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Polymer coating based enhancement of fertilizer use efficiency and growth of wheat crop

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Abstract

Fertilizer is a precious but costly input which boosts production but sideways also increases cost of production. Present study was conducted to check the efficiency of polymer coated fertilizer and its effect on the growth and nutrient uptake of wheat plant. Calcium ammonium nitrate (CAN), Nitrophos (NP) and Murate of potash (MOP) were double coated with organic polymer. The treatment combination used includes i.e. T_1 = Uncoated NP, CAN and MOP at sowing, T_2 = Polymer coated CAN + uncoated NP and MOP at sowing, T_3 = Polymer coated NP and CAN + uncoated MOP at sowing, T_4 = Polymer coated NP, CAN and MOP at sowing, T_5 = Polymer coated CAN 50% at sowing + Polymer coated CAN 50% at 1st irrigation + polymer coated NP and MOP 100% at sowing, were used. Data was recorded on morphological traits and NPK uptake in grains and straw. Treatments having polymer coated fertilizer showed an increased uptake of the respective nutrients. Maximum plant growth, nutrient uptake and nutrient use efficiency was observed in the T_5 followed by T_4 whereas the lowest growth and NPK uptake were recorded under T_1. Hence polymer coated fertilizer enhanced the fertilizer use efficiency, yield and nutrient uptake.

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Introduction

World food demand is increasing day by day putting pressure on cultivated land to produce more food per unit area to fulfill the dietary needs of ever increasing population. There is a big gap between supply and demand of food which needs to be fulfilled. This gap can be fulfilled either by increasing the varietal potential, by increasing the application of inputs or by increasing the efficiency of applied inputs. Fertilizer application provides a better option for enhancement of grain yield. As fertilizer contain nutrients necessary for enhancement of growth of crop plants. So maintenance of optimum level of nutrition in the soil profile is inevitable to support the growth and development of plants. Almost all the soils in Pakistan have poor fertility status due to arid climate due to their formation under severe climate and low quantity of organic matter, nitrogen, phosphorus and Sulphur (Aulakh, 2010).

Nitrogen is an essential macro-nutrient which help plants in structural development and functioning of different plant systems. It usually combines with Carbon, Hydrogen, Oxygen and Sulphur to form the building blocks of DNA (Coruzzi and Bush, 2001). Protoplasm is also formed by amino acids that provide the place for chemical reactions. Nitrogen is an essential constituent of enzyme and it is also major component of chlorophyll. The quality and the quantity of the grain proteins in the cereal crops is also affected by nitrogen (Uchida, 2000). Nitrate (NO_3^-) and ammonium (NH_4^+) ions are available to plants as only source of nitrogen. Ammonia volatilization, denitrification, leaching and runoff losses are the major causes which lower nitrogen use efficiency in plants (Choudhury and Kennedy, 2005).

Phosphorus is second most important macronutrient necessary for plant growth and development (Jackson and Williams, 1985). It is an important component of plant cell and is crucial for cell division. It play a major role in crucial plant process like energy metabolism, production of nucleic acid, membrane formation, photosynthesis, respiration and regulation of enzymes (Canfield and Bachmann, 1981). It also has essential involvement in increasing water use efficiency and quality of seed (Sajid *et al.,* 2012). It is inaccessible to the plant (Holford, 1997) as it is fixed mineral nutrient in many cropping environments. Application of inorganic fertilizers over years, continuously raised phosphorous level in soils leading to negligible plant response. In fact, it is a "finite and irreplaceable" mineral. Its deficiency is widespread in 90% of Pakistani soils and the application of phosphatic fertilizers is considered essential for crop production (Masood *et al.,* 2011). Potassium (K) also have a crucial role in regulation of plant growth although it does not become the part of the plant (Ashley *et al.,* 2006) but have role in transport of photosynthates, transport of sugars, enzyme activation (Brunt, 1998) stomatal conductance, regulation of photosynthesis, synthesis of starch, proteins and maintenance of protein quality as well (Cochrane and Cochrane, 2009). However fertilizers use is optional because of cost infectivity. Fertilizer prices are increasing day by day making it difficult for the farmers to purchase more inputs. Therefore, methods should be devised to maximize the fertilizer use efficiency (FUE). FUE can be increased through several ways importantly by use of controlled release fertilizers. Controlled release fertilizers are formed by coating layers of plaster of paris, resins and waxes organic polymer on nitrogenous and phosphatic fertilizers. Thus preventing the fertilizers losses and to retain them in available form for longer period of time by absorbing water many times of its original weight (Ferguson *et al.,* 1995).

