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USE OF CONTROLLED RELEASE PHOSPHATIC FERTILIZER TO IMPROVE GROWTH, YIELD AND PHOSPHORUS USE EFFICIENCY OF WHEAT CROP

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Phosphorus (P) use efficiency is very low (5 to 25%) due to fixation with Ca^{+2}/Mg^{+2} in alkaline/calcareous soils which decreases P availability for plant uptake. There is need to improve P availability for plant growth. For this purpose, coating of phosphatic fertilizer with the organic polymer may reduce P fixation and cause the steady release of P to increase its use efficiency. This study accesses enhanced phosphorus use efficiency along with improved growth of wheat at different rates of polymer coated di-ammonium phosphate (DAP) in comparison with uncoated DAP. In laboratory experiments, release pattern of P in soil from different coating concentrations (0, 0.5, 1.0, 1.5%) and number of coatings (uncoated, single, double, triple) were tested under controlled conditions. The best screened polymer concentration (1%) and coating layers (double coating) were tested under field conditions on wheat crop growth, yield and fertilizer efficiency. Results showed that application of 100% of recommended rate of P as polymer coated DAP increased plant height (4%), biological yield (39%), grain yield (29%), agronomic efficiency (58%), recovery efficiency (130%) and nitrogen, phosphorus and potassium contents of wheat grain and straw was also increased compared to uncoated DAP. These results revealed that polymer coated DAP can be proved more effective fertilizer to improve growth, yield and phosphorus use efficiency of the wheat crop over commercial DAP.
Keywords: Agronomic efficiency, polymer, recovery efficiency, yield, phosphatic fertilizer

INTRODUCTION

Soil nutrient management at sufficient level is important for maintaining high quality and sustainable crop production. Exogenous fertilizer application is an instant source of nutrient replenishment. Many types of research revealed that commercial chemical fertilizers increased 30 to 50% crop yield (Stewart *et al*., 2005). The replenishment of nutrients is usually carried out by the introduction of organic and inorganic substances such as soil amendments, manures, organic or chemical fertilizers (Timilsena *et al*., 2015). The mineral fertilizers are applied to increase crop yields but the main limitation in achieving the crop potential is limited use of applied fertilizers particularly P by crop compared to other fertilizers. Availability of P in soils of Pakistan is very low; about 90% soils suffer from adequate to severe P deficiency (NFDC, 2003). From applied fertilizer, only a small amount of it goes to soil solution that may be either taken up by crops or precipitates in soil (Leytem and Mikkelsen, 2005).

Soil nutrient deficiency can be fulfilled to a great extent by the application of appropriate fertilizer type, application rate, and method of application (Timilsena *et al*., 2015). But due to the high cost of fertilizers, these are not profitable to farmers (Shaheen *et al*., 2004). Unavailability of P from applied phosphatic fertilizers to plants due to fixation with soil constituents can be prevented by using a number of techniques including acid application, band placement of phosphatic fertilizers, the addition of organic matter, microbial inoculation and bio-fertilizers (Trolove *et al*., 2003). But still, P availability of applied fertilizer is a big issue in almost all soils. The efficiency of applied phosphatic fertilizers under all circumstances is not exceeding 25%.

Commercially available fertilizers are proving insufficient for sustainable crop production. To achieve yield goals it is necessary to improve the applied fertilizer's feature by coating with suitable material. That would increase its use efficiency in such a way that they should be able to produce higher yield even at reduced rate of application compared to conventional application of phosphatic fertilizers (Trenkel, 2010). Polymer coated or controlled release fertilizers (CRF) can be one of the best approaches to improve phosphorus use efficiency (PUE) as these release P according to plant demand. So less P is interacting with soil, the ultimately small amount of P is available for fixation, which in turn increase use efficiency, reduce negative effects associated with overdosage, reduce rate of the application (Zahrani, 2000; Yaseen *et al.*, 2014, 2017). But the material used for coating should be economical and reveal a good coating property. However, most of the available polymer is more expensive and increase the production cost along with environmental problems. So, there is need to choose cost effective coating material. Therefore, the present study is focusing on the screening of polymer concentrations and number of coating layers on phosphatic fertilizers to prolong the availability of P in the soil to meet the plant requirements in field application for wheat production.

