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SYNCHRONIZED NITROGEN RELEASE FROM POLYMER COATED NITROCHALK ENHANCES NITROGEN USE EFFICIENCY AND YIELD OF WHEAT

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Efficiency of conventionally applied nitrogen (N) fertilizers ranges from 35 to 45%. Poor efficiency due to prompt release of excess nitrogen in the soil also threats environment. The nitrogen fertilizers performance can be enhanced by controlling the release of nitrogen through encapsulation with polymer and synchronizing the nitrogen release with plant up-take pattern. To test this hypothesis series of experiments were conducted. Nitro-chalk (calcium ammonium nitrate) as test N fertilizer was used for polymer coating. Laboratory and pot experiments were conducted to determine the effective polymer thickness coated on nitro-chalk, and results revealed that two layers of polymer performed the best as consistent release of N significantly increased growth and yield attributes of wheat. Similarly, coated nitro-chalk also corresponded well to the nitrogen requirements of wheat plants in field. Consequently, polymer coated treatments significantly improved wheat grain yield by 10 to 17% compared with uncoated fertilizer at the same nitrogen application rate. Reducing the rate of application of polymer coated nitro-chalk by 25% produced more grain yield as compared with the application of recommended rate of commercial nitro-chalk. Therefore, the results suggested efficient release of nitrogen from coated nitro-chalk increased production and nitrogen use efficiency. Furthermore, a 25% less application of nitrogen as polymer coated nitro-chalk than recommended application rate of nitrogen can be an effective measure to save input cost as well as increase in grain yield.
Keywords: Wheat, nitro-chalk, polymer, nitrogen volatilization, grain yield

INTRODUCTION

Nitrogen has a significant role in yield production of wheat. The availability of nitrogen is the main factor that affect grain yield of wheat (Halitligil *et al*., 2000). Consequently, in developing countries bulky amount of nitrogen fertilizers are applied over the past 20 years to meet crops demand (Mueller *et al*., 2012; Huang *et al*., 2008). However, response of crop yield is much lower compared to increasing application rate of nitrogen (Cai *et al*., 2002). While excessive application of nitrogen fertilizers in field cause adverse effect on environment and soil through leaching and volatilization (Shang *et al*., 2014; Rochette *et al*., 2009). So, it is mandatory to optimize nitrogen inputs with wheat requirement and to reduce environmental pollution.

Nitrogen use efficiency (NUE) could be improved by synchronizing nitrogen release from applied fertilizer according to wheat requirement. Different strategies have been employed to improve efficiency and to reduce losses of nitrogen (Chen *et al*., 2012; Soon *et al*., 2011). Basic point is reducing the time span, that nitrogen spent in soil prior to crop uptake, could decrease the exposure of nitrogen to loss and increasing its efficiency (Grant *et al*., 2012).

Polymer coated fertilizers have been introduced to provide consistent nutrient supply for a longer period (Song *et al*., 2005). As polymer thickness significantly affects release rate of nutrient (Suharti *et al.*, 2016), so release rate of ammonium and nitrate can be controlled by thickness of the coating film (Perez-Garcia *et al.*,2007).

Polymer coated fertilizers are very expensive and its use is only limited to valuable ornamental plants. It is crucial to develop an economically viable and environment and user-friendly polymer coated nitrogen source which synchronizes nitrogen release with wheat demand. Effectiveness of polymer coating on nitrogen source (Nitro-chalk) was investigated in this study. Ideal combination which synched with wheat requirement was identified that fulfilled crop nitrogen demand. Series of laboratory, pot and field experiments were conducted to find out number of coating layers of polymer on fertilizer suitable for improving wheat growth and yield.

MATERIALS AND METHODS

***Laboratory and pot study*:** Commercially available nitro-chalk was coated with water soluble polymer (Carbonyl Polyacrylamide) in Soil Fertility and Plant Nutrition Lab, Institute of Soil and Environmental Sciences, University of Agriculture, Faisalabad. Coating thickness, of 1% polymer strength, was maintained as (single, double and triple) on fertilizer for lab and pot trials. Coated fertilizers were allowed to dry under laboratory conditions at 25°C and stored in polyethylene bags till the application as described by Yaseen *et al.* (2017).

