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EFFECT OF HORMONES ENRICHED POLYMER COATED FERTILIZER ON GROWTH, YIELD AND PHOSPHORUS USE EFFICIENCY OF WHEAT (*Triticum aestivum* L.) UNDER SALINITY STRESS

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Efficiency of applied P fertilizers is very low in alkaline soils. There is need to adopt certain economical approaches to enhance uptake of P from applied P fertilizer. Coating of di-ammonium phosphate (DAP) granules with polymer improves P availability. This technique can further be improved by the addition of certain hormones with the objective of strengthening plant defense against stresses. Plant hormones are considered necessary endogenous molecules which are involved in regulating plant development. Experiments were performed to check the efficacy of hormones enriched polymer coated di-ammonium phosphate on yield and phosphorus use efficiency of wheat (*Triticum aestivum* L.) under saline and non-saline soils. In laboratory experiments, the polyacrylamide (PAM) with different concentrations (0, 1, 1.5 and 2%) was coated on phosphatic fertilizer to check the release pattern of P in soil over different time intervals. Selected best concentration of PAM (1%) was mixed with growth regulators (L-tryptophan at 10 and 20 mg L^{-1}, L-methionine at 1 and 5 mg L^{-1} and salicylic acid at 5 and 10 mg L^{-1}), and coated on DAP fertilizer to investigate P and hormones release pattern in soil. The best concentrations of these hormones blended with best concentration of polymer collectively to check their effect on wheat crop under field conditions. Hormones enriched polymer coated di-ammonium phosphate (HPCDAP) was applied at different rates (25: 50: 75: 100% of recommended-P) along with polymer coated and uncoated DAP fertilizer. Results showed that application of HPCDAP at 100% of recommended rate of P boosted plant height (20%), number of fertile tillers m^{-2} (20%), grains yield (19%), straw yield (17%), biological yield (16%), total N, P and K- uptakes (26, 32 and 22%, respectively) on normal/non-saline soil, whereas plant height (27%), number of tillers m^{-2} (27%), grains yield (26%), straw yield (22%), biological yield (23%), total N, P and K- uptakes (26,47 and 25%, respectively)were increased on saline soil in same treatment. The treatment of 75% rate of HPCDAP had non-significant results compared to full dose (100%) of HPCDAP fertilizer on saline soil. A highly positive relationship between polymer enriched with hormones coated DAP and crop revealed promising results on growth, yield, and P use efficiency of wheat in both saline stressed and non-stressed soil. These results recommend this a novel approach to get optimum cereal yield under salt stress.
Keywords: L-tryptophan, L-methionine, salicylic acid, saline soil, polymer.

INTRODUCTION

Salinization is a widespread problem all over the world. About 6% of the world's land and 20% irrigated land are under saline stress threat (Munns *et al*., 2008; Qadir *et al*., 2014). Reduced germination rate and less growth of seedlings were observed by many scientists at high salinity levels (Flowers *et al*., 2015). Different plant species as well as different concentration level of salt have different sensitivity or tolerance level of salts (Saqib *et al*., 2005, khan *et al*., 2018). Use efficiency of nutrients in salt stressed soils is low and has negative interactions with ions. Therefore, refined concentrations of nutrients are required in saline soil. The soil and plant management practices for nutrients recovery in saline soil comprise of soil adjustments to diminish influence of salt like application of farmyard dung to build healthy environment for plant growth and planting salt tolerant species (Fageria *et al*., 2002). Insufficient or imbalance use of nutrients leads to decline in yield of crop (Balemi and Nagisho, 2012).

Phosphorus (P) is a vital macronutrient, involved in many processes i.e., respiration, photosynthesis, enzyme activities, synthesis of membrane and its stability etc (Fahad *et al*., 2016; Vance *et al*., 2003). Agricultural productivity can be limited by less soil phosphorous. Due to phosphorous deficiency 30–40% of the world's arable lands gave very low production (Chen *at el*., 2014). Different inorganic P sources are being used to increase P level in soil. Plants are unable to uptake much of the applied P due to its adsorption and fixation in the soil (Holford,1997; Marschner *et al*., 2006). Depending on soil properties, mostly phosphatic fertilizers undergo diverse reactions (e.g. precipitation, adsorption, sorption) and converted in such forms which are less soluble in water, hence result into reduced availability to plants (Anderson, 2010).

The solubility of P is greatly reduced in salt-affected soils due to high Na concentration and soil pH. The research findings indicated that phosphorous uptake is disturbed by sodium transfer in plants, however, it is recognized that the response of different genotypes of barley grass to salinity is different as shoot and root P uptake increased (Fahad *et al*., 2016; Hu *et al*., 2005; Talbi *et al*., 2011). So, the interaction of P supply and salinity seems to have great practical implications for achieving sustainable crop production on salt-affected soils (Maas *et al*., 1977). It is important to use fertilizers very effectively to minimize production costs and protect natural resources. Now-a-days, use of polymers coated P-fertilizer (PCF) reduces the nutrients loss to the environment and ensures its prolonged availability (Trenkel, 2012, Yaseen *et al*., 2017). They are also termed as "controlled release fertilizers" as time, pattern and amount of released nutrient might be anticipated inside certain limit (Trenkel, 2010). Use of PCF reduces its fixation due to high cation exchange capacity and water absorbing properties (Dubey *et al*., 2013). However, nutrients release from PCF depends upon many factors including coating material concentration, thickness, soil moisture, and temperature etc. Many benefits have been reported to agriculture by using coated P fertilizer as nutrient losses via fixation and chemical reactions with soil were substantially decreased (Trenkel, 2010; Yaseen *et al*., 2017).

Growth of stressed plants can be activated through phytohormones/plant growth regulators (Iqbal *et al*., 2014). Phytohormones play very important role in mediating plant response to abiotic stress (Harrison, 2012; Skirycz and Inze, 2010). Salinity causes many hormonal changes in many plants such as wheat (*Triticum aestivum*) and rice (*Oryza sativa*) (Javid *et al.*, 2011). Ethylene plays very important role in seed germination as it breaks its dormancy. Its role in plants ranging from seed germination to organ senescence and modulated the physiological effects induced by salinity (Gomez-Cadenas *et al.*, 1998). ACC level in many plants increased because salinity stress altered ethylene biosynthesis (Bar *et al*., 1998; Lutts *et al*., 1996). In addition, many authors indicated ACC conversion to ethylene should decrease due to less ACC oxidase activity (Li and Ni, 2001; Lutts *et al*., 1996). In higher plants the physiological precursor of auxin biosynthesis is L-tryptophan. Growth and yield of many crops can be enhanced by exogenous application of tryptophan (Akhtar *et al.*, 2007; Zahir *et al*., 2004, 2005). Different concentration of auxins released from its precursor is required for better growth and it varies with type and variety of crop. In higher plants, it has been reported that L-tryptophan has better effects on seed germination, growth, nutrient uptake and yield as compared to pure auxin (Frankenberger and Arshad, 1991). Similarly, salicylic acid involved in many physiological processes of plants and induces tolerance under biotic and abiotic stresses (Najafian *et al.*, 2009). The positive effect of S.A application in plants depends upon plant growth stage, its concentration and environment (He and Zhu, 2008; Stevens *et al*., 2006).