MATERIALS AND METHODS

***Experimental material for laboratory studies*:** Coating of the water soluble polymer on commercially available DAP (di-ammonium phosphate) (Yaseen *et al*., 2017) was carried out in Soil Fertility and Plant Nutrition Lab, Institute of Soil and Environmental Sciences, University of Agriculture, Faisalabad. This coating was done according to polymer strength (0, 0.5, 1, 1.5%) in experiment 1 and coating thickness (uncoated, single, double, triple) in experiment 2. Coated DAP fertilizer was dried under laboratory conditions at ambient temperature and stored in polyethylene bags till application.

The soil was collected from the block allotted for field experiment at Research Area of Institute of Soil and Environmental Sciences, University of Agriculture, Faisalabad, Pakistan. Soil of the experimental site was sandy clay loam in texture with ECe 1.96 dS m^{-1} (Richards, 1954), pH 7.7 (Prasad *et al.*, 2006), organic matter contents 0.64% (Walkey and Black, 1934), total N contents 0.04% (Jackson, 1962), Olsen P 6.2 mg kg^{-1} soil (Olsen *et al*., 1954), extractable K 115 mg kg^{-1} soil (Hanways and Heidel, 1952) and $CaCO_3$ 5%. Disposable cups of 250 cm^3 were used during the study. Each cup was filled with 200 g soil. Saturation percentage of soil used was determined to maintain required moisture contents in cups. Coated and uncoated DAP was applied (0.25 g P 100 g^{-1} of soil) in cups with respective concentrations according to the treatment plan and mixed in soil thoroughly. Cups were placed randomly in an incubator (Sanyo; MIR 253) at 25$\pm$2°C temperature after addition of distilled water to maintain moisture content at field capacity and it was maintained after every 24 hours. Olsen P was determined after a different time interval (15, 30, 45 and 60 days) by method (Olsen *et al.*, 1954). Results of the 1st experiment proposed the best polymer concentration while the 2nd proposed the best number of layers to be coated on DAP fertilizer granules.

***Field experiment*:** The experimental plan for wheat crop was comprised of five treatments i.e. T_1 = Control (without any fertilizers), T_2 = NK + P from uncoated DAP at 100% recommended rate, T_3 = NK + P from polymer coated DAP at 100% recommended rate, T_4 = NK + P from polymer coated DAP at 75% of recommended rate, T_5 = NK + P from polymer coated DAP at 50% of recommended rate. Randomized complete block design with three replications was used to collect. Recommended rates of fertilizers used for wheat were N = 120 kg ha^{-1}, P_2O_5 = 90 kg ha^{-1} and K_2O = 60 kg ha^{-1}. In all treatments except control, recommended doses of N and K were added. Sources of fertilizers used were urea (46% N) for N, sulphate of potash (50% K_2O) for K and di-ammonium phosphate (P_2O_5 46% and 18% N) for P. P and K fertilizers were applied during soil preparation and N fertilizer was applied in three splits. One-third of required N as per treatment requirement was applied before sowing and remaining N was applied in two splits at 25 and 45 days after germination. Drill sowing of wheat cv. Faisalabad-2011 was done and the crop was five times irrigated with canal water. One square meter area was randomly selected in each plot for measuring growth and yield attributes 20 days before harvesting and average values were computed. At harvest, grain and straw yield was recorded for each plot. The biological yield was calculated by the formula given below.

Biological Yield =Total biomass of plants in the plot (grain+straw yield)

At vegetative stage (before booting stage) parameter i.e. photosynthetic rate (A) and water use efficiency were measured by using CIRAS-3 (PP System, Amesbury, MA, USA) with PLC3 universal leaf cuvette, measuring both sides of the fully expanded upper leaf. The cuvette was provided light via light emitting diodes (LED) and with a photon flux of 1000 µmol m^{-2} s^{-1}, ambient leaf temperature and 390 µmol mol^{-1} CO_2.

Chlorophyll content in flag leaves was measured with the help of portable Chlorophyll Meter SPAD-501 before grain formation.