Bulk amount of soil used for the lab and pot trials was collected from the field 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) and extractable K 115 mg kg^{-1} soil (Hanways and Heidel, 1952). Disposable cups of 250 cm^3 were used during lab study. Each cup was filled with 200 g soil. Saturation percentage of soil was determined to maintain required moisture content. Fertilizers with respective thickness i.e. uncoated, single, double and triple layers of coating (at the rate of 0.25 g N/100 g of soil) were applied in cups according to treatment plan and mixed in soil thoroughly. Cups were placed randomly in incubator (Sanyo; MIR 253) at temperature 25$\pm$2°C after addition of water as per field capacity which was maintained by adding distilled water after every 24 hours. Total nitrogen was determined after different time interval 15, 30, 45 and 60 days by method (Keeney and Nelson, 1982). Two the best performing polymer thicknesses (double and triple layer) were selected for pot experiment.

Above described soil was filled in pots at the rate of 14 kg per pot with gentle packing. This experiment was comprised of four treatments i.e. T_1 = Control (without any fertilizers), T_2 = PK (phosphorus + potassium) + uncoated nitrochalk, T_3 = PK + double coated nitrochalk, T_4 = PK + triple coated nitrochalk. Treatment was planned according to completely randomized design with three replications. Recommended rates of fertilizers for wheat (N = 120 kg ha^{-1}, P_2O_5 = 90 kg ha^{-1} and K_2O = 60 kg ha^{-1}) were added as coated and uncoated nitrochalk (26% N), single super phosphate (18% P_2O_5) and sulphate of potash (50% K_2O). Five seeds of wheat cv. Faisalabad-2008 per pot were sown at 1 cm depth and only two seedlings were maintained after germination at two leaf stage. Pots were irrigated with canal water to maintain approximate field capacity level. At harvest, grain and straw yield was recorded for each pot. At booting stage, physiological parameters like photosynthetic rate and water use efficiency were determined using CIRAS-3 (PP System, Amesbury, MA, USA) and for chlorophyll content, portable meter SPAD-501 was used. Nitrogen and potassium contents (Chapman and Pratt, 1961) and phosphorus (Olsen *et al*., 1954) were also determined.

***Field study*:** The field experimental plan for wheat crop was comprised of five treatments i.e. T_1 = Control (without any fertilizers), T_2 = PK (phosphorus + potassium) + N from uncoated nitro-chalk at 100% recommended rate, T_3 = PK + N from polymer coated nitro-chalk at 100% recommended rate, T_4 = PK + N from polymer coated nitro-chalk at 75% recommended rate, T_5 = PK + N from polymer coated nitro-chalk at 50% recommended rate. The experimental design used was randomized complete block design with three replications and analyzed statistically (Steel *et al*., 1997). Recommended doses of NPK and fertilizer sources were same as used in pot study. Soil textural class and wheat variety (Faisalabad-2008) was similar as lab and pot trials. Crop was irrigated five times with canal water. At harvesting 1 square meter area was randomly selected in each plot for measuring growth and yield attributes 20 days before harvesting and average values were computed. Grain and straw yields were recorded for each plot. The total productivity of crops was worked out while biological yield was calculated by formula given below.

$$\text{Biological Yield} = \text{Total biomass of plants in plot (grain} + \text{straw yield)}$$

For physiological and chemical parameters determination, same procedure was followed as in pot experiment. Nitrogen uptake was calculated by the formula:

$$\text{Nitrogen Uptake} = \frac{oven\ dried\ weight\ of\ plant \times N\ (\%)}{100}$$

$$\text{Total N uptake} = \text{N uptake in grain} + \text{N uptake in straw}$$

Agronomic recovery efficiency (ARE)

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

RESULTS

***Laboratory experiment*:** Interaction of different coating thicknesses of polymer on nitro-chalk and days were statistically analyzed and found significant effect. Uncoated nitro-chalk was found less efficient in slowing down nitrogen release as maximum nitrogen contents were released within first 15 days compared to different number of coatings of polymer on fertilizer grain (Table 1). While the nitrogen release from coated fertilizers was slow and consistent because coatings of polymer hold the nutrient, and slowed down rate of its release. Among days, maximum nitrogen release was observed in single coated nitro-chalk fertilizer after 15 days interval as this coating thickness was comparatively less firm than other number of coating layers on fertilizer. After 30 days of incubation, coated fertilizers showed almost constant nitrogen release from one time interval to another up to certain limit except single layer of coating. Maximum nitrogen content was observed in double layer coated fertilizer. Triple coated nitro-chalk fertilizer also showed significant increase in nitrogen content compared to previous determination, but release was slow compared to double layer. After 45 days of incubation period there was increased nitrogen concentration in soil treated with triple layer coated nitro-chalk followed by double layer coated fertilizer. From single and double layer of polymer coated fertilizers the nitrogen release was decreased. After 60 days of incubation single layer coated fertilizer showed least

Table 1. Release pattern of nitrogen (μg g^{-1}) in soil treated with polymer coated nitro chalk.

