Evaluation of Nitrogen Sources and Polymer Coated Fertilisers on Wheat Yield in Sandy Soil

Comment [S1]: Preferred UK spelling

Rehab H. Hegab[1*]

[1]Department of Soil fertility and Microbiology, Desert Research Center, El-Mataria, Cairo, Egypt.

Original Research Article

Controlled-release fertilisers are the novel and most technically advanced way of supplying mineral nutrients to crops. Compared to conventional fertilisers, their gradual pattern of nutrient release better meets plant needs, minimises leaching, and therefore improves fertiliser use efficiency. A field experiment was carried out to study the effects of different nitrogen sources, application times, and nitrogen rates at south El-kantra Research Station, Desert Research Center, North Sinai, Egypt. The study aimed to investigate nitrogen rates at 107,160, and 214 kg/ha on wheat yield components, nutrients content and uptake by straw and grains of wheat crop (var. Sakha 93) and the level of available nutrients in the soil.

The study revealed that increasing the application rate of N, increased yield components, nutrients content and uptake of wheat as well as increased the elements in soil. Application of 214 kg/ha of Polymer-Coated Urea (PCU) at the heading stage resulted the highest yield and recorded 6.47, 3.02, 3.35 ton/fed and 51g for dry weight of biological yield, grain, shoots and 1000-grain, respectively. This study highlights the efficiency of fertilisers that can be significantly improved with the use of PCU as N sources and subsequently minimisethe pollution hazard with other studied N sources. The highest value of N recovery efficiency (30.99%) was recorded by application of 214 kg/ha PCU at the heading stage when compared with the conventional source.

Comment [S2]: Preferred UK spelling
Comment [S3]: Preferred UK spelling
Comment [S4]: Preferred UK spelling
Comment [S5]: Preferred UK spelling
Comment [S6]: Preferred UK spelling

**Corresponding author: E-mail: drrehabhh@yahoo.com;*

Keywords: N fertilisers; Polymer-Coated Urea (PCU); nutrients uptake; efficiency of fertilisers; wheat production.

1. INTRODUCTION

Nitrogen plays an essential role in plant growth; it is a major component of the building blocks of almost all plant structures such as proteins, enzymes and chlorophyll. The optimal concentration of N increases leaf area, photosynthetic processes, and net assimilation rate which eventually contribute towards higher grain yield. In most of the soils, ammonium is quickly converted to nitrate, which is not held in soil particles and is easily dissolved in water; thus it is susceptible to leaching. Therefore, timing and rates of nitrogen has effect on the plant growth and environment.

Overuse of fertilisers is one of the primary reasons for the degradation of environment and soil. Slow release fertilisers are the most technically basic way of supplying mineral nutrients to crops in compare to conventional fertilisers; their gradual pattern of nutrient release meets plant needs, minimises leaching, and therefore improves fertiliser use efficiency (Subbarao, *et al.,* 2013).

Nitrogen-recovery efficiency for cereal production has been estimated globally at only 33% (Raun and Johnson, 1999). Some of the N has not been used by the crop due to an assumption of lost through denitrification, runoff, volatilisation, and leaching. Such losses raise concerns about water contamination and greenhouse gas emissions in the environment. Low use efficiency of fertiliser N also reduces economic returns from fertiliser inputs. Nitrogen-use efficiency (NUE) can be improved by reducing N losses (Englesjord, *et al.,* 1997).

Controlled release N fertilisers or CRN composed of urea with a polymer coating. Polymer-coated urea (PCU) fertilisers use a hydrophobic coating that temporarily isolates the urea prill from the soil environment. These polymer coatings may be resins or mineral-based products that act as semipermeable membranes or impermeable membranes with tiny pores. Nutrient release through these membranes is controlled by the properties of the coating material, i.e., its permeability characteristics as affected by temperature and moisture.

CRN sources are a group of N fertilisers that may remove or reduce labour intensive and costly in-season N applications, as well as increase NUE. CRN releases N at controlled rates to retain maximum growth and minimise N loss. The two primary forms of CRN are compounds of low solubility and coated water-soluble fertilisers (Blaylock, *et al.* 2005). Previous studies with CRN, has been mostly unsuccessful in potatoes as the N release was too early and unpredictable, resulting in delays in tuberization and yield loss.

