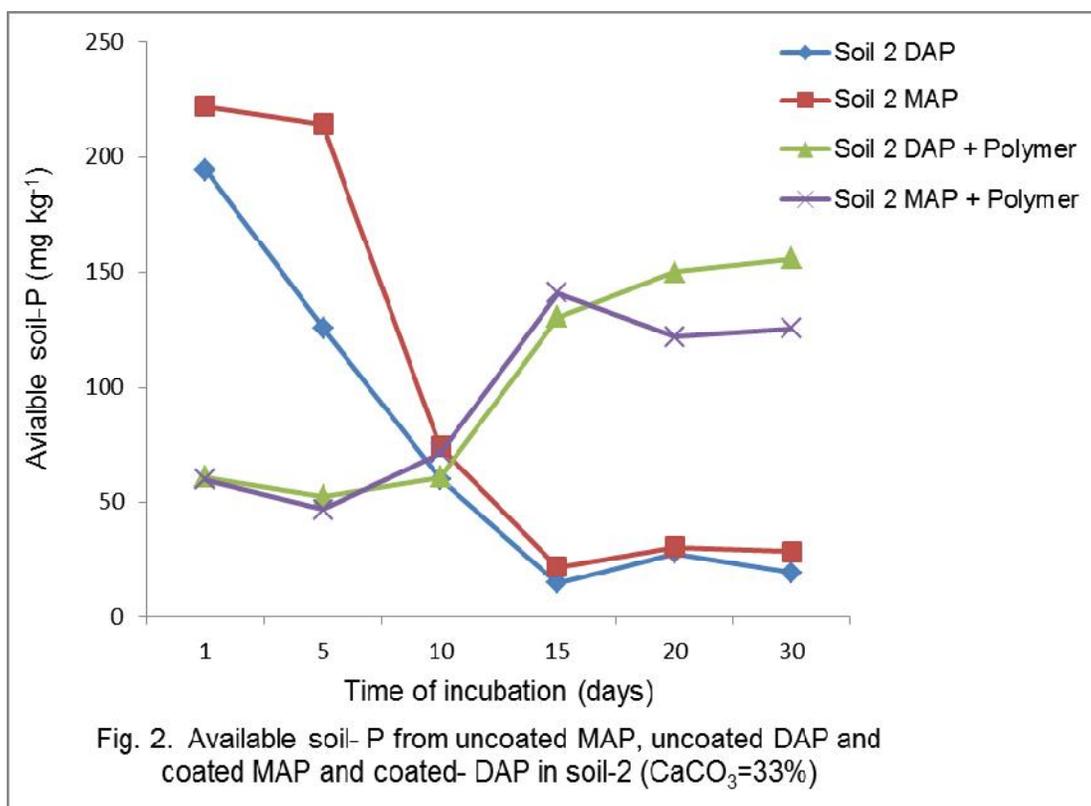
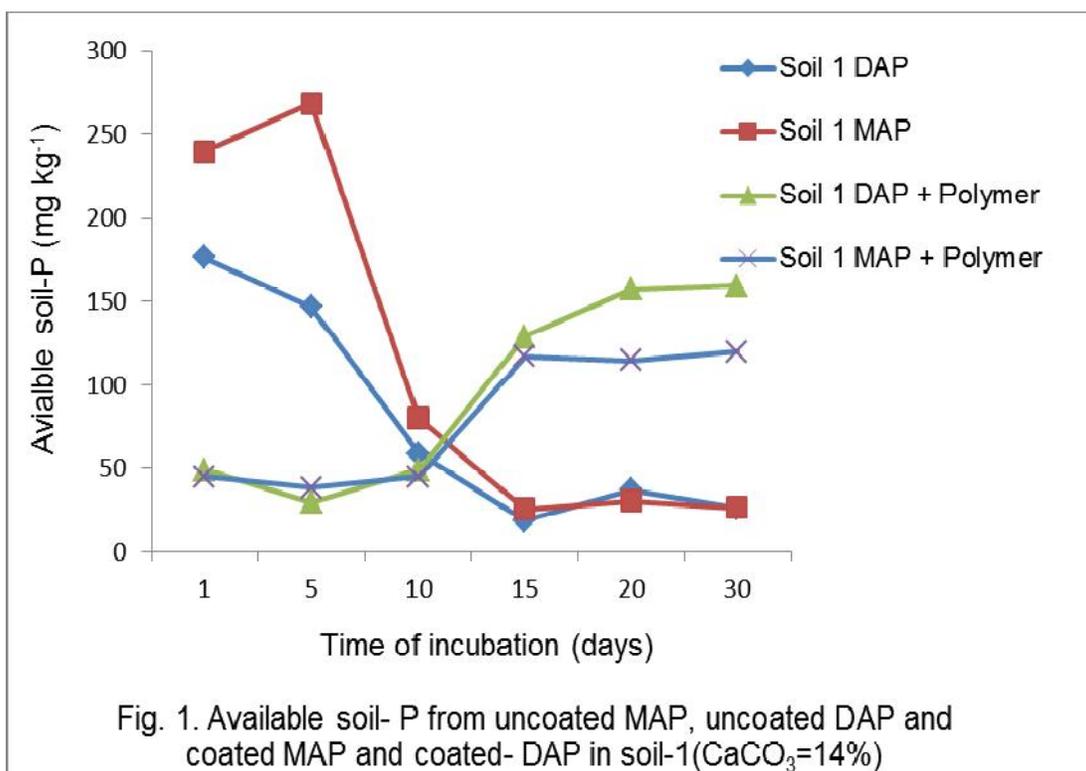
Treatments		Soluble and exchangeable P	Fe and Al-P mg kg ⁻¹ (5 days after incubation)	Ca -P	Residual P	Total P
	MAP	403.0	222.5	228.4	42.2	697.1
	DAP + Polymer	130.6	40.9	207.1	25.7	310.2
	MAP + Polymer	118.1	52.0	172.0	20.0	279.1
Soil-2	DAP	239.7	207.8	380.5	75.0	706.9
	MAP	285.7	178.7	366.5	62.6	726.9
	DAP + Polymer	109.0	69.2	406.3	47.0	570.4
	MAP + Polymer	112.5	81.4	329.5	74.6	523.4
Soil-3	DAP	212.2	170.9	226.7	47.7	501.9
	MAP	229.1	262.8	197.0	82.2	518.5
	DAP + Polymer	121.3	24.9	196.7	40.7	320.8
	MAP + Polymer	147.5	37.5	189.8	100.5	379.2