***Chemical analysis for total P uptake in wheat*:** At harvesting time, samples of grain and straw were drawn from each plot of the experiment for the chemical analysis of NPK concentration. Nitrogen and potassium contents of harvested samples were estimated by using method (Chapman and Parker, 1961). Phosphorus was determined on a spectrophotometer at 420 nm wavelength by using absorbance mode (Olsen *et al.*, 1954). By the P content of straw and grain, phosphorus uptake (PU) by the wheat plant was calculated by the formula:

$$PU = \frac{\text{oven dried weight of plant} \times P\ (\%)}{100}$$

Total P uptake=P uptake in grain+P uptake in straw

***Nutrient use efficiencies*:**

$$AE\ (g/g) = \frac{\text{Fertilized plant biomass} - \text{unfertilized plant biomass}}{\text{Amount of fertilizer applied}}$$

$$ARE\ (\%) = \frac{\text{uptake by fertilized plant-uptake by unfertilized plant}}{\text{Amount of fertilizer applied}} \times 100$$

AE = Agronomic efficiency, ARE = Agronomic recovery efficiency

***Statistical analysis*:** Data was analyzed statistically according to Fisher's analysis of variance (Steel *et al*., 1997). Means were compared by using HSD test at 5% probability level.

RESULTS

***Phosphorus release pattern in soil in response to different concentrations of polymer coated on DAP*:** Soil treated with uncoated diammonium phosphate (DAP) showed the highest concentration of Olsen's P in the soil after 15 days of incubation period as compared to DAP coated with different concentrations of polymer. At 30 days of incubation period, a decrease in P release in uncoated DAP fertilizer was recorded. Maximum P release was recorded in DAP coated with 0.5% polymer concentration. Decreasing trend in Olsen's P in soil in uncoated DAP treatment with the passage of time indicated maximum release of P immediately after application of this fertilizer. Treatments of 1 and 1.5% polymer concentrations on DAP fertilizer caused increase in P release in soil with an increase in a number of days. At incubation time of 45 days, soils treated with uncoated DAP showed further decrease in soil P concentration. Maximum P release was observed in soil treated with 0.5 and 1% polymer coated DAP. However, DAP fertilizer coated with 1.5% polymer concentration showed increasing trend in P release in soil compared to their previous incubation days. At 60 days of incubation, no significant release of P was observed in the treatment of uncoated DAP fertilizer. Among coating concentrations of polymer on DAP, 0.5% polymer concentration showed minimum P release; even then this released concentration was greater than uncoated fertilizer sources. DAP coated with 1% polymer concentration showed significantly maximum but at par with 1.5% polymer concentration on P release in soil at 60 days of incubation. Significant differences in Olsen's P concentrations in soil treated with coated and uncoated DAP fertilizer sources at different time intervals are shown in (Table 1). On these results basis, 1% polymer concentration was found better and selected for next experiment.

***Effect of number of polymer layers coated DAP on P release in the soil*:** Statistical analysis of data related to number of coatings of 1% polymer concentration (the best selected from experiment 1) on DAP fertilizer for the release of phosphorus in soil showed significant differences in P release pattern among coated and uncoated DAP fertilizer over different incubation time periods (Table 2). Statistical analysis of P release with respect to incubation time period revealed that phosphorus availability decreased with increasing number of coating layers and days than uncoated phosphatic fertilizer DAP, furthermore, uncoated DAP fertilizer treated soil had maximum released P during 15 days of incubation. With the passage of time, P release was increased from coated fertilizer compared to uncoated fertilizer. At 30 days of incubation single coated DAP gave maximum P release in soil, whereas after 45 days of incubation double layer coated DAP released maximum P. At 60 days of incubation, triple layer polymer coated DAP showed an increase in soil P concentration than their previous incubation time periods. From the results, it can be concluded that double layer coating of polymer on DAP fertilizer indicated maximizing trend of P release in soil and also matched with plant required compared to all other number of coatings as well as uncoated DAP.

***Field Experiment*:**

***Wheat growth and yield parameters*:** Polymer coated DAP fertilizer application showed significant effect on growth and yield of wheat over commercial fertilizer use (uncoated DAP). However, a significant difference in wheat plant height was observed; 100% recommended rate of polymer coated DAP and uncoated DAP increased wheat plants height over control i.e., 13.4 and 4.1%, respectively. All other rates of polymer coated DAP have also increased plant height as compared to control (Table 3). Polymer coated DAP application at 100% rate of recommendation increased

Table 1. Release of P in soil (mg P kg^{-1}soil) treated with different concentrations of polymer coated on DAP.