PCU fertilisers are one kind of CRN that have the potential to provide enhanced N release timing. One such PCU is Environmentally Smart Nitrogen (ESN, Agrium U.S. Inc., Denver, CO). ESN is considered to release N to the crop with supplementary control and predictability with a micro-thin polymer coating. The N release rate is controlled by soil temperature that coincides with plant growth and nutrient demand. The process of release is called temperature-controlled diffusion. In this process, water moves into the fertiliser granule through the coating and dissolves the N into solution. As temperature increases, N moves out through the polymer coating into the soil solution (Agrium, 2005) and (Trent, *et al.* 2007).

CRN fertiliser consists of urea with a polymer coating which is permeable to water and gradually releases N in response to increasing temperatures over the growing season (Agrium Inc. 2011). It costs around 15 to 30% more than uncoated urea and considerably less than other such fertiliser products or earlier generation coated fertilisers (Hopkins *et al.*, 2008 and Wilson, *et al.,* 2009), which makes it a more attractive product for use for field crops. Field experiment of grains and potato indicated that PCU may increase crop yield, reduce the need for split N application, and decrease NO_3-N leaching compared to conventional N fertilisers (Nelson *et al.* 2009; Wilson *et al.* 2009 and 2010; Blackshaw *et al.* 2011; Ziadi *et al.* 2011 and Bernard *etal*. 2012**)**. However, the crop yield response was mostly dependent on soil moisture, and little difference should be expected where the risk of N loss is minimum (Malhi *et al.* 2010; McKenzie *et al.* 2010).

The study aims to constitute comparisons of PCU with a variety of conventional N fertilisers and application practices on growth, yield and N, P and K nutritional status in wheat crop grown in

Comment [S7]: Preferred UK spelling
Comment [S8]: Preferred UK spelling
Comment [S22]: Preferred UK spelling
Comment [S23]: The word is often overused
Comment [S24]: Preferred UK spelling
Comment [S25]: Preferred UK spelling
Comment [S9]: Preferred UK spelling
Comment [S10]: Preferred UK spelling
Comment [S11]: Preferred UK spelling
Comment [S26]: Preferred UK spelling
Comment [S12]: Preferred UK spelling
Comment [S13]: Preferred UK spelling
Comment [S27]: Preferred UK spelling
Comment [S14]: Preferred UK spelling
Comment [S28]: Preferred UK spelling
Comment [S15]: Preferred UK spelling
Comment [S29]: Preferred UK spelling
Comment [S16]: Preferred UK spelling
Comment [S17]: Preferred UK spelling
Comment [S30]: Preferred UK spelling
Comment [S18]: Preferred UK spelling
Comment [S31]: The word is often overused
Comment [S19]: The word seems to be miswritten
Comment [S32]: Preferred UK spelling
Comment [Ed20]: Acronyms are generally written out in full for the first reference with the acronym following inside parentheses if the term is to be used again in the document.
Comment [S21]: Preferred UK spelling

a sandy soil and finally to compare N-use efficiency as Recovery use efficiency of N (RUE), physiological use efficiency of N (PUE) and Agronomy use efficiency of N (AUE**)** of PCU against the conventional N fertiliser.