Wheat is moderately tolerant to salinity. There is dire need to study themorpho-physiological wheat responses to the combined effects of salinity and less phosphorous availability. This goal can be achieved through integrated approach of using polymer coated P fertilizer (DAP) enriched with hormones. Polymer protects the P fertilizer grains from quick reaction in soil and hormones create resistance against stresses along with continuous release of nutrients according to crop requirement. Wheat crop was grown as a test crop and its response to application of PCDAP enriched with hormones was monitored for P use efficiency and grain yield. So, according to above details, integrated uses of hormone enriched polymer coated DAP fertilizer were undertaken in a series of different experiments to investigate:

1. Release pattern of P in normal and saline soil using hormone enriched polymer coated DAP.
2. Release pattern of hormones in normal and saline soil cured with hormone enriched polymer coated DAP at different moisture levels and temperatures.
3. Influence of hormone enriched PCDAP on wheat production.

MATERIALS AND METHODS

***Experimental material for laboratory studies*:** Commercially available di-ammonium phosphate fertilizer was coated by water soluble polymer (Yaseen *et al*., 2017) in Soil Fertility and Plant Nutrition Laboratory, Institute of Soil and Environmental Sciences, University of Agriculture Faisalabad. Polymer coating of di-ammonium phosphate was carried out according to the polymer strength (0, 1, 1.5 and 2%) in experiment 1 and hormones enriched polymer coated di-ammonium phosphate (HPCDAP) in experiment 2. For experiment 2 different hormones concentrations were selected for coating purposes. After coating, the fertilizer granules were left to dry for some time under laboratory conditions and stored in polyethylene bags. Soil was collected from Postgraduate Agricultural Research Station (PARS), University of Agriculture Faisalabad. Soil samples (0-15cm depth) were collected from normal and saline soils. In all laboratory experiments ground and screened (2mm sieve) soil was used. The collected soil samples were analyzed for their properties (Table 1).

The method of Bouyoucos hydrometer described by Moodie *et al.* (1959) was used to measure the soil texture of normal and saline soil samples. The soil texture classification system of USDA was used for classification. Prepared paste of both types of soils by adding distilled water and then dried in oven at temperature 105^{0}C. Given formula was used to determine soil saturation percentage:

$$SP = \frac{\text{wt. of wet soil} - \text{wt. oven dried soil}}{\text{wt. oven dried soil}}$$

Table 1. Some characteristics of the studied soil (0-15 cm depth)

Properties	Units	Readings (normal soil)	Readings (saline soil)
Sand	%	47	69
Clay	%	25	19
Silt	%	28	12
Textural class		Sandy clay loam	Loamy sand
Organic matter	%	0.74	0.29
CEC	meq/100 g	4.07	13.38
ECe	dSm^{-1}	1.95	7.9
pHs	-	7.55	7.9
Total nitrogen	%	0.041	0.029
Extractable Potassium	$mg\ kg^{-1}$ soil	125	90
Olsen Phosphorus	$mg\ kg^{-1}$ soil	6.52	4.97
Exchangeable Na	meq/100 g	0.78 ± 0.00	2.72 ± 0.32
Exchangeable Ca	meq/100 g	2.00 ± 0.00	18.5 ± 0.70
Exchangeable Mg	meq/100 g	1.00 ± 0.00	2.75 ± 1.06

Soil pH was measured by using pH meter. To determine the EC of soil samples, a Jenway-410 EC instrument was used. The instrument was first calibrated with a KCl (0.01N). Organic matter was determined through standard procedure (Moodie *et al*., 1959) for both types of soil samples. Soil (200 g) maintained at field capacity (60% of saturation%) was filled in disposable cups of 250 cm^3. Phosphorus was applied as UCDAP and CDAP (0.25 g P in 100g of soil) and mixed thoroughly in soils (normal as well as saline soil). For maintaining field capacity in cups distilled water was used after every 24 hours in an incubator (Sanyo; MIR 253). To calculate the phosphorus in soil Olsen method (Olsen *et al*., 1954) was followed with the intervals of 15 days till 60 days at 25±2°C to select effective polymer level from experiment 1 and best concentration of hormones release pattern from coated DAP granules in the form of hormone enriched polymer coated fertilizer.

***Salicylic acid determination*:** Salicylic acid was determined by colorimeter method. After gentle mixing of 0.2 g NaCl, 0.5 mL sample solution, 1.0 mL of Pentachloronitrosyliridate (PCNI) in 10 mL flask, the flask was kept in the dark for at least one hour. Ascorbic acid (0.2 mL) was added to it and diluted with 4M hydrochloric acid and observed absorbance at 446 nm.

***L-tryptophan determination*:** Auxin production of polymer impregnated fertilizer, both in the presence and absence of L-tryptophan (TRP), was determined on spectrophotometer (Sarwar *et al*., 1992). Supernatant (3 mL) was mixed with 2 mL Salkowski's reagent (12 g L^{-1} $FeCl_3$ in 429 mL L^{-1} H_2SO_4) and incubated for color development for half an hour at room temperature. Auxin concentration was measured using a spectrophotometer at 535 nm.

***L-methionine determination*:** Erlenmeyer flasks (125 mL) containing 50 g of soil was capped with valves (Pierce, Rockford, IL). Methionine precursor of ethylene was added in soil by coated fertilizer at field capacity (-33 kPa). Methionine concentration was determined by gas chromatography which was equipped with FID detector and a 6 ft column (80-100 mesh) at 80°C. The operating conditions consisted of the following: sample (1 cm^3) carrier gas (N_2 at 13 mL min^{-1}), H_2 flow (30 mL min^{-1}), air flow (300 mL min^{-1}), detector temperature (200°C) and integrator (HP3390A). Peak area and retention times for C_2H_4 were compared to reference standards which were made by diluting 99.5% C_2H_4 (East Rutheford, N J).