Concentration of polymer coated on DAP fertilizer (%)	Incubation intervals (days)				Mean
	15	30	45	60	
Uncoated (Control)	958.31 b	757.92 d	307.47 g	178.33 i	550.51 B
0.5	323.91 g	852.63 c	796.28 d	624.67 e	649.37 A
1.0	247.28 h	569.72 f	795.26 d	1011.40 a	655.92 A
1.5	54.32 k	106.05 j	634.26 e	864.11 c	414.68 C
Mean	395.96 D	571.58 C	633.32 B	669.63 A	

Values sharing same letter do not differ at p = 0.05 according to HSD test. HSD values (critical values for comparison): Mean for days (A) = 17.4, Mean for polymer coating concentration (B) = 17.4, Interaction (A×B) = 47.72.

Table 2. Release of P (mg P kg^{-1} soil) in soil treated with DAP coated with different number of polymer layers.

Number of 1% polymer coating layers on DAP	Incubation intervals (days)				Mean
	15	30	45	60	
Uncoated	877.13 b	632.55 e	348.23 h	153.66 k	502.89 C
Single	278.01 i	747.64 d	775.73 d	514.37 f	578.94 B
Double	195.11 j	596.24 e	861.37 b	941.52 a	648.56 A
Triple	98.51 l	208.47 j	453.39 g	816.15 c	394.13 D
Mean	362.19 C	546.22 B	609.68 A	606.43 A	

Values sharing same letter do not differ at p = 0.05 according to HSD test. HSD values (critical values for comparison): Mean for days (A) = 13.8, Mean for polymer coating layers (B) = 13.8, Interaction (A×B) = 37.98.

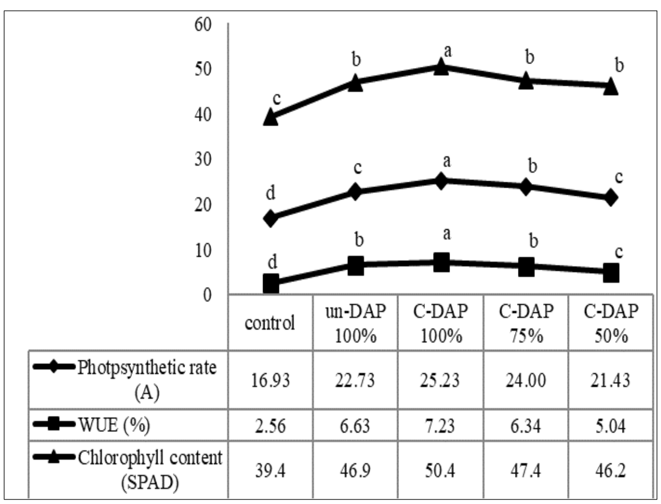
Table 3. Effect of polymer coated DAP on growth and yield components of wheat in field conditions.

DAP application rate (as per recommended rate)	Plant height (cm)	No. of fertile tillers (m^{-2})	1000 grain weight (g)	Yield attribute (kg/ha)	
				Grain yield	Biological yield
Control	94.83 b	192 e	24.57 d	3147 e	8080 e
Uncoated DAP (100%)	103.33 a	371 c	40.61 b	4347 d	11803 d
Polymer coated DAP (100%)	107.58 a	456 a	46.91 a	5607 a	16493 a
Polymer coated DAP (75%)	105.67 a	408 b	40.05 b	5247 b	14780 b
Polymer coated DAP (50%)	102.50 a	358 d	37.77 c	4477 c	12967 c
HSD at 0.05	6.8	12.9	2.3	84.2	1008.1

Values sharing same letter do not differ at $p = 0.05$ according to HSD test.