A polymer is a large molecule composed of repeated subunits. Both synthetic and natural polymer have an essential and ubiquitous role in everyday life (Żywociński *et al.,* 2011). Polymers are mostly used in coating of fertilizers because of slow release of fertilizer from PCF fertilizer. In horticultural industry majority of CRF comprises of polymer coated fertilizer. In PCF the nutrient release occurs through diffusion by semi-permeable membrane (Gambash *et al.,* 1990). Release of nutrients from polymer coated fertilizers depend on type, thickness, temperature, moisture, nature of coating material and effectiveness of coating. Two factors i.e. thickness and effectiveness of coating material are of prime importance. Thickness of coating material depends on effective coating. More thickness of coating material on nitrogenous and phosphatic fertilizers will favor the control release of nitrogen/phosphorous and vice versa (Jacobs, 2005). Similarly, the effective coating depends on experience of worker because if there are cracks on the layer of polymer then efficiency of fertilizers will also reduce.

The controlled release fertilizers (CRF) are partially soluble in water due to formation of an impermeable layer around the fertilizer granules which hinders the penetration of water to fertilizer and release nutrient in control fashion and avoids nutrients loss (Morgan *et al.,* 2009). It is estimated that only about 30 to 50% of the fertilizer applied conventionally is recovered by plant where as rest is wasted in soil. The controlled release fertilizer keeps the fertilizer in soil solution in a way that it will be more beneficial to the plants and releases the nutrients according to plants need (Tyliszczak *et al.,* 2009). Comparative advantage of controlled fertilizer to conventional fertilizer is that nutrients are released in a manner that meet plant needs, reduces leaching and therefore increases fertilizer use efficiency. Use of controlled release fertilizers enhances fertilizers use efficiency, minimize nutrient loss by leaching and fixation. Polymer coating also prevent losses due to fixation and precipitation (Basu and Kumar, 2008). The objectives of the present study was to check the effect of different combination of polymer coated CAN, NP and MOP on growth of wheat plant and their effect on the nutrient use efficiency of wheat.

Materials and methods

Fertilizer coating

Commercial calcium ammonium nitrate (CAN) nitrophos (NP) and MOP were coated with polymer in Soil Fertility and Plant Nutrition Laboratory, Institute of Soil and Environmental Sciences, University of Agriculture, Faisalabad. Synthetic polymers solution (Polyacrylamide 1%) was prepared in distil water and used for coating CAN, NP and MOP separately. Prepared solution was applied at each fertilizer @ 1 L per 50kg fertilizer. After thorough mixing of the solution with fertilizers, the fertilizers were dried under shade and second layer of coating was also applied following same procedure under controlled condition to avoid any foreign contamination. Polymer Coated fertilizers were properly stored for application.

Experimental site

Present study was conducted at the experimental fields of Institute of soil and Environmental Sciences, University of Agriculture Faisalabad. Mechanical analysis of the experimental site revealed that it was sandy loam having Sand = 52.54%, Silt = 24.26% and Clay 23.20%. Saturation percentage 29%, pH 7.67, electric conductivity EC 1.96 dsm^{-1}, total nitrogen 0.05%, available phosphorus 6.5mg $Kg^{-1,}$ extractable potassium 140mg kg^{-1} and 0.5% organic matter. Recommended seed rate (50kg $acre^{-1}$) of Galaxy-2013 was sown in each plot. CAN, NP and MOP were used as a source of Nitrogen (N), Phosphorus (P) and Potassium (K) respectively. Fertilizers were applied as per requirements i.e. 120: 90: 60kg N, P and K ha^{-1}. The experiment was conducted under Randomized Complete Block Design. Treatment plan followed was T_1 = Uncoated NP, CAN and MOP at sowing, T_2 = Polymer coated CAN + uncoated NP and MOP at sowing, T_3 = Polymer coated NP and CAN + uncoated MOP at sowing, T_4 = Polymer coated NP, CAN and MOP at sowing, T_5 = Polymer coated CAN 50% at sowing + Polymer coated CAN 50% at 1st irrigation + polymer coated NP and MOP 100% at sowing. Each treatment was subjected to 5 marla with four replicates.