Table 3b. Continued; P fractions as influenced by different fertilizers type at 15 days after incubation

Treatments		Soluble and exchangeable P	Fe and Al-P	Ca -P	Residual P	Total P
		mg kg ⁻¹ (15 days after incubation)				
Soil-1	DAP	263.2	13.1	206.0	47.4	529.4
	MAP	375.7	11.7	213.0	47.6	647.5
Soil-2	DAP + Polymer	31.3	9.4	213.5	46.5	300.4
	MAP + Polymer	59.0	14.7	177.5	53.2	298.7
	DAP	185.7	12.5	487.0	68.8	749.3
	MAP	200.4	8.0	645.5	61.3	915.0
Soil-3	DAP + Polymer	77.7	11.2	553.0	61.7	699.9
	MAP + Polymer	90.4	8.9	581.0	60.8	740.7
	DAP	140.0	11.9	257.5	81.8	488.7
	MAP	192.5	8.9	207.5	38.9	447.8
	DAP + Polymer	40.8	4.9	248.5	43.2	337.2
	MAP + Polymer	53.6	9.5	194.5	23.5	278.0

Table 3c. Continued; P fractions as influenced by different fertilizers type at 30 days after incubation

Treatments		Soluble and exchangeable P	Fe and Al-P	Ca -P	Residual P	Total P
		mg kg ⁻¹ (30 days after incubation)				
Soil-1	DAP	186.6	12.8	305.3	44.2	549.0
	MAP	222.5	12.45	302.65	18.2	555.8
	DAP + Polymer	40.9	8.96	204	25.45	279.1
	MAP + Polymer	52.0	8.6	198.9	23.75	283.1
Soil-2	DAP	207.75	7.42	585	68.9	868.8
	MAP	178.65	6.44	672.3	32.45	890.1
	DAP + Polymer	69.15	10.265	589.5	30.1	698.6
	MAP + Polymer	81.4	8.265	550.5	34.4	674.4
Soil-3	DAP	170.9	10.58	217	56.5	455.2
	MAP	262.75	12.355	267.4	77.6	620.2
	DAP + Polymer	24.9	6.48	207	25.15	263.2
	MAP + Polymer	37.5	7.795	252	35.18	332.4
	LSD _{0.05}	43.5	5.0	48.9	27.7	71.5