***Field experiment*:** The best concentrations of all hormones (salicylic acid, L-tryptophan, L-methionine), selected from study 2, were mixed collectively with best polymer solution concentration (selected from experiment 1), and coated on DAP fertilizer to check the combined effect of all hormones and polymer impregnated DAP fertilizer on wheat crop (Faisalabad 2008) under field conditionsat PARS, UAF in both normal and saline soils. Treatment plan comprised of seven treatments i.e., T1 = Control (without any fertilizers), T2 = NK + P from uncoated DAP at 100% recommended rate, T3 = NK + P from polymer coated DAP at 100% recommended rate, T4 = NK + P from hormones enriched polymer coated DAP at 100% of recommended rate, T5 = NK + P from hormones enriched polymer coated DAP at 75% of recommended rate. T6= NK + P from hormones enriched polymer coated DAP at 50% of recommended rate. T7= NK + P from hormones enriched polymer coated DAP at 25% of recommended rate for both normal and saline soils. Factorial design under randomized complete block design with three replications was used. Urea, DAP and SoP as N, K, P sources (120-60-90 kg ha^{-1}, respectively). The 1/3rd nitrogen and full phosphorous and potash were fertilized at sowing and remaining N was broadcasted with following irrigations. Nitrogen and potassium fertilizer were applied at recommended rate without coating. Wheat (variety, Faisalabad-2008) was used with five numbers of irrigations of canal water. All growth and yield attributes were measured from an area of one square meter (selected randomly) before twenty days of harvesting. Average values were used. Chlorophyll contents were measured by portable Chlorophyll Meter SPAD-501 before grain formation. Biological yield of wheat crop was calculated by the formula:

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

***Chemical analysis*:** Plant samples (grain and straw samples) were taken from each plot for chemical analysis. Nitrogen concentration of wheat grains and straw samples were determined through Kjeldhal method (Jackson, 1982). Phosphorus, in digested samples of plants, was determined by vanadate molybdate spectrophotometer method (Olsen *et al*., 1954). Digested filtrate K was analyzed on flame photometer (410 Sherwood) as described by Chapman and Pratt (1961). Phosphorus uptake in grain and shoot was calculated by using formula described as below:

PU = Oven dried weight grains or straw × P (%) / 100

PU= Phosphorus uptake

Total P uptake= P uptake g pot^{-1} (grains + straw)

Nutrient use efficiency was determined by:

PUE determined through formulae:

AE (g grains/g fertilizer) = (P fertilized pot yield – P unfertilized pot yield) / (Amount of fertilizer applied)

RE (%) = (total P uptake by fertilized plant – total P uptake by unfertilized plant) / (Amount of fertilizer applied) × 100

AE = Agronomic efficiency, RE = Recovery efficiency

***Statistical analysis*:** All parameters were statistically analyzed (Steel *et al*., 1997) to determine the statistical significance of treatment effects. Means were compared with each other following ANOVA technique by using honestly significant difference (HSD) testat5% probability level.

RESULTS

***Comparative effect of different concentrations of coating material on DAP fertilizer to prolong P availability in soil*:** Data in Table 2 showed release of P at different incubation intervals in non-saline and saline soils where coated and without coated DAP fertilizer were applied. In non-saline soil (normal), release pattern of P was initially more in treatment of uncoated DAP (UNDAP) fertilizer at early incubation days of fertilizer application i.e. during 15 days. As the time passed, the release of phosphorous decreased in soil treated with uncoated DAP. However, in case of coated fertilizer, the release pattern of P from coated DAP fertilizer treatment was entirely different i.e. less at 1st interval and more during later intervals. Treatment of non-saline soil with uncoated DAP demonstrated the maximum P concentration (915.66 mg kg^{-1}) at 15 days. Phosphorous concentrations from uncoated DAP decreased after 30 days in both types of soils. However, at this time interval, there was an increase in phosphorous release in all polymer coated treatments. Maximum P release i.e., 646.12 mg kg^{-1} soil evidenced where DAP coated with 1% polymer concentration after 30 days of intervals in non-saline soil. Although, release of P from coated DAP with different polymer concentrations (1.5 and 2%) increased at this incubation interval as compared to the 1st interval yet it was less than 1% coating concentration. The released P concentrations at 1.5 and 2% concentration of polymer were 316 and 220mg kg^{-1}soil, respectively in non-saline soil after 15 days that increased to 585 and 355 mg kg^{-1} soil at 30 days incubation interval. Treatments of 1, 1.5 and 2% polymer concentration coated DAP increased P release in soil gradually over uncoated DAP fertilizer. More decline in phosphorous concentrations (at 45 days) was observed in treatments where uncoated DAP was applied i.e., 458.15 mg kg^{-1} soil. Maximum phosphorous release at that time interval was (998.22 mg kg^{-1}soil) where 1% of polymer coated di-ammunium phosphate (PCDAP) was applied and it was followed by 1.5 and 2% polymer concentration coated DAP. However, soil treated with 2% PCDAP showed minimum P concentration i.e., 427.7 mg kg^{-1} soil among all the coated concentrations. This might be due to more thickness of coating material. Results confirmed that there were noteworthy differences in release pattern of phosphorous in non-saline soil at 60 days of time. By increasing the incubation time, phosphorous availability in soil was decreased from uncoated fertilizer, might be due to fixation and vice versa from coated fertilizer. At 60 days interval, there was gradual increase in soil available P in coated concentration treatments while it was decreased in uncoated DAP. Maximum P release at 60 days of interval was found in the soil treated with 1% polymer concentration i.e., 923.21 mg kg^{-1}. In 1.5 and 2% concentrations, the P release was 855.37 and 454.28 mg kg^{-1} soil, respectively.

Data regarding uncoated and coated DAP with different concentrations of PAM fertilizer on Olsen's phosphorous release in saline soil at different intervals (Table 2) indicated that treatment of uncoated DAP fertilizer caused maximum phosphorous release (605.64 mg kg^{-1}) after 15 days as compared to coated DAP treatments. At 15 days of

Table 2. Comparative effect of PCDAP fertilizer and incubation time on soil-P availability

	Treatment	**Time interval (day)**				
	Coating concentration	**15**	**30**	**45**	**60**	**Mean**
Soil type	**of polymer (%)**	**P in soil (mg kg^{-1}soil) at field capacity**				
Non-saline	Uncoated DAP	915B	605FG	416KL	224Q	540C
(Normal)	1	333MN	615EF	99A	933B	719A
	1.5	316NO	585G	863C	845C	652B
	2	220Q	355M	427K	454J	364F
	Uncoated DAP	605FG	542H	396L	114S	414E
Saline	1	295O	518I	677D	635E	531C
	1.5	253P	468J	602FG	588G	478D
	2	168R	222Q	345M	305O	260G
Mean		388D	488C	590A	512B	

Note: Data is averaged of three replicates, Values followed by the same letter (s) are not significantly different from each other at 5% level of significance, Tukey honestly significant difference (HSD) test value of P for: interval = 5.548, soil type = 2.9698, interaction (interval * soil) = 9.3207, interaction (interval* treatment) = 14.992 and interaction (interval* treatment*soil) = 23.552.

incubation, comparison among polymer treatments elucidated maximum Olsen's P release (295.74 mg kg^{-1} soil) treated with 1% polymer solution concentration. The release pattern in 1.5% and 2% concentration of PCDAP fertilizer was observed with 253.34 and 168.53 mg P kg^{-1} soil, respectively. However, this trend of phosphorous release in saline soil was different; where P significantly decreased in UCDAP fertilizer compared to already shown maximum P at 15 days interval (Table 2). This trend was more or less equal to that at 45 and 60 days of incubation time periods. Estimated phosphorous in saline soil after 45 days was 396.44, 677.97, 602.97 and 345.14 mg kg^{-1} soil in uncoated, 1, 1.5 and 2% polymer concentration coated DAP, respectively. At 60 days of incubation, maximum Olsen's P (618.24 mg kg^{-1}) was released by 1% polymer solution which was followed by 1.5% (578.21 mg kg^{-1} soil) and 2% polymer solution (299.91 mg kg^{-1} soil).