Plant phenotyping

Five samples of one meter square area from each experimental unit was taken and data were recorded on plant height (cm), number of tillers/m^2, spike length (cm), seeds per spike, thousand seed weight (g), grain biomass (kg m^{-2}), total biomass (kg m^{-2}) Chlorophyll Content with the help of spad (mg/g) and average was computed.

Plant Biochemical analysis

NPK concentration in grains and straw was determined using reference methods (Olsen, 1954; Varley, 1966; Weih, 2014). Sun dried grains and straw samples were further oven-dried to constant weight at 65°C. Samples were then grinded and stored in polyethylene bags for analysis.

The dried and ground grains and straw material (0.5g) was placed in digestion tubes, 2mL of conc. H_2SO_4 was added and incubated over night at room temperature. Then 1mL of H_2O_2 (35%) A. R. grade extra pure was poured down through the sides of the digestion tubes and was rotated. Tubes were placed in a digestion block and heated up to 350°C until fumes were produced and continued to heat for another 30min. Digestion tubes were removed from the block and cooled. Then 1mL of H_2O_2 was slowly added and tubes were placed back into the digestion block until fumes were produced. Above step was repeated until the cooled material became colorless. The volume of extracts was made up to 50mL with distilled water. Then it was filtered and used for determination of mineral elements.

Nitrogen Determination

After dilution of the filtrate nitrogen was determined. Nitrogen contents of harvested wheat samples were estimated using micro Kjeldhal method (Chapman and Pratt, 1961) which comprises of two steps: a) Distillation and b) Titration. Before determining N, about 4% Boric acid solution at fix pH 5, 0.01 N Sulphuric acid (H_2SO_4) standard solution, 40% sodium hydroxide solution and mixed indicator of bromocresol green (0.330g) with methylene red (0.165g) were prepared.

10mL of digested samples solution was taken in Kjeldhal flask and placed it on the Kjeldhal ammonia distillation unit. Then added 20mL of 40% NaOH solution and immediately connected the flask to distillation apparatus. Took 10mL of 4% Boric acid solution with few drops of mixed indicator in 100mL conical flask and placed under condenser for collection of distillate. When the distillate was approximately 40-50mL and the solution became colorless, the conical flask was removed and distillation unit was turned off. Cooled the distillate for few minutes and titrated it against 0.01 N standard sulphuric acid (H_2SO_4) until the boric acid indicator solution turned to its original color i.e. violet. N contents were determined using the following equation (Kjeldahl, 1883).

$$N\,\% = \frac{(V2 - V1) \times N \times 0.01 \times 100}{W}$$

Whereas,

V_2 = Volume of standard H_2SO_4 required to titrate the sample solution.

V_1 = Volume of the blank solution (Blank reading = 0.3mL)

N = Normality of standard H_2SO_4 =0.01 N

1mL of 0.01 N H_2SO_4 = 0.0014g N

W = Weight of sample obtained by using the formula

$$\frac{\text{Weight of dry sample} \times 10\ \text{mL of digested sample solution}}{\text{total volume of digested sample solution (50mL)}}$$

N contents calculated in percentage were converted to mg g^{-1} of dry weight and mean of replicates were also calculated.