Treatment	Incubation intervals (days)				Mean
	15	**30**	**45**	**60**	
Uncoated Nitro chalk (Control)	1692.6a	731.2e	115.0h	45.0i	645.9D
Single coated Nitro chalk	1360.5b	1021.9c	526.0f	229.0g	784.3C
Double coated Nitro chalk	1287.3b	1018.0c	816.8de	457.1f	894.7A
Triple coated Nitro chalk	741.9e	862.5d	965.6c	743.0e	828.2B
Mean	1039.6A	740.1B	486.4C	295.8D	

Values sharing same letter(s) do not differ at p = 0.05 according to HSD test. HSD values (critical values for comparison): Mean for days = 31.08, Mean for polymer coating layers = 37.03, Interactions (days × coating layers) = 98.24

Table 2. Effect of polymer coated nitro chalk on growth and yield components of wheat under greenhouse (pot) experiment.

Treatment	Plant height (cm)	Grain weight (g pot^{-1})	Photosynthetic rate	Chlorophyll content	Water use efficiency (%)	Nutrient composition in wheat grain (%)		
						N	**P**	**K**
Control	42.3d	5.89c	7.1d	33c	2.59d	0.40d	0.09d	1.08d
U-Nitro chalk	55.3c	6.47c	9.3c	41b	3.01c	1.37c	0.31c	1.66c
D-Nitro chalk	70.7a	10.41a	13.8a	45a	4.12a	2.26a	0.47a	2.39a
T-Nitro chalk	66.0b	8.46b	11.1b	41b	3.67d	1.96b	0.39b	2.27b

Control = without any fertilizer, U-Nitro chalk = Uncoated nitro chalk, D-Nitro chalk = Double layer of polymer coated nitro chalk, T-Nitro chalk = Triple layer of polymer coated nitro chalk. Values sharing same letter do not differ at p = 0.05 according to HSD test

Table 3. Effect of coated nitro chalk on growth and yield components of wheat under field experiment.

Fertilizer application rate (kg ha^{-1})	Plant height (cm)	No. of fertile tillers (m^{-2})	1000 grain weight (g)	Yield parameter (kg ha^{-1})	
				Grain yield	**Biological yield**
Control	95.5c	260.7b	25.03c	2460.0d	6972c
U-Nitro chalk (100%)	99.0bc	342.7ab	32.40b	4446.7bc	9200bc
C-Nitro chalk (100%)	102.3a	469.3a	38.27a	5213.3a	12007a
C-Nitro chalk (75%)	101.1ab	385.3ab	35.47a	4880.0b	10507ab
C-Nitro chalk (50%)	99.5bc	347.7ab	29.43b	4526.7c	8947bc

Control = without any fertilizer, U-Nitro chalk (100%) = Uncoated nitro chalk at recommended rate, C-Nitro chalk (100%) = Polymer coated Nitro chalk at recommended rate, C-Nitro chalk (75%) = Polymer coated Nitro chalk at 75% of recommended rate, C-Nitro chalk (50%) = Polymer coated Nitro chalk at 50% of recommended rate. Values sharing same letter(s) do not differ at p = 0.05 according to HSD test

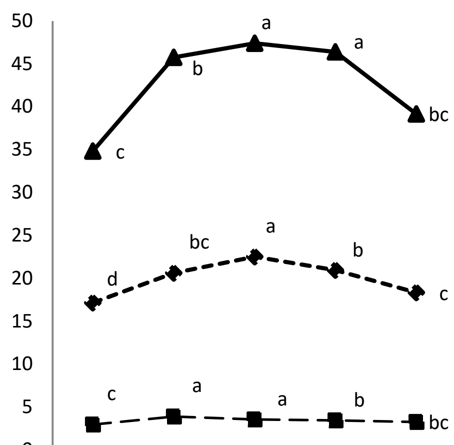
nitrogen release among the coated fertilizers treatments but it was still significantly higher than uncoated fertilizer (Table 1). In case of three layers of polymer on fertilizer, nitrogen concentration in soil was also significantly higher from the previous incubation period. Moreover, nitrogen concentration in soil was also more than that of double layer coated nitro-chalk, because of the presence of three layers of polymer.