In both soils (salt-containing soil and non-salt-containing soil), 1% polymer concentration showed considerably better results as compared to that of 1.5% and 2%. At 45 days of interval 1% polymer solution gave better results as compared to other intervals. There was about 22% more release of P in 1% PCDAP as compared to uncoated di-ammunium phosphate (UDAP) fertilizer in non-saline soil and it was 27% more in saline soil.

***Performance of hormone impregnated polymer coated DAP fertilizer on release pattern of P and hormone in soil*:** Results showed noteworthy differences in Olsen's phosphorous release in normal and saline soils in response to different concentrations of hormones imbedded in best selected polymer concentration (1% from experiment 1) on phosphatic fertilizer (DAP). Treatments of uncoated DAP had maximum P release in both type of soils over 15 days incubation interval. On an average, release patterns in commercially available DAP fertilizer treated in saline and non-saline soil was 426 and 548 mg kg^{-1}soil, respectively. On an average the release pattern of P from alone PCDAP treatment was 639 and 530 mg kg^{-1}soil in non-stressed and stressed soils, respectively. Comparison among all polymer coated treatments along with different hormones with different concentrations showed that polymer + 20 mg L^{-1} L-tryptophan showed the highest release of P i.e., 688 mg kg^{-1} soil in normal soil. This treatment also showed similar trend regarding P in saline soil (564 mg kg^{-1} soil), though this

Table 3. Performance of hormones impregnated polymer coated DAP fertilizer and incubation time on P release pattern in soil

Soil type	Treatment: Coating concentration of hormones enriched polymer on DAP fertilizer		Time interval (day) 15	30	45	60	Mean
			P in soil (mg kg^{-1} soil) at field capacity				
Non-saline (Normal)	L-tryptophan	Uncoated DAP	901BC	627R	426c	240m	548HI
		Coated DAP	312ij	521U-W	889DE	834I	639E
		Coated DAP enriched with 20 ppm L-Try	360e	569R	924A	899B-D	688A
		Coated DAP enriched with 10 ppm L-Try	333f	524UV	891 C-E	875FG	655C
	L-methionine	Uncoated DAP	901BC	627R	426C	240m	548HI
		Coated DAP	312ij	521U-W	889DE	834I	639E
		Coated DAP enriched with 5 ppm methionine	319gh	529U	892B-D	852H	648D
		Coated DAP enriched with 1 ppm methionine	303jk	507WX	871FG	840I	630F
	Salicylic acid	Uncoated DAP	901BC	627R	426c	240m	548HI
		Coated DAP	312ij	521U-W	889DE	834I	639E
		Coated DAP enriched with 10 ppm S.A	356f	552S	902B	874FG	671B
		Coated DAP enriched with 5 ppm S.A	326gH	512WX	881EF	866G	646D
Saline	L-tryptophan	Uncoated DAP	699N	514V-X	384e	109n	426M
		Coated DAP	272l	458b	734K-M	656P	530K
		Coated DAP enriched with 20 ppm L-Try	311ij	496Y	756 I	694N	564G
		Coated DAP enriched with 10 ppm L-Try	293 k	482Z	727M	681O	545I
		Uncoated DAP	699N	514V-X	384e	109n	426M
	L-methionine	Coated DAP	272l	458b	734K-M	656P	530K
		Coated DAP enriched with 5 ppm methionine	299jk	462b	741KL	660P	532J
		Coated DAP enriched with 1 ppm methionine	279l	441c	730M	639Q	522L
	Salicylic acid	Uncoated DAP	699N	514V-X	384e	109n	426M
		Coated DAP	272l	458b	734K-M	656P	530K
		Coated DAP enriched with 10 ppm S.A	303jk	477Za	744K	681O	551H
		Coated DAP enriched with 5 ppm S.A	281i	469ab	731LM	674O	538J
	Mean		429D	515C	712A	614B	

Note: Values are averaged of three replicates and those followed by the same letter(s) are not significantly different at 5% level of significance. Tukey honestly significant difference (HSD) test value of P for: interval =1.6684, soil type =0.9003, interaction (interval*soil) =2.7837, interaction (interval*treatment) = 6.9430 and interaction (interval*treatment*soil) =10.650.

concentration was less than normal soil when evaluated with other treatments. It was followed by soil treated with polymer + 10 mg L^{-1} S.A + 5 mg L^{-1} L-methionine coated DAP fertilizer (671 and 648 mg kg^{-1} in normal soil, respectively), 551 and 532 mg kg^{-1} in stressed soil, respectively. Release pattern of UCDAP fertilizer after 15 days in normal soil was 901 mg kg^{-1} while it was 699 mg kg^{-1} in saline soil. Alone PCDAP and HPCDAP showed relatively more increase of P in soil after 30 days. The release pattern of phosphorous in soil which was treated with only PCDAP, polymer + 20 mg L^{-1} L-tryptophan, polymer + 5 mg L^{-1} L-methionine and polymer + 10 mg L^{-1} S.A was observed as 521, 569, 529 and 552 mg of P kg^{-1} of soil, respectively in non-stressed soil. In stressed soil hormones enriched PCDAP gave more release of P as compared to simple DAP and alone PCDAP. Maximum release of phosphorous in saline soil after 30 days interval was observed as 496 mg kg^{-1} soil where polymer + tryptophan (20 mg L^{-1}) was applied. Release patterns of P from polymer enriched with salicylic acid and L-methionine was also increased in contrast to alone PCDAP fertilizer. Results pointed out that there was gradual decline in P from uncoated DAP fertilizer in both soils, while there was gradual increase in alone polymer coated and hormone PCDAP fertilizer during respective later intervals. At incubation period (45 days), treatment containing DAP fertilizer coated either with L-tryptophan, L-methionine and/or S.A depicted P (maximum) in normal as well as in saline soil (Table 3). Higher concentration of hormones (L-tryptophan, L-methionine and S.A) performed better when compared with other treatments with lower concentration of the respective hormones. The average concentration of phosphorous all over the intervals showed that at 45 days interval P release pattern was the highest i.e., in normal and saline soil as shown in Table 3. Further Olsen's P decreased at 60 days of incubation interval from uncoated DAP (240 and 109mg kg^{-1} soil in normal and saline soils, respectively). At 60 days interval, polymer mixed with L-tryptophan coated DAP showed higher Olsen's P (899 and 694 mg kg^{-1} in normal and saline soils, respectively) followed by polymer enriched with S.A and polymer enriched with L-methionine coated DAP. Comparison between concentration of S.A at 10 and 5 mg L^{-1}, L-methionine at 1 and 5 mg L^{-1} and S.A and methionine at 10 and 5 mg L^{-1}, respectively performed better and gave more soil P release in soil (Table 3) in both types of soils. In short, with increase in incubation time interval, there was reduction in available P in soil treated with uncoated DAP while this trend was reversed in the case of coated DAP fertilizer. L-tryptophan, salicylic acid and L-methionine enriched PCDAP showed maximum P after 45 day, after this it showed decreasing trend with increase in time of incubation. However, at all incubation time periods L-tryptophan enriched PCDAP fertilizer application exhibited increasing trend in P release in both types of soils.