Phosphorus

Ammonium heptamolybedate (22.5g) dissolved in 400mL distill water (a solution). Ammonium metavanadate (1.25g) was dissolved in 300mL hot distilled water (b solution). Solution (a) was added to solution (b) in a 1L volumetric flask and mixture was led down to cool at room temperature. Concentrated nitric acid (250mL) was slowly added to the mixture, cooled at room temperature and brought to 1L volume. Standard solution was also run on the spectrophotometer to develop standard curve. For this purpose, KH_2PO_4 was oven-dried at 105°C for 1 hour. Took 2.156g KH_2PO_4 and made 1L volume (1000 ppm solution). Took 25mL of stock solution and made 250mL volume (100 ppm solution). Standards were made of 1, 2, 3, 4 and 5 ppm strength from 100 ppm solution in 100mL volumetric flask. P in plant samples was determined by using yellow color method. 5mL of digested liquid was taken into 50mL volumetric flask + 5mL of colored reagent (Molybdate Vanadate solution) + 40mL of distilled water and it was left for 30 minutes to develop color. After that samples were run on spectrophotometer (at 420nm wavelength) and reading was noted Olsen *et al.* (1954).

$$\%\,P = \text{ppm P (from calibration curve)} \times R/Wt \times 100 \times 10000$$

Where,

R = Ratio between total volume of digest

Wt = Weight of total dry plant (g)

Potassium

Potassium was determined by flame photometer according to the method described by Chapman and Parker (1961). Quantity of element was estimated in ppm by comparing the emission of flame photometer with standard curve which was then converted into percentage by using the following formula:

K (%) = ppm on graph × dilution × 100

Statistical analysis

Data for different growth and yield attributes was collected and analyzed statistically using Statistix 8.1® and means were compared using LSD test (Steel and Dickey, 1997) at 5% probability level.

Results

Effects of polymer coating was checked to enhance the efficiency of the nitrogenous, phosphatic and potash fertilizer.

The ANOVA results showed that the polymer coating have significantly affected the plant traits. Highly significant differences were found among treatments for spike length, spikelet's per spike, seeds per spike, grain yield, total biomass, harvest index, thousand seed weight, chlorophyll contents and plant height. Similarly treatments were found significantly different for NPK uptake in the grains, straw and NPK use efficiency (Table 1).

Table 1. Analysis of morphological and physiological traits.

Trait	Treatments MS	Blocks MS	Error MS
DF	4	3	12
Spike length (cm)	22.42**	7.10**	0.23
Seeds per Spike	99.92**	134.51**	2.709
Spikelet's per spike	65.3**	20.4**	2.5
Grain yield (Kg)	2816493**	496673**	20784
Total biomass (Kg)	4005777**	803732**	31858
Harvest index	10.3**	5.2**	0.82
Thousand seed weight (g)	65.15**	41.16**	4.05
Chlorophyll contents (mg/g)	209.2**	100.8**	2.68
Plant height (cm)	382.85**	185.58**	6.307
Nitrogen uptake in grains	473.23**	52.85**	5.148
Phosphorus uptake in grains	179.6**	53.56**	3.21
Potassium uptake in grains	154.09**	24.5**	1.08
Nitrogen uptake in straw	253.6**	14.35**	1.06
Phosphorus uptake in straw	19.9**	1.72**	0.17
Potassium uptake in straw	47.39**	6.57**	0.13

* Describe the significant results at $P < 0.05$, whereas ** describe the significant results at $P < 0.01$.

Effect of PCF on morphological traits

PCF promoted the growth of wheat plant over the non-coated fertilizer. It was observed from the Fig. 1 that the T_1 has minimum spike length, spikelet's per spike and seeds per spike whereas their maximum magnitudes were recorded in T_5. T_2 showed an average increase of 4.5, 6.7 and 4.4% over control treatment for spike length, spikelet per spike and seeds per spike respectively. Similar results were observed under T_3 and T_4 which showed an improvement of 14.7, 14 and 8.8% and 18.2, 28.3 and 11.2% over control treatment respectively.