2. MATERIALS AND METHODS

A field experiment was carried out on wheat cultivated during two successive seasons (2014-2015) at south El -kantra Research Station of Desert Research Center, North Sinai, Egypt (Latitude: 30°53′27″ N; Longitude: 32° 44′ 67″ E).. The objective was to study the effects of three nitrogen sources (ammonium nitrate (AN, 33 % N), ammonium sulphate (AS, 20.5% N) and the polymer coated urea (PCU, 43% N), two application timing (a basal N fertilisation one time after one month of germination and as twice-split equal fertilisation, the first was added after one month of germination and the other dose at the heading stage of plant growth) and four nitrogen rates (0, 107, 160 and 214 kgN/ha) on the chemical composition and productivity of wheat. The recommended dose of NPK fertilisers for wheat was 214kg N/ha (as ammonium sulphate), 71 kg P_2O_5/ha (as ordinary superphosphate) and 120 kg K_2O/ha (as potassium sulphate) **(**Shehab El-Din and El-Shamy, 2003**)**. The experimental design was randomised complete block design split-split plots where nitrogen sources treatments were represented in the main plots. Application timing were in the sub-main plots and N rates were in the sub-sub-main plots. Each treatment included three replicates. This experiment contained 24 treatments. The plot area was 10.5 m^2 (3.5 long × 3 wide). Yield parameters were recorded for two seasons. Sprinkler irrigation system for irrigation the grown plants was used in the experiment**.** Wheat grains (var. Sakha 93) were sown on 17th November in both the seasons. Wheat was harvested during May 2015 and 2016. Soil samples were collected from the studied plots (at depth 0-30 cm) for determinations of some physical and chemical properties. Initial analysis is shown in Table 1.The following data were recorded.

2.1 Growth and Yield Parameters

At maturity, 1 m^2 in the center of each experimental plot was chosen to be harvested for the estimation of biological parameters (biological yields, dry weights of shoots and grain and 1000 grain weight).

Table 1. Some physical and chemical properties of the initial studied soil

Depth	**0-30 cm**
Particle size distribution %	
Sand	90.5
Silt	2.7
Clay	6.88
Texture class	Sandy
pH (1:5) Suspension	8.6
EC(1:5) $dS.m^{-1}$ soil extract	0.61
Soluble ions (meq/L)	
Na	4.34
K	0.23
Ca	0.876
Mg	0.605
Cl	4.00
HCO_3	1.77
SO_4	0.281
Available nutrients (mg/kg)	
N	25
P	1.47
K	32

2.2 Determination of Nitrogen, Phosphorus and Potassium in Straw and Grain of Plant

N, P and K in both grain and shoots were determined in acid digested solution, which was prepared according to the method described by Cottenie *et al*. (1982).

2.3 Soil Properties of the Experiment

2.3.1 <u>Mechanical analysis</u>

Mechanical analysis was determined according to the method described by Piper (1950).

2.3.1.1 Chemical properties

Soil hydrogen potential (pH) was determined electrometrically in soil suspension 1:5 using bench Beckman Glass Electrode pH-Meter, total soluble salts (EC) were determined in soil suspension 1:5 were determined according to the method described by Jackson (1973).

2.3.1.2 Determination of available nitrogen, phosphorus and potassium in soil

Available nitrogen in soil samples was extracted by 2M potassium chloride solution and determined according to the method described by Dhank and Johnson (1990). Available

Comment [S33]: Preferred UK spelling

Comment [S34]: Preferred UK spelling

Comment [S35]: Preferred UK spelling

Comment [S36]: Preferred UK spelling

potassium and phosphorous were extracted by DTPA + ammonium carbonate solution and measurement according to the method described by Soltanpour (1985).

2.4 Nutrient Efficiency Parameters

Nutrient efficiency parameters were evaluated by using the following equations (Yadvinder *et al.*, 2004):

Recovery efficiency of N (RE) = 100 x (N uptake kg/fed of treated- N uptake kg/fed of untreated)/ Applied N kg/fed

Physiological efficiency of N (PE) = (grain yield kg/fed of treated - grain yield kg/fed of untreated)/ (N uptake kg/fed of treated- N uptake kg/fed of untreated)

Agronomy efficiency of N (AE) = (grain yield kg/fed of treated - grain yield kg/fed of untreated)/ Applied N kg/fed

2.5 Statistical Analysis

Data were statistically analysed and the differences between the means of the treatments were considered significant when they were more than the least significant differences (L.S.D) at the 5% level by using computer program of Statistics version 9 (Analytical software, 2008). Regression analyses were performed by using Statistical Product and Service Solutions (SPSS 18.0).