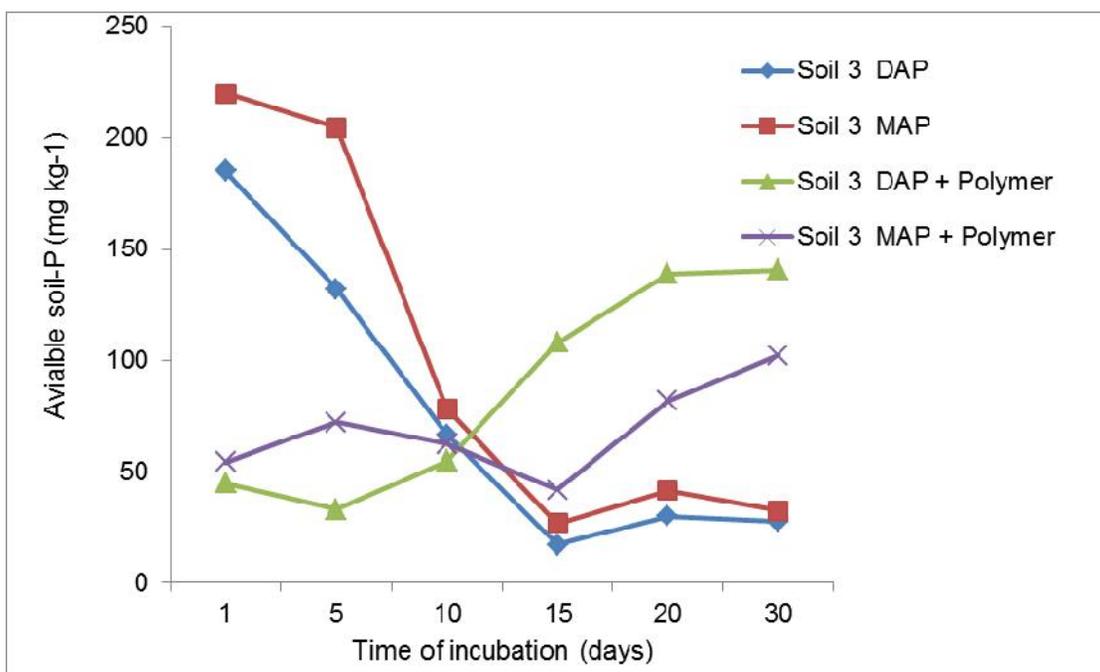


Fig. 3. Available soil- P from uncoated MAP, uncoated DAP and coated MAP and coated- DAP in soil-3 (CaCO₃=43%)