Whereas maximum improvement in the spike length, spikelet per spike and seeds per spike was observed under T_5 with an average increase of 28.3, 43.3 and 22.3% respectively. Fig. 2 elaborated that the treatments with PCF significantly enhanced total biomass (TB), grain biomass (GB) and harvest index (HI). Maximum increase was observed under T_5 with an average increase of 33.3, 48.3 and 11.3% for TB, GB and HI respectively followed by T_4 which showed an average increase of 25.3, 35.3 and 8.06% successively. Thousand seed weight, plant height and chlorophyll contents also showed positive intent towards application of PCF. T_2 showed an average increase of 3.3, 3.6 and 1.6% over control treatment for thousand seed weight, chlorophyll contents and plant height respectively. Maximum increase over control treatment was observed under T_5 with an increase of 27.3, 15.5 and 5.7% for thousand seed weight, chlorophyll contents and plant height respectively. The other treatments also showed a positive increase over the control (Fig 3).

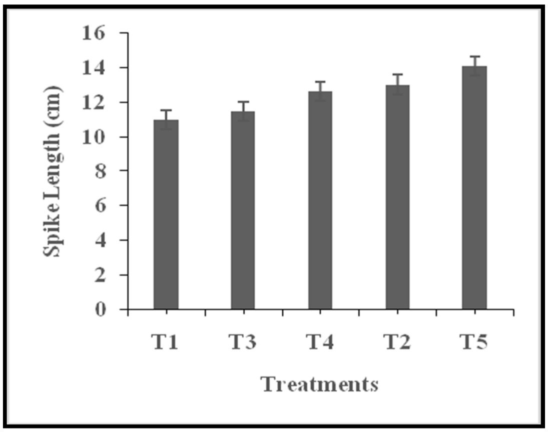

Fig. 1. Effect of polymer coated fertilizer on spike length.

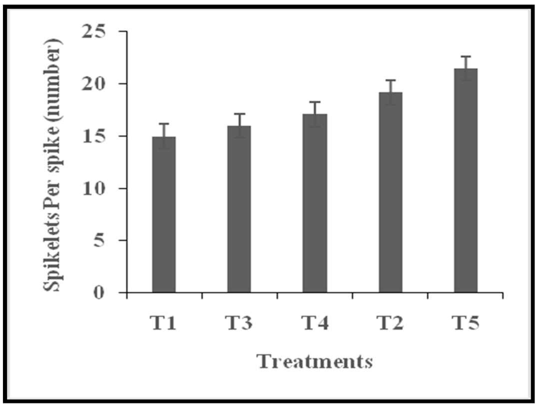

Fig. 2. Effect of polymer coated fertilizer on spikelet's per spike.

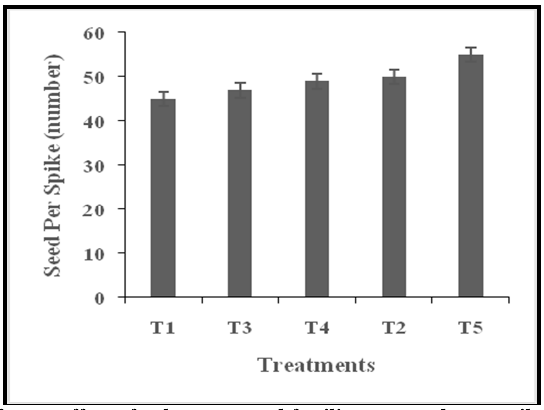

Fig. 3. Effect of polymer coated fertilizer on seeds per spike.

Effect of PCF on NPK uptake

The nutrient uptake was enhanced by the application of PCF as compared to the non-coated fertilizer. Fig. 4 demonstrated that nutrient uptake in straw is more in the treatments subjected to PCF as compared to treatment having non-PCF. Nitrogen uptake in the T_2 was improved much 15.33% whereas the P and K uptake remained the same. In case of T_3 the uptake of N and P was increased 27.3% and 29.4% respectively and concentration of K was comparable to the control (with negligible increase of 0.7%). T_4 however showed an increased uptake of all nutrients (NPK) with an average of 38.2 66.3 and 99.1% respectively. However NPK uptake under T_5 was much higher with an average increase of 50.3, 68.2 and 111.3% respectively in the straw.