3. RESULTS AND DISCUSSION

3.1 Effect of Nitrogen Sources, Application Times and Nitrogen Fertiliser Rates on Yield Component of Wheat

The wheat yield was significantly affected by the different treatments through two seasons (Table 2). The second season followed the same trend of the first season and mean values of two seasons were considered for the yield of both shoots and grains. Polymer-Coated Urea (PCU) showed a significantly higher increase of yield of wheat (dry weights of biological yields, shoot, grain as well as 1000-grain weight)as compared to conventional fertilisers (AS or AN). PCU applied at twice split produced higher yields at heading stage compared to one-split application. Also, yield increased significantly with increasing the rates of N fertilisers. The most effective treatment was 214 Kg N/ha of PCU when splitted the added fertiliser. The highest yield was recorded as 6.37, 3.02, 3.35 ton/fed and 51 (g) dry weights for biological yields, grain, shoot and 1000-grain weights, respectively. The PCU avoids at least some N losses. Wheat plants require nutrients continuously for the growth, but they absorb nutrients differently in quantity and speed as plants absorb critical elements in different plant growth stages. Nitrogen is an essential macronutrient that is required mostly for wheat production (Hou *et al.* 2007), but N deficiency adversely affect wheat growth as well as yield (Kawakami *et al.* 2012). The release rate of PCU was slow in the first month, and then accelerated under the field condition; the successive releases of N from PCU corresponds well to the requirements of N in the growth stages of wheat (Geng *etal.* 2016)

Hence using these materials once as a N source produced lower yields than applied in two equal doses. This may be due to loss of N through de-nitrification, leaching, or ammonia volatilisation in single application. The loss mechanism was also supported by Blaylock *et al.* (2005), Blackshaw *et al.* (2011), and Nelson *et al.* (2014), who reported that split-N application resulted in higher wheat biomass (2.77 Mg ha^{-1}) and N uptake (28.5 kg ha^{-1}) as compared to fall-applied N.

3.2 Effect of Nitrogen Sources, Application Times, and Nitrogen Fertiliser Rates on Nutrients Contents of Wheat

The study revealed that the N, P and K content (%) in straw and grain of wheat were significantly affected by the treatments (Table 1). The highest significant increase in nutrient content was recorded by using PCU when compared with As and AN. Also, the result showed that the values increased with increasing the rates of N fertilisers. The treatment, 214kgN/ha of PCU applied twice split resulted the values of 0.900, 0.076 and 2.35 % for N, P and K content, respectively in straw, while in seeds, the values were 2.627, 0.267 and 0.600%, respectively. It should be noted that the application of PCU (twice split) was as effective as (one time) application of either AS or AN. The second season followed the same trend of the first season. Blaylock, *et al.* (2005), Henry, *et al.* (2010) and Nelson *et al.* (2014) also reported that split-applied N resulted in higher wheat tissue N concentration which is in accordance with the present study.

Comment [S41]: Preferred UK spelling

Comment [S42]: Unnecessary comma deleted

Comment [S43]: Preferred UK spelling

Comment [S37]: Preferred UK spelling

Comment [S44]: Preferred UK spelling

Comment [S38]: Preferred UK spelling

Comment [S45]: Preferred UK spelling

Comment [S39]: Preferred UK spelling

Comment [S40]: Preferred UK spelling

Table 2. Effect of nitrogen sources, application times and nitrogen fertiliser rates on yield components of wheat

Comment [S46]: Preferred UK spelling

N sources	Time application	N Rates	Biological dry yield (t/fed.)	Grain dry weight t/fed.	Shoot dry weight t/fed.	1000 grains dry weight (g)
AS	Once	0	3.81	1.69	2.12	24.10
		107	3.96	1.93	2.03	32.57
		160	4.55	2.22	2.33	37.47
		214	5.35	2.55	2.80	45.15
	Twice split	0	3.87	1.72	2.15	24.40
		107	4.55	2.22	2.33	37.44
		160	5.23	2.55	2.68	43.08
		214	6.28	3.07	3.21	50.90
AN	Once	0	3.83	1.7	2.13	24.20
		107	4.17	2.04	2.13	33.35
		160	5.81	2.35	2.46	38.37
		214	6.05	2.83	2.95	46.23
	Twice split	0	3.89	1.73	2.16	24.30
		107	4.59	2.25	2.34	36.65
		160	5.27	2.58	2.7	42.16
		214	6.38	3.11	3.27	50.80
PCU	Once	0	3.85	1.71	2.14	24.30
		107	4.43	2.05	2.38	36.70
		160	5.54	2.68	2.86	44.30
		214	6.06	2.84	3.22	44.80
	Twice split	0	3.88	1.74	2.14	32.57
		107	4.78	2.4	2.38	44.00
		160	5.84	2.98	2.86	47.10
		214	6.37	3.02	3.35	51.00
LSD 0.05 for N source			0.09	0.08	0.18	1.90
Time Application			0.1	0.04	0.02	0.20
N rates			0.09	0.11	0.13	2.15
N source x T. Application			0.16	0.09	0.18	1.92
N source x N rates			0.16	0.18	0.26	3.72
N rates x T. Application			0.15	0.13	0.16	2.65
3 Factors			0.23	0.24	0.31	5.64