***Release pattern of IAA (L-tryptophan) in soil with L-tryptophan enriched PCDAP at different incubation intervals*:** Indoleacetic acid (IAA) is a precursor of L-tryptophan and is released in the soil by applying L-tryptophan. After 45 days, IAA in saline treated soil treated with L-tryptophan-enriched polymer was 20 mg kg^{-1}(maximum). It was intimately followed by same treatment after 60 days of incubation interval (Figure 1). Data premised that in control where no fertilizer was applied there was very less/negligible release of IAA in both types of soils at all intervals. Behavior of PCDAP and uncoated DAP fertilizer was found almost same. The extent of IAA release from hormone enriched PCDAP was more than the DAP (uncoated). IAA from DAP fertilizer (uncoated) decreased but the release from PCDAP and HPCDAP increased (30 days interval). A significant increase in IAA release was found from tryptophan enriched PCDAP in both types of soils after 45 days. There was very less amount of P release from uncoated phosphorous fertilizer and alone PCDAP after 60 days of interval but the HPCF performed better at this time interval. Results demonstrated that hormone enriched polymer layer on DAP gave highly significant results over simple uncoated DAP in both saline and non-saline soils but results were more significant in saline soil.

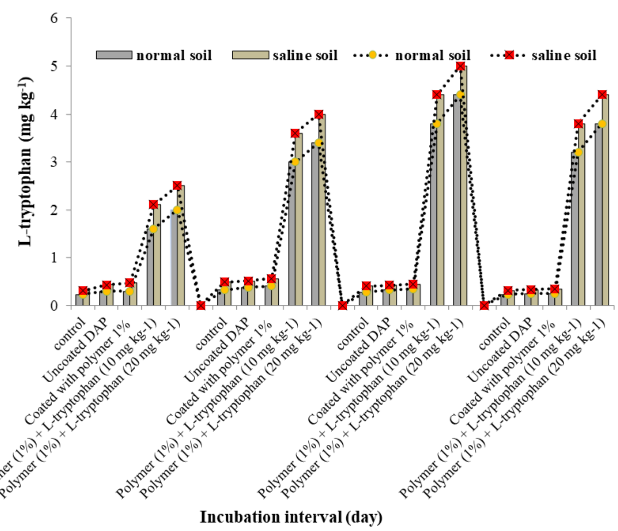

Figure 1. Release pattern of IAA (L-tryptophan) in soil with L-tryptophan enriched PCDAP at different incubation intervals

***Release pattern of ethylene in soil with L-methionine enriched PCDAP at different incubation intervals*:** Methionine is precursor of ethylene. Application of methionine into soil is resulted in the release of ethylene. Graphical representation of ethylene concentration in soil, applied in the form of L-methionine (precursor of ethylene) enriched polymer with different concentrations (1 and 5 mg kg^{-1} soil) coated on DAP (Figure 2). The lowest ethylene concentration was found in control where no hormone was applied in non-saline and saline soil i.e., 0.4 and 0.67 µmolkg^{-1}, respectively after 15 days of incubation interval. The concentration was increased up to 58 and 56% by the application of polymer enriched with 5 mg kg^{-1} L-methionine coated DAP in saline and non-saline soil, respectively at 15 days interval. It is obvious from Figure 2 that among all four intervals, diammonium phosphate coated with polymer enriched 5 mg kg^{-1} caused utmost results in ethylene concentration in saline soil after 45 days of interval. Figure 2 also depicted that with the passage of time, released concentration of ethylene also increased in both types of soils until 45 days of interval when compared to the control (without any amendment) and uncoated fertilizer and alone PCDAP fertilizer. After sixty days intervals, PCDAP and MPCDAP (methionine enriched DAP) showed significantly less ethylene than the preceding interval. Release of ethylene through commercially available DAP and alone PCF was negligible at this incubation interval in non-saline soil and very less concentration of ethylene in saline soil. Increasing ethylene release trend with respect to soils observed was saline soil > non-saline soil. Performance of DAP coated with 5 mg kg^{-1} enriched L-methionine polymer at all intervals was significantly describable in saline soil.

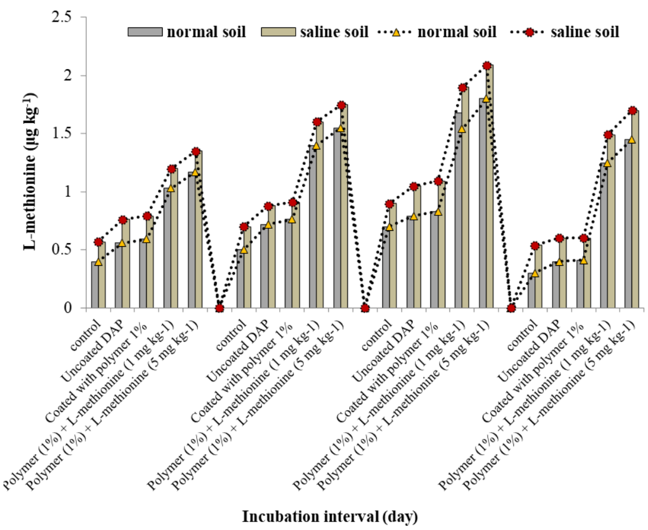

Figure 2. Release pattern of ethylene in soil with L-methionine enriched PCDAP at different incubation intervals

***Release pattern of salicylic acid in soil with salicylic acid enriched PCDAP at different incubation intervals*:** Performance of different concentrations of salicylic acid (S.A) enriched polymer coated, PCDAP and uncoated DAP analyzed for salicylic acid release (Figure 3).Salicylic acid release from coated DAP was higher than UCDAP (15 days interval) in both saline and non-saline soil. The highest SA release was calculated in saline soil where DAP was coated with polymer enriched with 10 mg kg^{-1} of salicylic acid and it was followed by coated DAP with polymer enriched with 5 mg kg^{-1} of salicylic acid. This released concentrations were less in the treatment of uncoated DAP fertilizer in both types of soils. By increasing salicylic acid concentration, salicylic acid release increased in both soils. The behavior of uncoated fertilizer and alone PCF were different in comparison with coated fertilize in both type of soil. The increase in salicylic acid release in soil treated with S.A enriched PCF was surely due to the application of S.A and slow release at later incubation intervals was due to polymer layer.