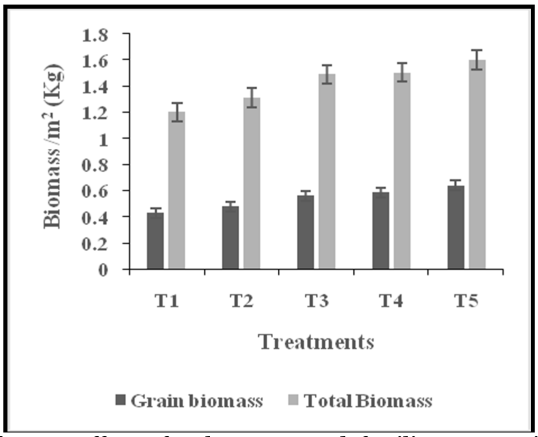

Fig. 4. Effect of polymer coated fertilizer on grain biomass and total biomass.

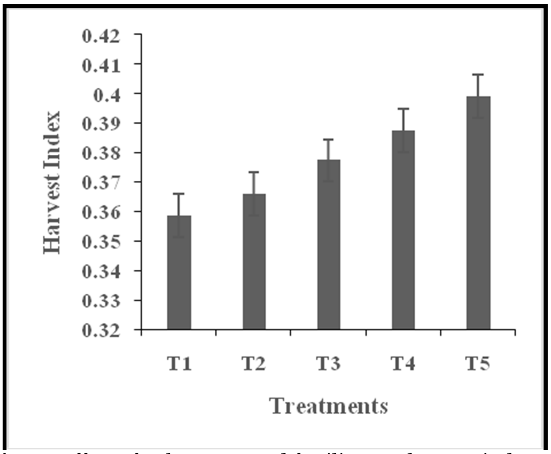

Fig. 5. Effect of polymer coated fertilizer on harvest index.

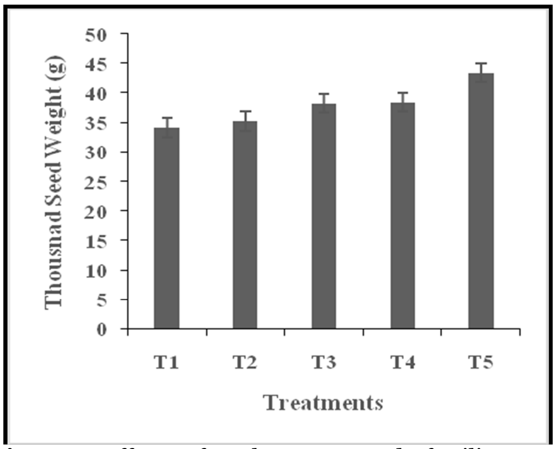

Fig. 6. Effect of polymer coated fertilizer on thousand seed weight (g).

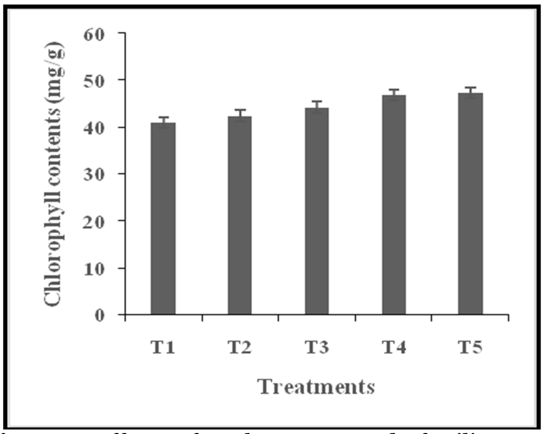

Fig. 7. Effect of polymer coated fertilizer on chlorophyll contents (mg/g).