***Pot experiment*:** This experiment was conducted to screen the best performing polymer layer on fertilizer regarding nitrogen release to fulfill plant requirement. Table 2 indicated that double layer polymer coated nitro-chalk gave significant results over triple coated and uncoated nitrogenous fertilizer (Table 2). Double layered polymer coated increased number of fertile tillers, grain weight and photosynthetic rate 36, 61 and 48%, respectively, over uncoated fertilizer application.

Field experiment

***Wheat growth and yield parameters*:** Polymer coated nitro-chalk showed significant results over commercial uncoated nitro-chalk. Plant height and number of fertile tillers increased by 3.3% and 37% in plots treated with polymer coated nitro-chalk than uncoated nitro-chalk fertilizer. There was 18% increase in 1000 grain weight with application of polymer coated nitro-chalk equal to recommended rate over recommended rate of uncoated nitro-chalk. Grain yield (kg ha^{-1}) in the treatment of recommended rate of polymer coated nitro-chalk was statistically higher than all other treatments and it was 17% higher compared to uncoated fertilizer treatment. Moreover, application of polymer coated nitro-chalk equal to 75% of recommended rate of nitro-chalk brought 10% improvement in grain yield (kg ha^{-1}) compared to uncoated nitro-chalk (Table 3). Furthermore, biological yield (kg ha^{-1}) was also improved in response to different rates of polymer coated fertilizer as compared to control as well as uncoated nitro-chalk fertilizer application. Maximum increase in biological yield (kg ha^{-1}) was recorded in the treatment receiving recommended rate of polymer coated nitro-chalk, and it was 30% more as compare to uncoated nitro-chalk fertilizer application (Table 3).

Physiological parameters**:** Maximum chlorophyll contents were observed in plants treated with recommended rate of polymer coated nitro-chalk over uncoated nitro-chalk i.e. 3% (Fig. 1). In the same way, a significant improvement in photosynthetic rate was recorded with the application of polymer coated nitro-chalk over control and uncoated treatments. There was, 9% and 2% increase in photosynthetic rate, with the application of 100% and 75% recommended rate of polymer coated nitro-chalk over uncoated fertilizer. With increase in photosynthetic rate water use efficiency was also increased 19% with the application of polymer coated fertilizer at 100% rate of recommendation compared to control (Fig. 1).

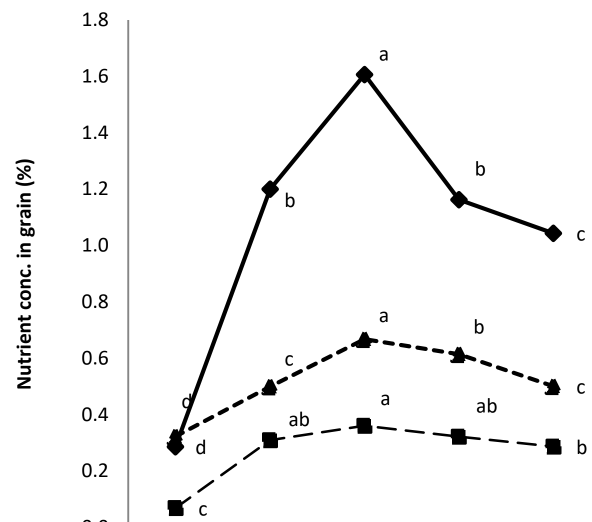


	Control	U-Nitrochalk 100%	C-Nitrochalk 100%	C-Nitrochalk 75%	C-Nitrochalk 50%
Photosynthetic rate (A)	17.13	20.60	22.50	20.93	18.33
WUE (%)	2.96	3.88	3.55	3.44	3.27
Chlorophyll conent (SPAD)	34.83	45.77	47.40	46.40	39.17

Control = without any fertilizer, U- Nitro chalk 100% = Uncoated nitro chalk at recommended rate, C-Nitro chalk 100% = Polymer coated Nitro chalk at recommended rate, C-Nitro chalk 75% = Polymer coated Nitro chalk at 75% of recommended rate, C-Nitro chalk 50% = Polymer coated Nitro chalk at 50% of recommended rate. Values sharing same letter(s) do not differ at $p = 0.05$ according to HSD test

Figure 1. Effect of polymer coated nitro chalk on physiological parameters of wheat.