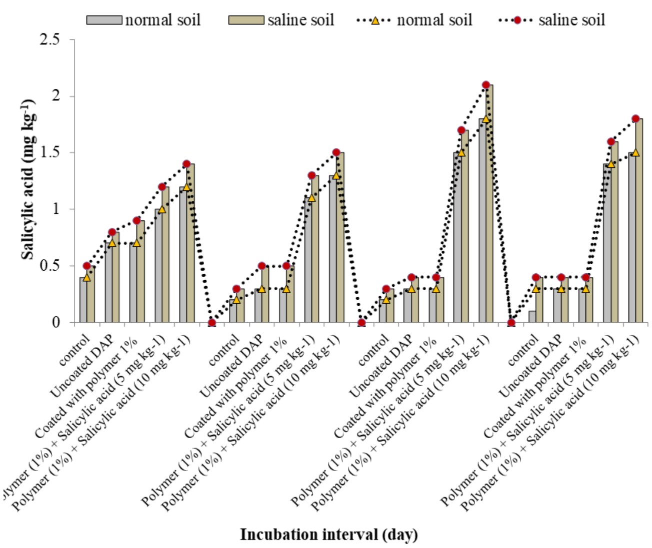

Figure 3. Release pattern of salicylic acid in soil with salicylic acid enriched PCDAP at different incubation intervals

***Field Experiment: Growth and yield parameters of wheat crop*:** Polymer coated DAP enriched with and without hormones increased the plant height over uncoated DAP fertilizer (Table 4). There was 20% increase in plant height (110 cm) where 100% of recommended rate of HPCDAP along with recommended rates of nitrogen and potassium fertilizers were applied on normal soil as compared to the recommended rate of uncoated DAP fertilizer. The response of 50% of recommended rate of HPCDAP fertilizer were non-significant with recommended rate of uncoated DAP fertilizer i.e., 86 cm and 88 cm, respectively. In case of saline soil, maximum plant height was measured in the treatment where 100% rate of HPCDAP was applied (Table 5). Treatments including recommended to reduced rate i.e., 75% rate of HPCDAP also showed significant increase in plant height cm as compared to 100% of uncoated DAP and alone PCDAP. There was a 27 and 25% increase in plant height by 100and 75% rate of HPCDAP fertilizer, respectively on saline soil. Increase in height of plant in the treatment of alone PCDAP fertilizer on saline soil was 16% than uncoated DAP. Number of fertile tillers was significantly increased in PCDAP

Table 4. Effect of hormones enriched polymer coated DAP fertilizer on growth and yield components of wheat crop under normal soil

Treatments	Plant height (cm)	No. of fertile tillers (m^{-2})	1000 grain weight (g)	Chlorophyll contents (SPAD)	Grain yield (kg/ha)	Straw yield (kg/ha)	Biological yield (kg/ha)
Control	62 f	178 h	28 g	32 g	2100 h	3400 h	5500 g
UDAP @ 100%	88 d	363 cd	41 d	43 d	4700 d	6300 d	11000 a-d
PDAP @ 100%	104 ab	415 ab	48 b	51 b	5200 bc	7115 b	12166 ab
HPDAP @ 100%	110 a	454 a	54 a	55 a	5700 a	7640 a	13240 a
HPDAP @ 75%	102 bc	405 bc	47 b	50 b	5100 bc	6900 bc	12000 ab
HPDAP @ 50%	86 d	351 de	38 e	45 e	4500 d	6000 d	10666 b-e
HPDAP @ 25%	72 e	258 fg	33 f	37 g	3300 f	4900 f	8200 ef

Table 5. Effect of hormones enriched polymer coated DAP fertilizer on growth and yield components of wheat crop under saline soil

Treatments	Plant height (cm)	No. of fertile tillers (m^{-2})	1000 grain weight (g)	Chlorophyll contents (SPAD)	Grain yield (kg/ha)	Straw yield (kg/ha)	Biological yield (kg/ha)
Control	43 g	107 i	21 h	23 i	1600 i	2400 i	4066 h
UDAP @ 100%	86 e	240 g	34 f	35 f	4000 e	5400 e	9400 c-e
PDAP @ 100%	72 d	305 ef	39 de	41 de	4600 d	6100 d	10700 b-d
HPDAP @ 100%	98 bc	388 b-d	48 b	48 b	5300 b	7000 bc	12200 ab
HPDAP @ 75%	96 c	360 cd	44 c	45 c	5000 c	6700 c	11700 b-d
HPDAP @ 50%	74 e	249 de	33 f	34 fg	3800 e	5100 ef	8900 d-f
HPDAP @ 25%	58 f	181 h	27 g	28 h	2600 g	3900 g	6533 fg

treatments both with and without hormones as compared to uncoated DAP fertilizer treatment. Maximum increase in number of fertile tillers in the treatment receiving 100% of recommended rate of HPCDAP on normal soil was 20% more than uncoated DAP (Table 4).

The increase in number of fertile tillers in the treatment of 75% of recommended rate of HPCDAP was 10%, and it was 12% in the treatment of 100% rate of alone PCDAP on non-saline soil. However, results regarding number of fertile tillers were more conspicuous on saline soil (Table 5). The DAP fertilizer coated with polymer enriched with hormones and applied at 100% and 75% rate of DAP showed statistically non-significant response, either due to the role of hormones under stress condition. The number of fertile tillers on saline soil in the treatments of 100 and 75% rate of P were 398 and 376, respectively. The half dose of HPCDAP and 100% rate of UCDAP resultedin276 and 275 number of fertile tillers, respectively. Application of hormones enriched polymer coated DAP fertilizer significantly improved chlorophyll contents of wheat over control. Statistically analyzed data depicted that chlorophyll contents attained maximum upturn (55 SPAD) in the treatment receiving 100% of recommended rate of HPCDAP, (Table 4). The chlorophyll content in the treatment of 100% rate of UCDAP was 43 SPAD. Treatment effect was more significant on saline soil i.e., 27 and 22% increase in chlorophyll contents were recorded in 100 and 75% rates of P (as HPCDAP), respectively than plants treated with UCDAP fertilizer (Table 5). Application of 100% rate of alone PCDAP caused 14%increaseover uncoated DAP treatment. The statistical data of wheat biological yield revealed that there was 16% increase in wheat biological yield in treatment where100% rate of HPCDAP was applied as compared to the 100% of recommended rate of uncoated DAP fertilizer in normal soil (Table 4) and 23%increase in case of saline soil (Table 5). In saline soil, 75% of recommended rate of HPCDAP also showed significant result. There was 19% increase in biological yield on saline soil where 75% of recommended rate of HPCDAP was applied in comparison to 100% rate of UCDAP. Biological yield increased by12% due the treatment of alone PCDAP fertilizer over UCDAP. Polymer coated and hormones enriched polymer coated treatments also increased the wheat straw yield. Data revealed maximum upsurge of wheat straw yield up to 16% where 100% of recommended rate of P (HPCDAP) was applied over uncoated DAP on normal soil (Table 4) and 22% more wheat straw yield in saline soil (Table 5) than UCDAP. Application of 75% rate of HPCDAP also showed the significant results in saline soil that were not on normal soil. There was 19% increase in wheat straw yield on saline soil having 75% of recommended rate of HPCDAP fertilizer was applied in comparison to uncoated phosphatic fertilizer (100% of recommended rate). Polymer enriched with hormones and alone PCDAP treatments showed noteworthy effect in wheat grain yield at control. Maximum wheat grain yield was recorded on normal soil which was 19% higher in treatment where full dose of HPCDAP than uncoated DAP (Table 4). Analysis of variance data regarding grain yield proved that application of alone PCDAP increased wheat grain yield up to 13% as compared to uncoated DAP on normal soil. In saline soil, maximum increase was found in treatment have 100% rate of CDAP (coated di-ammonium phosphate) with hormones plus polymer was applied i.e. about 26%as compared to uncoated DAP fertilizer. Application of 75% rate of HPCDAP enhanced wheat grains yield 20% over uncoated DAP in saline soil. Polymer enriched with hormones and alone PCDAP treatments revealed significant response on 1000 grain weight (Table 4). Maximum increase in 1000 grains weight was found in 100% of rate of HPCDAP. It was also more in UCDAP, up to 31% over control (no-fertilizer) in non-saline soil and 29% in the treatment where100% of rate of DAP coated with hormones + polymer was applied than UCDAP.