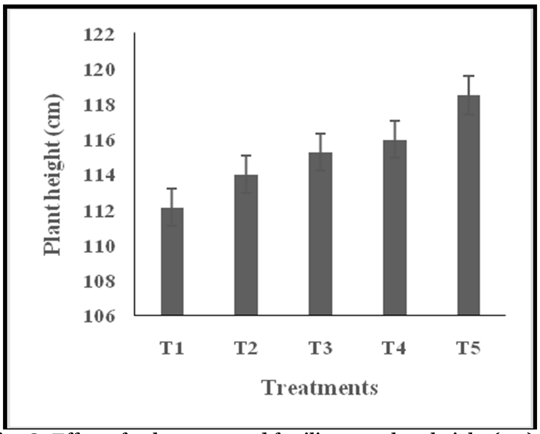

Fig. 8. Effect of polymer coated fertilizer on plant height (cm).

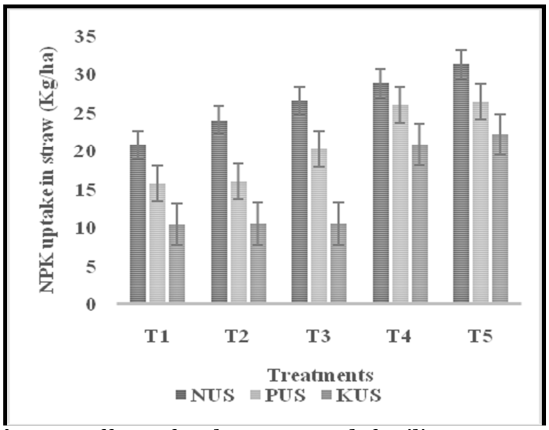

Fig. 9. Effect of polymer coated fertilizer on NPK uptake in straw (mg/g).

Not only the nutrient uptake in the straw was enhanced but its affects were also observed in the grains. The trend was similar to that of the nutrient uptake in the straw as in T_2 the uptake of the N was increased (20.73%) as compared to the control whereas the uptake of P and K remains the same (0.11% and 0.44% increase respectively). Similarly T_3 showed an increase uptake of both N (39.1%) and P (42.12%) whereas K uptake was comparable with control (1.50% increase). In T_4 the NPK uptake was much improved as compared to the control with an average increase of 80.2, 32.2 and 81.2% respectively. However T_5 outnumber the rest of all treatments with respect to NPK uptake in the grains with an average increased uptake of 115.6, 130.6 and 116.8% respectively for NPK in the grains Fig 4.

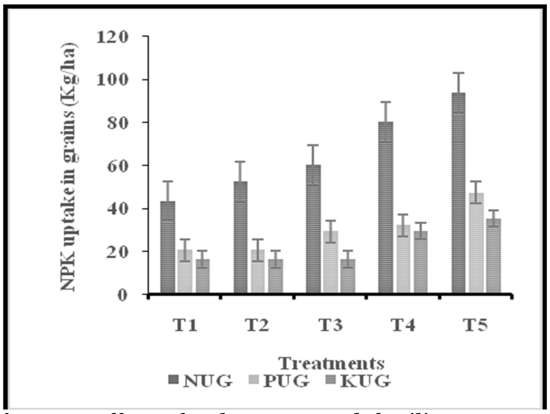

Fig. 10. Effect of polymer coated fertilizer on NPK uptake in grains (mg/g).

Discussion

Fertilizer provides the essential nutrition to the crop plants to facilitate the normal growth and development. Prices of the fertilizer are increasing making their use costly. A lot part of the fertilizer lost because of mismanagement. There is need to develop a strategy that will reduce the use of fertilizer without restricting the growth of crop plants. Use of PCF promise the effective utilization of fertilizer and also minimize the cost of production of crops. Polymer coated fertilizer enhance the fertilizer use efficiency. PCF releases fertilizer slowly and for longer periods of time hence improving the nutrient use efficiency of the plant. Release of fertilizer from PCF depends upon the temperature. As the temperature rises up plant also speeds up its growth, polymer also starts releasing the fertilizer, hence nutrient release perfectly matching the demand of the plant. When the temperature is low and plant growth period is not so active, the release of fertilizer also slows down (Hopkins *et al.,* 2008; Hutchinson *et al.,* 2002; Patil *et al.,* 2010; Wilson *et al.,* 2010). The timing and pattern of fertilizer release from the PCF favors the development of the plant and improves the grain yield and quality of the produce (Worthington *et al.,* 2007;