AS= ammonium sulphate AN= Ammonium nitrate PCU=polymer coated urea

3.3 Effect of application of nitrogen sources, application times and nitrogen fertiliser rates on nutrients uptake by wheat

Comment [S47]: Preferred UK spelling

The results from yield and nutrients content showed that the treatment PCU provided higher nutrients uptake by wheat plant during two seasons than other studied treatments (Table 4). The N, P and K uptake increased with increasing rate of N application for all the treatments. The highest significant increase was recorded for 214 kg N/ha of PCU at the heading stage treatment with the values of 30.17, 2.55 and 78.66 for N, P and K kg/fed uptake by straw, respectively. For seeds, the values were 84.18, 8.58 and 19.20 kg/fed uptake, respectively. The nutrients uptake in seeds and straw in the second season showed similar trends as the first season. These results could be due to the fact that successive releases of N from PCU corresponded well to the requirements of N in the growth stages of wheat. Nutrient release rates of PCU are known to be significantly affected by temperature and moisture content (Geng *et al.* 2015). Thus, the N release longevity of PCU in field condition was longer when compared with the conventional fertilisers. In contrast, the rapid hydrolyses process of urea caused heavy N losses which is supported by Khan, *et al.* (2015). These results are in accordance with those reported by Blaylock *et al.* (2005). Henry *et al.* *(*2010) and Nelson *et al.* *(*2014), who reported that split-applied N

Comment [S48]: Preferred UK spelling

resulted in greater wheat tissue N concentration.

The relationship between total N uptake and wheat grain yields at timing of application of PCU has been depicted in Fig. 1. There was a good quadratic relationship between yield and N uptake at pre-plant stage (R^2 = 0.9763), and at the heading stage (R^2 = 0.9957). These indicate that the increasing rate of PCU fertiliser had a potential to increase the grain yield. This figure can be modified later according to target grain yields for economic considerations of the application rate of PCU fertiliser.

3.4 Effect of Application of Nitrogen Sources, Application Times, and Nitrogen Fertiliser Rates on Nutrient Efficiency Parameters of Wheat

Recovery efficiency, physiological efficiency and agronomic efficiency of wheat were affected by the different studied treatments (Table 5). The highest value of recovery efficiency (41.88%) was obtained by adding 214kgN/ha of PCU under split-application. Highest agronomic efficiency (8.08 kg grain/kg N uptake) was recorded by 160kg N/ha of PCU under split-application due to more availability of N from PCU, while The highest value of physiological efficiency was obtained by 107kgN/ha of PCU at one time N treatment. Also, increasing NPK dose decreased the physiological efficiency of wheat but it increased recovery efficiency and agronomic efficiency. The data also showed that with using only a rate of 160kg N/ha of PCU source gave recovery efficiency higher than applying 214 kg N/ha of the ordinary source in both seasons. Controlled-release fertilisers are more effective in reducing N losses, stimulating plant growth, and increasing nitrogen use efficiency (Kiran *etal*. 2010). PCU has higher N recovery as compared to AS or AN. One time use of N fertilizers is less effective than split fertiliser treatments and is apparently subject to greater N loss by leaching since N is not recovered by the crop during the growing season. These results are in accordance with the previous study of Salvagiotti and Miralles (2008), Rehab (2013) and Chen *etal.* (2017). The lower recovery efficiency was possibly due to less availability of N due to lower grain yields during the particular year as endorsed by Yadvinder *et al.* (2004).