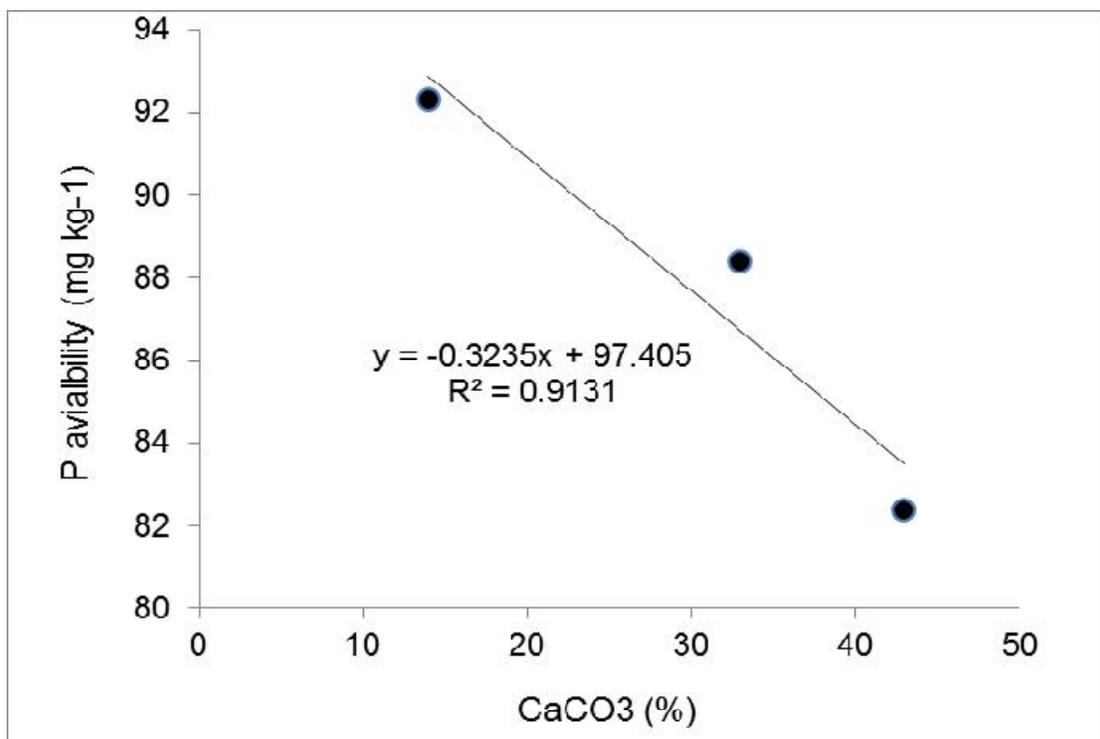


Fig. 4. Relationship between available soil-P and CaCO₃ % in different soil

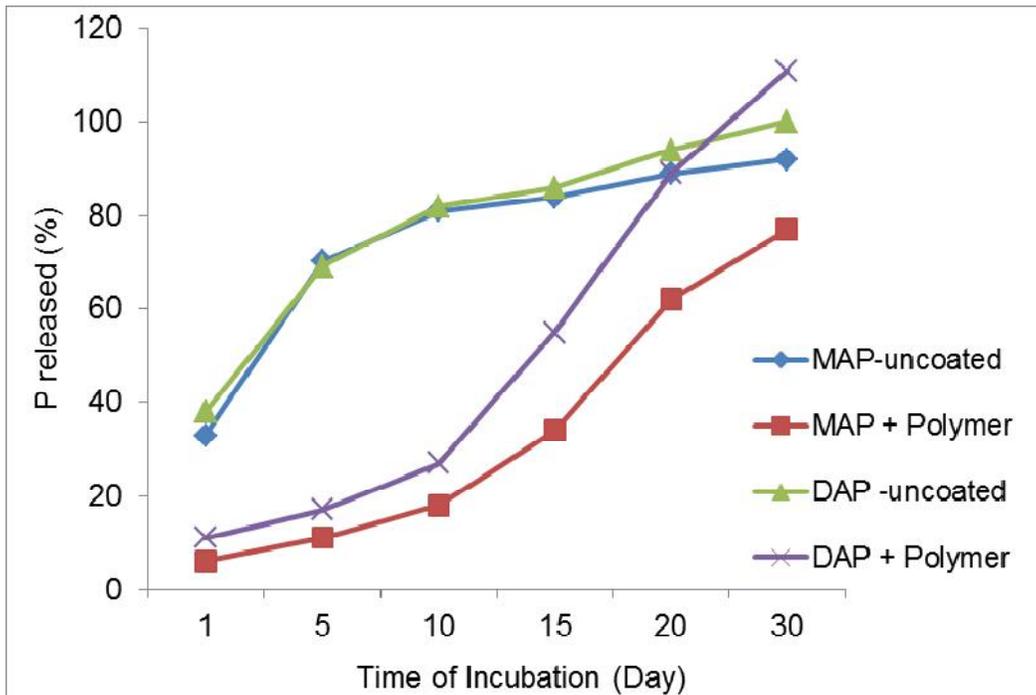


Fig. 5. Phosphorus release behaviour into soil-1 from commercial-MAP, commercial-DAP, slow-release MAP and slow-release DAP