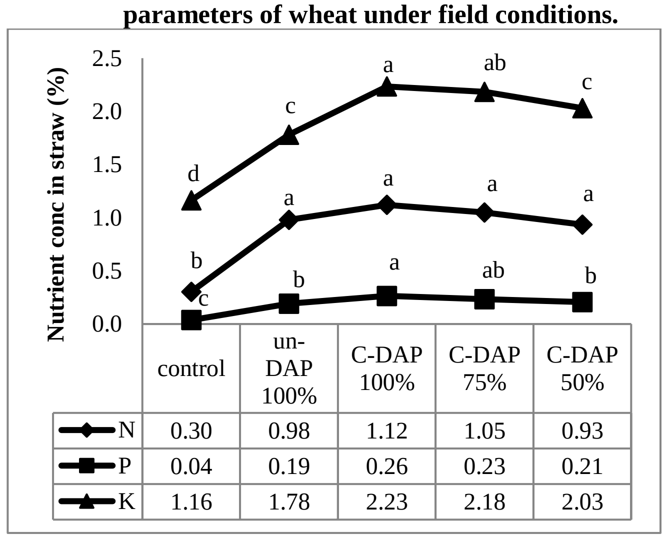
number of tillers 23% compared to uncoated DAP application (Table 3). 1000 grain weight in the treatment of 100% recommended rate of polymer coated DAP fertilizer increased by 16% over recommended rate of uncoated DAP fertilizer application. Grain yield kg ha^{-1} as a result of treatment of 100% recommended rate DAP coated with polymer was varied statistically from all other treatments and it was 29% higher compared to uncoated DAP fertilizer application. Moreover, application of 75% of recommended rate of polymer coated DAP improved 20% grain yield compared to uncoated DAP, respectively. The maximum increase in biological yield was observed in treatment receiving 100% recommended rate of polymer coated DAP and that was 39% higher as compared to uncoated DAP (Table 3).

***Physiological parameters*:** Application of 100% recommended rate of polymer coated DAP increased the chlorophyll contents by 28 and 8% as compared to control and uncoated DAP, respectively (Fig. 1).



Control = without any fertilizer, Un-DAP = Uncoated DAP at 100% of recommended dose, C-DAP 100% = Polymer coated DAP at 100% of recommended dose, C-DAP 75% = Polymer coated DAP at 75% of recommended dose, C-DAP 50% = Polymer coated DAP at 50% of recommended dose. Mean values sharing same letter do not differ at $p = 0.05$ according to HSD test.

Figure 1. Effect of polymer coated DAP on physiological parameters of wheat under field conditions.



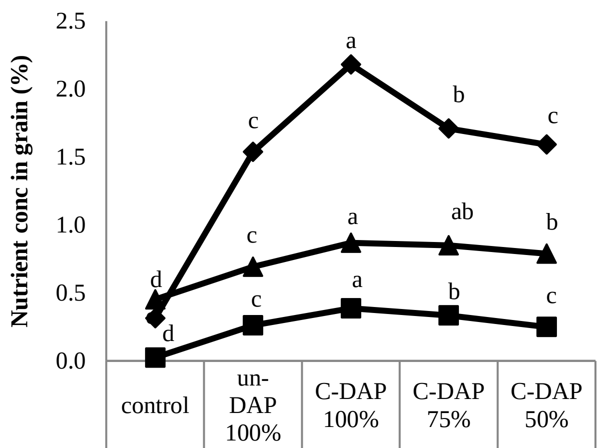
Control = without any fertilizer, Un-DAP = uncoated DAP with 100% rate of recommended dose, C-DAP 100% = Polymer coated DAP at 100% rate of recommended dose, C-DAP 75% = Polymer coated DAP at 75% rate of recommended dose, C-DAP 50% = Polymer coated DAP at 50% rate of recommended dose.

Mean values sharing same letter(s) do not differ at $p = 0.05$ according to HSD test.

Figure 2. Effect of polymer coated DAP on N, P and K concentrations (%) in straw of wheat under field conditions.

Similarly, a significant improvement in photosynthetic rate was recorded in the treatments of polymer coated DAP over control and uncoated treatments. There was 6.32 and 1.12% increase in photosynthetic rate with the application of 100 and 75% of recommended rate of polymer coated DAP over uncoated DAP. With the increase in photosynthetic rate water use efficiency was also increased (9.15%) in the treatment of polymer coated DAP fertilizer applied at 100% rate of recommendation (Fig. 1).