Blythe *et al.,* 2002; Miltner *et al.,* 2004; Pack and Hutchinson, 2003). PCF also increases the availability of fertilizer for extended period of time hence successive application of fertilizer may also be omitted making it economically beneficial (Hyatt *et al.,* 2010). In present study polymer coated CAN, NP and MOP were used and their efficiency was compared with the non-coated fertilizer. It was observed that the PCF enhanced the growth and quality of the wheat plant as was also reported in the previous studies (Blythe *et al.,* 2002; Worthington *et al.,* 2007). PCF improved the physical parameters of wheat plant i.e. spike length was improved 28.3% similarly spikelet's per spike and seeds per spike also showed an improvement of 44.3 and 23.3% respectively over non coated fertilizer. PCF favors the uniform and persistent availability of the fertilizer. Similar effects were also observed on the other plant traits e.g. grain yield, total biomass, harvest index, chlorophyll contents, thousand seed weight and plant height as was previously reported (Nyborg *et al.,* 1995; Junejo *et al.,* 2010; Zhao *et al.,* 2013 and Dong *et al.,* 2016). PCF improved the biomass, plant growth and quality of the rice grains (Khan *et al.,* 2015). One report on the application of PCF to improve the grain yield, plant vigor and grain quality of wheat plant is already available (Ingle *et al.,* 2010).

PCF causes slow release of fertilizer hence making it more effective and assure its availability in the soil profile for longer period of time. PCF enhanced the availability of fertilizer and the uptake of the NPK improved which resulted in improve growth, productivity nutrient uptake in grains and grain quality. The uptake of NPK in the respective coated treatments was higher than the non-coated i.e. the uptake of nitrogen from T_2 to T_5 increased continuously (with increase of 50.3% and 115.6% in grains, as compared to the control (Non-coated). Also the uptake of P and K were improved in all coated treatment (especially 68.2 and 111.3% in straw and 130.6 and 116.8% in grains in T_5) over the control (non-coated) treatment. Similar results were also reported by the (Li *et al.,* 2015) who also reported that polymer coated fertilizer increase the uptake of NPK in plant. Ali and Danafar (2015) also reported that PCF increased the grain yield, total biomass and uptake of NPK. Treatment plan offered comparative effectiveness of polymer coating for all fertilizer sources namely NPK. In T_2, N was coated whereas as P and K were non coated. Plant growth, grain yield and nitrogen uptake both in grains and straw were high but P and K remained comparable to the control treatment. However in T_3, N and P were coated and K was non-coated the growth of plant, N and P uptake was higher but K uptake in both straw and grains was not affected. In T_4 all fertilizer sources were coated.

Growth was enhanced but also the uptake of the all three nutrients in the grains and straw was much higher than rest of three treatments. However in T_5, N source was applied in tow splits, half at sowing and other half at first irrigation, the efficacy of the fertilizer was also enhanced comparative to all four treatments. Rizwan *et al.* (2003) also reported that split application of nitrogen is more effective as compared to the singlet application on maize growth. (Ali *et al.,* 2005) also favored that the wheat plant growth is more under the split nitrogen application as compared to the single dose applied at the sowing.

Conclusion

It was concluded that PCF enhanced the efficiency of all three types of nutrients i.e. increased plant growth and quality under the PCF fertilizer as compared to the control (non-coated fertilizer). Further it was also observed that application of N in two split doses (Half at sowing remaining half at first irrigation) is more beneficial in the crop growth and also improves the NPK uptake in grains and straw. This study thus suggested that farmers should use the PCF fertilizer and also they should apply the fertilizer in split doses (Especially the nitrogenous fertilizer). Further it is needed that a study should be designed to assess the quality of wheat straw and grains and needed to explore that is there any effect of PCF on the grain or straw composition or did it have any effect on the uptake of other macro and micronutrients uptake. It needs to be explored that whether PCF fertilizer have any role in modification of physiological processes or any change in the quality and composition of grain and straw proteins and other molecules.

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