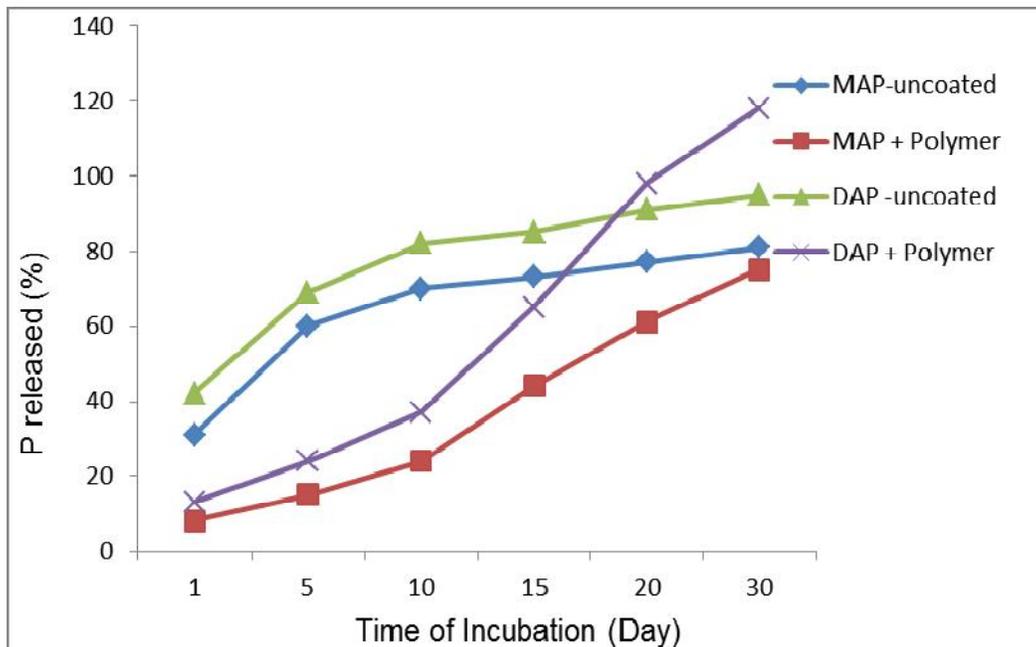
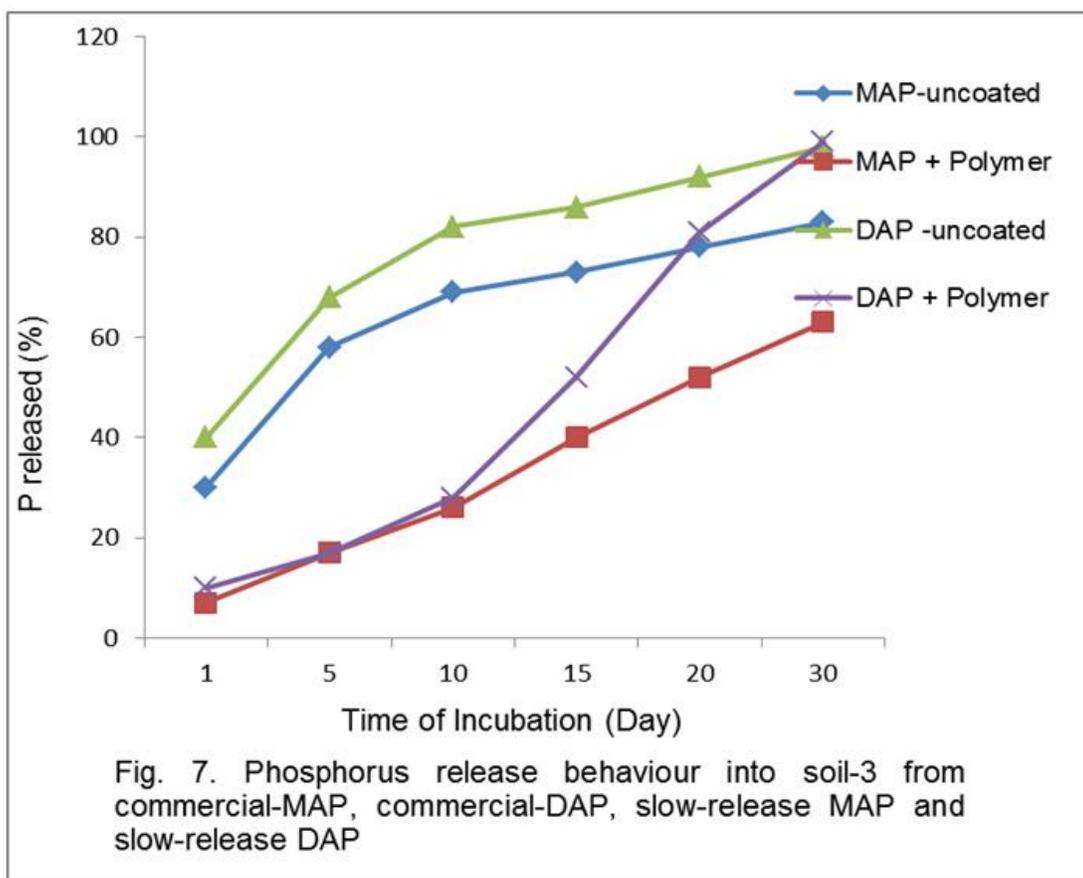


Fig. 6. Phosphorus release behaviour into soil-2 from commercial-MAP, commercial-DAP, slow-release MAP and slow-release DAP



4. CONCLUSIONS

The slow-release MAP and slow-release DAP was prepared to supply P to the plant at a controlled release rate and to increase the phosphorus fertilizer use efficiency (PFUE) under calcareous soil condition. The results concluded that, the developed MAP and DAP fertilizers could be considered as slow-release for deliver P to the plant for long time compared with uncoated MAP and DAP and therefore could be increase the phosphorus use efficiency under calcareous soil conditions. The results indicated in this small scale laboratory test experiment to establish a thesis indicating that there might be significant differences between the effects of different P fertilizer types on soluble + exchangeable- P, Ca-occluded P fraction, residual-P fraction, Fe& Al-occluded P fraction and total P, but that thesis require further applied research and field tests under true value agricultural production conditions in different calcareous soil types with different environmental, pH, climatic and cultivation performances.

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COMPETING INTERESTS

Authors have declared that no competing interests exist.

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