***Effect of HPDAP on Total N, P and K concentrations (%) of wheat under field conditions*:** Treatment effect as individual factor as well as interaction of factors showed improvement in total N, K and P uptake in both soils with and without hormones in PCDAP than uncoated DAP treatment. Data revealed that maximum increase in total N, P and K uptake was appeared in treatment where HPCDAP was applied at 100% rate of P i.e.,26%,32% and 22%, respectively in normal soil and 26%, 47% and 25% in saline soil, respectively. Likewise, hormones enriched polymer coated DAP fertilizer significantly improve the nutrients (N, P, and K) use efficiencies (recovery efficiency and agronomic efficiency). Maximum use efficiencies were found in treatment where 50% of recommended rate of HPDAP fertilizer was applied in both soil types.

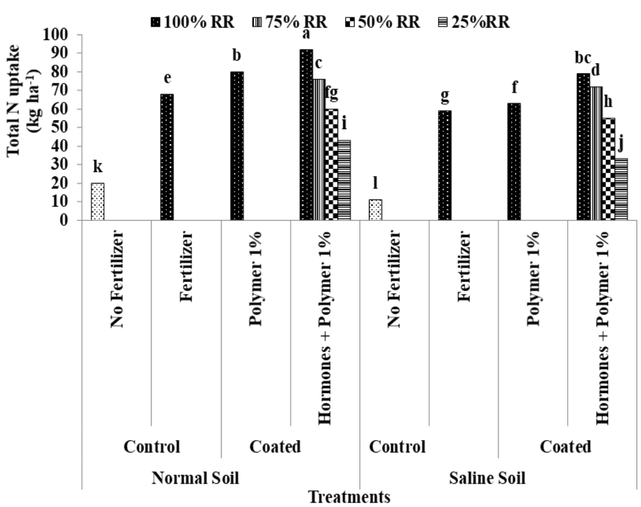

Figure 4. **Effect of HPCDAP fertilizer on total N uptake (kg ha^{-1}) in wheat crop**

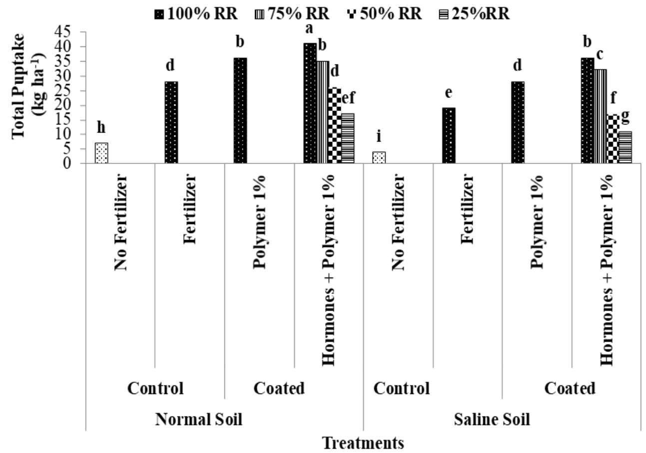

Figure 5. **Effect of HPCDAP fertilizer on total P uptake (kg ha^{-1}) in wheat crop**

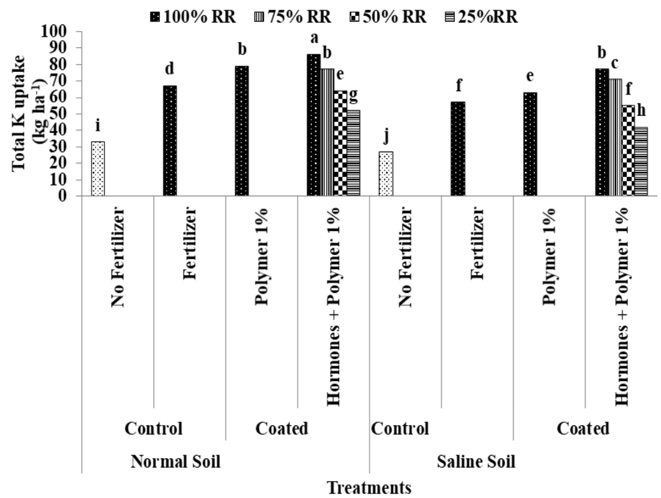

Figure 6. **Effect of HPCDAP fertilizer on total K uptake (kg ha^{-1}) in wheat crop**

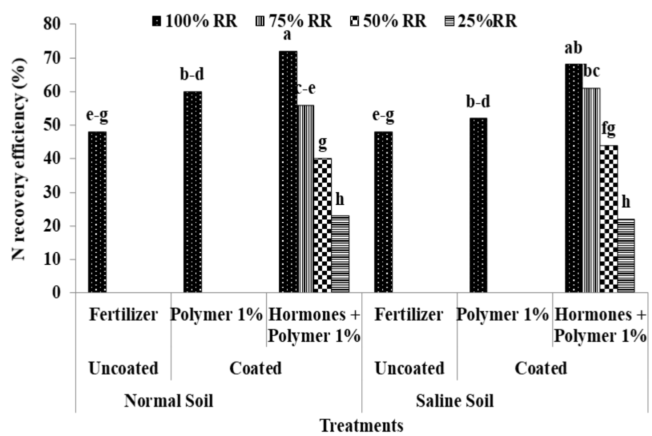

Figure 7. **Effect of HPCDAP fertilizer on nitrogen recovery efficiency (%) of wheat crop**

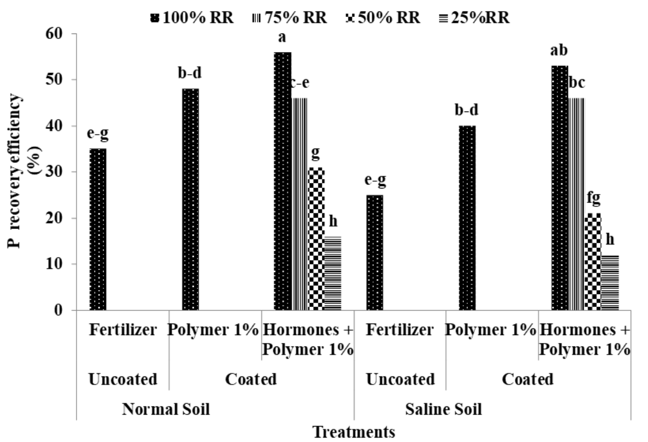

Figure 8. Effect of HPCDAP fertilizer on phosphorous recovery efficiency (%)