***Effects of polymer coated DAP on N, P and K concentrations in wheat*:** Data regarding N, P and K concentration in straw and grain is given in Figure 2 and 3. With the application of 100 and 75% of recommended rate significant increase in nutrients concentration in plant body (straw + grain) was recorded over uncoated DAP fertilizer application. Thus, the highest NPK concentration in wheat grain and straw was attained with application of 100% of recommended rate of polymer coated DAP by 42, 47 and 25%, respectively in grain and 14, 39 and 25%, respectively in straw.



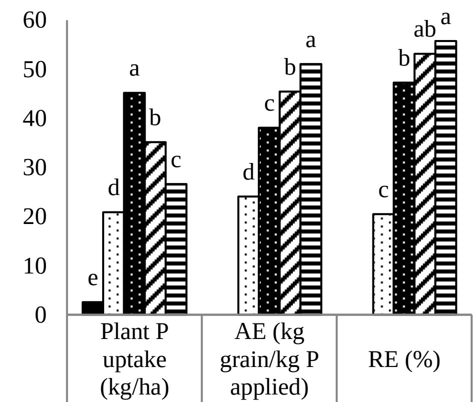
	control	un-DAP 100%	C-DAP 100%	C-DAP 75%	C-DAP 50%
N	0.31	1.54	2.18	1.71	1.59
P	0.02	0.26	0.39	0.34	0.25
K	0.45	0.69	0.87	0.85	0.79

Control = without any fertilizer,Un-DAP = uncoated DAP with 100% rate of recommended dose, C-DAP 100% = Polymer coated DAP at 100% rate of recommended dose, C-DAP 75% = Polymer coated DAP at 75% rate of recommended dose, C-DAP 50% = Polymer coated DAP at 50% rate of recommended dose. Mean values sharing same letter(s) do not differ at p = 0.05 according to HSD test.

Figure 3. Effect of polymer coated DAP on N, P and K concentrations (%) in grain of wheat under field conditions.

The results given in Figure 4 showed the impact of polymer coated DAP on the total uptake of P (grain + straw). The maximum increase in P uptake was observed in treatment with polymer coated DAP at 100% recommendation rate i.e. 116% over conventional uncoated DAP application. Moreover, there was 27 and 68% increase in total P uptake; by 75% and 50% of recommended rate of polymer coated DAP over uncoated DAP.

***Agronomic and recovery efficiency*:** Effects of polymer coated DAP on phosphorus use efficiencies is reflected from the data given in Figure 4. Results showed that agronomic and recovery efficiency of P was increased with decreasing the rates of polymer coated DAP fertilizer. The maximum increase in P agronomic efficiency was recorded in the treatment of 50% of recommended rate of polymer coated DAP i.e. 112% higher than uncoated DAP application. Similarly, maximum recovery efficiency was observed in polymer coated DAP at 50% rate of recommendation followed by 75 and 100% rate of recommendation i.e. 172, 159 and 130% increase over uncoated DAP application respectively (Fig. 4).



	Plant P uptake (kg/ha)	AE (kg grain/kg P applied)	RE (%)
control	2.60		
un-DAP 100%	20.88	24.074	20.50
C-DAP 100%	45.21	38.074	47.28
C-DAP 75%	35.16	45.432	53.15
C-DAP 50%	26.59	51.037	55.76

Control = without any fertilizer,Un-DAP = uncoated DAP with 100% rate of recommended dose, C-DAP 100% = Polymer coated DAP at 100% rate of recommended dose, C-DAP 75% = Polymer coated DAP at 75% rate of recommended dose, C-DAP 50% = Polymer coated DAP at 50% rate of recommended dose. Mean values sharing same letter(s) do not differ at p = 0.05 according to HSD test.

Figure 4. Effect of polymer coated DAP on P uptake, agronomic efficiency (AE) and recovery efficiency (RE) in wheat crop grown under field conditions.

DISCUSSION

Phosphorus fertilizer use efficiency is quite low in soils of Pakistan and it ranges as low as 5% to as high 25% depending on fertilizer management strategies. Its availability in alkaline and calcareous soil is quite low due to primary and secondary reaction with Ca/Mg which retards P availability. As phosphatic fertilizers are too costly, there is dire need to improve the use efficiency of applied phosphatic fertilizer (Trenkel, 2010).