Nutrient concentration in wheat straw and grain and total n uptake**:** Figure 2 shows the N, P and K concentrations in grain of wheat. Polymer coated nitro-chalk had direct influence on N concentration in grain and it was significant; however, P and K concentrations were also indirectly influenced. Concentrations of N, P and K in wheat grain were maximum with the application of polymer coated nitro-chalk particularly when applied at 100% rate of recommendation i.e. 34, 16 and 33%, respectively over uncoated. Application of 75% of recommended rate of polymer coated nitro-chalk showed statistically at par results of N, P and K concentration in grain with recommended rate of uncoated nitro-chalk (Fig. 2). Data on total N uptake by wheat is given in Figure 3. Total N uptake was influenced significantly by various rates of nitro-chalk coated with polymer. Maximum increase in N uptake was observed in the treatment receiving recommended rate of polymer coated nitro-chalk i.e. 17% over conventional uncoated nitro-chalk fertilizer application.

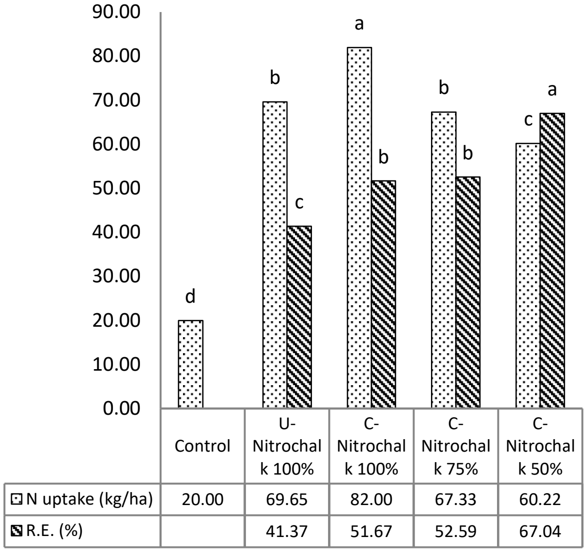


	Control	U-Nitrochalk 100%	C-Nitrochalk 100%	C-Nitrochalk 75%	C-Nitrochalk 50%
N	0.29	1.20	1.61	1.16	1.04
P	0.07	0.31	0.36	0.32	0.29
K	0.32	0.50	0.67	0.61	0.50

Control = without any fertilizer, U- Nitro chalk 100% = Uncoated nitro chalk at recommended rate, C-Nitro chalk 100% = Polymer coated Nitro chalk at recommended rate, C-Nitro chalk 75% = Polymer coated Nitro chalk at 75% of recommended rate, C-Nitro chalk 50% = Polymer coated Nitro chalk at 50% of recommended rate. Values sharing same letter(s) do not differ at $p = 0.05$ according to HSD test

Figure 2. Effect of polymer coated nitro chalk on N, P and K concentrations (%) in wheat grain.

Recovery efficiency**:** Effect of polymer coated nitro-chalk on nitrogen recovery efficiency is reflected from the data given in Figure 3. Maximum recovery efficiency was observed in polymer coated nitro-chalk at 50% rate of recommendation i.e. 62% increased over uncoated fertilizer application (Fig. 3) because from limited N available, plant utilize maximum of it.



Control = without any fertilizer, U- Nitro chalk 100% = Uncoated nitro chalk at recommended rate, C-Nitro chalk 100% = Polymer coated Nitro chalk at recommended rate, C-Nitro chalk 75% = Polymer coated Nitro chalk at 75% of recommended rate, C-Nitro chalk 50% = Polymer coated Nitro chalk at 50% of recommended rate. Values sharing same letter do not differ at p = 0.05 according to HSD test

Figure 3. Effect of polymer coated nitro chalk on N uptake and recovery efficiency in wheat crop.