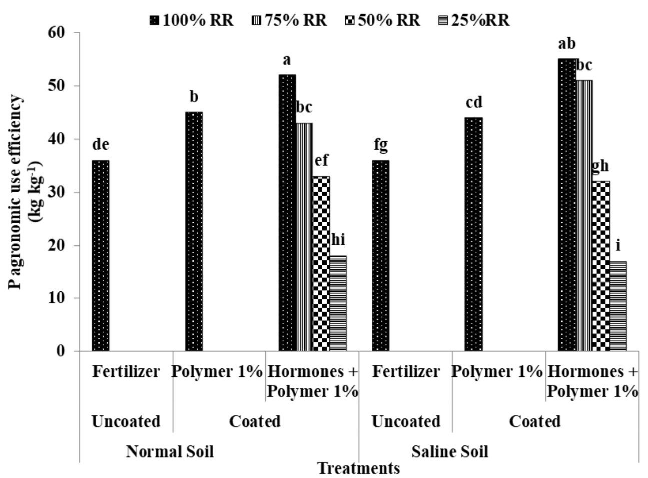

Figure 9. Effect of HPC DAP fertilizer on agronomic use efficiency (kg kg^{-1})

DISCUSSION

Saline conditions are characterized by nutritional disorders, osmotic effects, disturbances in soil ions balance and less nutrient use efficiency such as phosphorous which cause changes in soil fertility level and consequently lead to hormones imbalances, and disturbances in plant metabolism causing reduction in plant growth and production with low economic returns. It also affects ecological balance of the area. Plant growth and production can be improved by exogenous application of hormones or their precursors by altering their endogenous hormones level (Mustafa *et al*., 2016). Since polymer coating of phosphatic fertilizers enriched with stress/growth regulators (L-tryptophan, L-methionine, salicylic acid) may improve the phosphorous release pattern in saline soil paralleled to normal/non-saline soil. Owing to plant nutrient constraints, coating material was used for coating soluble fertilizer (Hanafi *et al*., 2000; Yaseen *et al*., 2017). Slow release or coated fertilizers have many beneficial effects such as decline in soil injuriousness/noxious effects, improvement in use efficiency and reduction in the cost of application due to low frequency of solicitation as testified by Noor *et al* (2016).

Laboratory experiments of current study revealed that DAP fertilizer coated with 1% PAM concentration gave higher phosphorous release in soil at all intervals in study time duration. However, the drift of release of phosphorus was same in both types of soils. Phosphorus solubility greatly abridged in salinity attributed with high Ca contents and pHs. Coating material plays very important role in controlling solubilization of DAP fertilizer because it develops a hydrated layer around the granule and slowly solubilizes it. Similarly in next incubation study L-tryptophan (20 ppm) enriched polymer coated DAP fertilizer gave maximum availability of phosphorous as well as hormone release pattern in both types of soils which was followed by salicylic acid and L-methionine, respectively (10 and 5 mg kg^{-1}). L-tryptophan, as bio-stimulant, promotes growth, improves availability of nutrients, and enhances quality of plants for extenuating toxicity/damages instigated by abiotic stresses (Gajewski *et al*., 2008). It acts as signaling features of different physiological progressions i.e. glutamate receptors (Rouphael *et al*., 2017). There is high stimulatory effect of L-tryptophan on shoot, root growth under saline stress condition (Egamberdieva, 2009). Application of HPCDAP improved wheat production in both types of soils but effect of application of phytohormones was more prominent in saline soil because of direct availability of phosphorous as well as growth promoters, determined by the boosted grain yield as well as other yield parameters under field conditions. Increase in plant growth parameters in saline soil was highly significant even at recommended to reduced rates of P application but the results were marginally more prominent in 100 and 75% rate of P (hormones enriched polymer-coated DAP). In case of normal soil, the results of full dose of P (hormones enriched polymer-coated DAP) were more significant but at reduced rates of HPCDAP (75%) non-significant when compared with alone polymer-coated DAP fertilizer on number of tillers in saline and non-saline soil. In the absence of NaCl toxicity, application of HPDAP enhanced fertile tillers with respect to control i.e. recommended rate of commercial DAP fertilizer. Increment in 1000 grains weight attributable to hormones embedded polymer-coated phosphorus fertilizer might be caused by greater uptake of phosphorus via application of PCF because of its involvement in formation of grain and addition of hormones which overcame the adverse effects of abiotic stress. Increase in wheat straw and grain yield in both saline and non-saline soil was due to better nutrient (P) use efficiency, resulted from more uptake of phosphorous throughout the growth period and less fixation due to presence of polymer layer on granule and the key role of phosphorus during emergence of radicle and formation of root as stated by Cook and Veseth (1991).

Application of PCF boosted up the grain yield and all yield parameters in contrast to uncoated fertilizer treatments Dunn and Stevens (2008). Also, Daniel *et al*. (1999) reported numbers of fertile tillers were increased in wheat by proper fertilizer application technique and by increasing of phosphatic application. In control treatment (without P fertilizer application) number of fertile tillers were less due to unsatisfactory supply of phosphorus which inhibits the emergence of root and leaves. Steady fertilizer availability caused increase in components of yield i.e. number of grains per spike and 1000 grain weight which gave the proof of phosphorus engrossment in formation of grain and growth of wheat (Rehim *et al*., 2010). Loss of nutrients from uncoated fertilizer is more due to unfavorable conditions, PCDAP and HPCDAP gave vigorous root growth and suppression of toxic effect of saline stress. High P with Auxin stimulates lateral root formation (Jose *et al*., 2002). At recommended and reduced rates of hormones enriched PCF application resulted in greater phosphorus uptake in straw and grain attributable to the availability of phosphorus. In PCFs, there are very few chances of P fixation over uncoated phosphatic fertilizer source, less contact with soil and minimum inhibitory effect of salt stress. For steady and slow release of nutrients, different coating materials are used like polymer which increases the nutrient use efficiency of applied fertilizers. Additional benefit of this coating technology is that it has greater exchange capacity which binds cations from soil solution and hinders free soluble phosphates formation as described by Tindall and Blaylock (2006). Curiosity to the use of PCFs has recently gained much attention among researchers because of its competent method for enhancing use efficiency of fertilizer (Xiang *et al*., 2008).

***Conclusion*:** In the current research, we demonstrated that manipulation of the micro-environment around fertilizer as well as application of growth regulators played significant physiological role in displaying the wheat growth, yield parameters, nutrient uptake efficiency, agronomic and recovery efficiency of P in saline as well as normal soil. We recommended to explore and evaluate such phytohormones enriched coated fertilizer techniques in different agro-climatic areas, which would help to achieve sustainable agriculture goals while reducing cost and improving farmers income in the form of sustainable and stable crop yield.

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