Coating of phosphatic fertilizers with the polymer is an innovative option to improve phosphorus use efficiency and consistent release of P in the soil. Polymer coated fertilizers gradually release its nutrient contents; correspond to the plant's requirement (Hanafi *et al.*, 2000). These fertilizers are water soluble which are coated with the materials which reduce their dissolution rate and fixation in soil. Better efficiency, due to slower and gradual release from coated fertilizers, can be helpful in term of reduced frequency of application and also minimize the negative effects associated with over dosage (Zahrani, 2000; Hopkins *et al*., 2008). Moreover, polymer coated phosphatic fertilizer have potential to reduce P fixation and precipitation mainly by holding the P complex making elements and absorption of water to increase its diffusion shell. The present studies demonstrated the release patterns of P in soil from polymer coated DAP with different concentrations and number of coating layers after that the effect of polymer coated phosphatic fertilizer (DAP) on growth; yield and phosphorus use efficiency in wheat crop was evaluated. It was found in laboratory studies that polymer coatings on DAP fertilizer with different polymer concentration showed linear increase in available P up to 2 months. Phosphorus release from DAP was the maximum at 1% polymer concentration. The additional benefits regarding the selection of 1% polymer concentration were that less quantity of polymer used that ultimately reduces the cost of polymer coated fertilizers and less effort required by microbes to degrade that polymer within the growing period of crop plants (Yaseen *et al*., 2017; Yaseen *et al*., 2014). Similarly, in next incubator study, DAP fertilizer with a double layer of the polymer showed the highest available P during the study. The thickness of coated material on fertilizer granules plays an important role in releasing of nutrient from polymer coated fertilizer. The release rates from two and three layered coated materials were relatively low compared to single coated material. Coated fertilizers release nutrients with the passage of time and maintain the optimum level of phosphorus for plant requirements (Sharma, 2006).

The boosted grain yield with application of polymer coated fertilizer is collective benefit from improved all yield components like 1000-grain weight, the number of grains per spike and number of the fertile tiller. The superiority of polymer coated phosphatic fertilizers was probably due to maintaining the intimate availability of P in the soil for developing root adjacent to fertilizer granules. The importance of P for emerging radicle and seminal roots during seedling establishment in wheat might be responsible for a higher number of fertile tillers (Murphy and Sanders, 2007). As P is directly involved in grain formation and development, so its availability throughout the growth period improved number and weight of grains and also save plants from stress. Consistent supply of P during growth period of wheat is capable of enhancing growth and yield attributes and polymer coated DAP has ability to supply P for a longer time than uncoated DAP (Yaseen *et al*., 2014, 2017).

Polymer coated fertilizers application at reduced recommended rate was also improved the P contents of the plant (straw and grain) resulted from higher P uptake, due to the increased availability of P according to the plant requirement throughout the growing season of the crop. There was low chance for P fixation in polymer coated fertilizers over uncoated phosphatic fertilizer sources of minimum contact with soil (Dunn and Stevens, 2008; Xiang *et al*., 2008). Polymer coated DAP applied at reduced rates resulted in higher PUE due to the strong root competition and thereby an efficient exploitation of applied P. Similarly, with a higher application rate of P, roots utilize the lower amount of P that resulted in low PUE (Sanders *et al*., 2012)

The use of polymer coated fertilizers also improved soil organic matter, and soil physical, chemical and microbial properties that ultimately affect P nutrition of plants (Yaseen *et al*., 2017). The most beneficial effect of the polymer coating is that it contributes towards the use of less amount of phosphatic fertilizer application that ultimately leads towards less cost of production with increased benefits.

***Conclusion*:** Manipulating or controlling reactions in the microenvironment around fertilizer grains has been revealed to have important benefits to availability of applied nutrients. By this polymer technology, nutrients released at a slower rate throughout the season, plants are able to take up most of the nutrients without waste by leaching. This technology not only has prospective to increase prolong availability of P, crop growth, yields and farmer incomes by reducing its application rates and losses.

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