DISCUSSION

Most of the conventional nitrogenous fertilizers are hygroscopic in nature (Obreza and Rouse, 2006), so highly soluble in water and immediately release maximum content of nitrogen after wetting. In contrast to this, plant nitrogen requirement is low at early growth stages, so little is taken up by plant where as remaining bulk amount of available nitrogen is left free and subjected to loss. For wheat, current nitrogen use efficiency (NUE) is not more than 50%. Volatilization loses are more than 35% from surface application of nitrogenous fertilizer on alkaline and calcareous soil. Rapid release of N can be controlled by coating of polymer on nitro-chalk that provides physical barrier around fertilizer granule and slowed down the release of nitrogen (Timilsena *et al.,* 2015).

The release rate of ammonium and nitrate can be controlled by thickness of the coating film (Perez-Garcia *et al.,* 2007). By altering the thickness of the coating, the rate of nitrogen diffusion can be reduced. Finding the best coating thickness is critical for determination of nutrient release rate (Timilsena *et al.,* 2015). By knowing the crop growth period and stages, an appropriate coating thickness can be used to match crop nitrogen demand (Fujinuma *et al*., 2009; Ellison *et al.,* 2013). Results of current experiments revealed that two numbers of coatings gave maximum control on nitrogen content released from nitro-chalk in soil, followed by three numbers of coatings.

Polymer coating on nitro-chalk can reduce nitrogen losses, but increase use efficiency only by appropriate coating thickness specific to crop (Chalk *et al.,* 2015). From pot study, it is evident that two number of coatings of polymer on nitro-chalk slowed the release of nitrogen in such a manner that the release pattern could closely match with the requirement of wheat plants. So, this competent treatment was also investigated with application of nitrogen fertilizer at reduced rates. Reduced application rates of controlled release nitrogen had positive effect on grain and straw yield of wheat (Yang *et al.,* 2011).

Results of field study indicated that application of polymer coated nitro-chalk fertilizer significantly increased number of fertile tillers, biological yield, grain yield and nitrogen recovery efficiency compared to uncoated, might be due to slow release of nitrogen from coated fertilizer that synchronized well with plant nitrogen requirements (Xu *et al*., 2005). The polymer coated nitro-chalk significantly improved growth and yield of wheat under field conditions (Beres *et al*., 2010; Liang *et al.,* 2012). Application of polymer coated nitro-chalk significantly increased the number of fertile tillers of wheat because of better nitrogen supply to the plants (Li *et al.,* 2013). Increased number of fertile tillers of wheat plant had a good relationship with the grain yield of wheat. As there was more number of spikes as well as grains, therefore grain weight in the treatment of polymer coated nitro-chalk was higher than that of treatment of conventional way of application of this fertilizer and its control treatment. Maximum grain weight in the treatment of polymer coated nitro-chalk might be as a result of consistent supply of nitrogen at anthesis and grain filling growth stages (Li *et al.*, 2013). It is also evident from increased chlorophyll content and photosynthetic rate of wheat plant due to application of recommended rate of polymer coated nitro-chalk. This treatment ensured normal regular supply of adequate nitrogen for wheat according to crop requirements.

The increased plant growth as a result of tillers, chlorophyll content, photosynthetic rate ultimately promoted the outcome i.e. grain yield. Consequences of all these are also depicted in the form of higher N recovery efficiency and lower N losses in the treatment of polymer coated fertilizer (Xu *et al*., 2013). Results of this experiment are evident that consistent nitrogen release from polymer coated nitro-chalk resulted in an improvement of nitrogen use efficiency (Tarlok and Rowsell, 2011) and reduction in nutrient losses (Emilsson *et al*., 2007). Nitrogen recovery efficiency and nitrogen uptake are major indicators of nitrogen use efficiency in the field studies (Peng *et al*., 2010; Weih *et al*., 2010; Zhang *et al*., 2008).

***Conclusion*:** All plants require nitrogen to complete their life cycles. Without adequate supply of nitrogen, plants produce less chlorophyll and proteins, which results in decreased growth and increased susceptibility to pests and diseases. Heavy applications of nitrogen based fertilizer are often applied to ensure high crop yields and to compensate for losses due to nitrogen escape from the soil. The process of applying fertilizers is often inefficient, thus leading towards a waste of natural resources and money. This practice often results in nitrogen loss as a pollutant to the environment through ammonia volatilization, nitrate leaching, and by-products of denitrification, such as nitrous oxide. Therefore, the economic benefits of better efficiency, reduced environmental pollution and future damage can be achieved using polymer coated nitro-chalk.

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