Comment [S49]: Preferred UK spelling

Comment [S52]: Preferred UK spelling

Comment [S50]: Preferred UK spelling

Comment [S53]: Preferred UK spelling

Comment [S51]: Preferred UK spelling

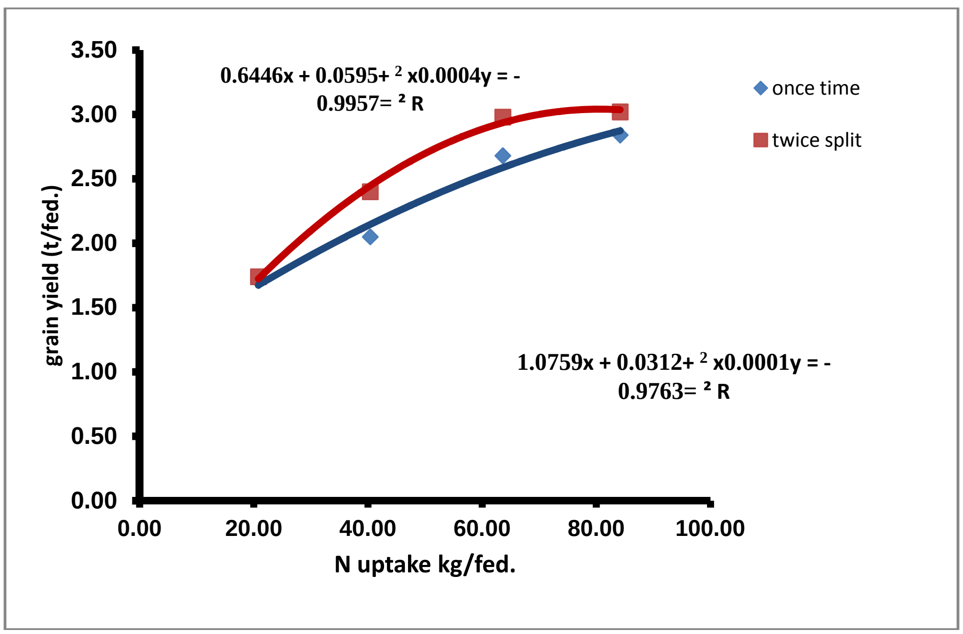


Fig. 1. Relationship between total N uptake and wheat grain yields

Table 3. Effect of nitrogen sources, application times and nitrogen fertiliser rates on nutrients contents in grain and straw of wheat

Comment [S54]: Preferred UK spelling

N sources	Time of application	N rates	Nutrients content in straw (%)			Nutrients content in seeds (%)		
			N	P	K	N	P	K
AS	Once	0	0.300	0.022	0.860	1.127	0.137	0.160
		107	0.507	0.037	1.347	1.590	0.14	0.34
		160	0.577	0.042	1.550	1.827	0.159	0.387
		214	0.697	0.051	1.870	2.200	0.191	0.467
	Twice split	0	0.330	0.024	0.890	1.157	0.143	0.167
		107	0.577	0.042	1.550	1.820	0.158	0.3867
		160	0.663	0.049	1.780	2.093	0.182	0.443
		214	0.800	0.058	2.147	2.523	0.219	0.540
AN	Once	0	0.310	0.023	0.870	1.137	0.141	0.170
		107	0.493	0.048	1.457	1.660	0.1783	0.34
		160	0.567	0.056	1.677	1.913	0.187	0.387
		214	0.683	0.067	2.017	2.297	0.225	0.470
	Twice split	0	0.310	0.025	0.910	1.177	0.145	0.170
		107	0.493	0.054	1.660	1.820	0.1623	0.37
		160	0.567	0.061	1.840	2.093	0.205	0.427
		214	0.683	0.074	2.213	2.523	0.247	0.510
PCU	Once	0	0.360	0.024	0.880	1.147	0.142	0.180
		107	0.400	0.026	1.707	1.327	0.156	0.29
		160	0.450	0.028	1.897	1.577	0.180	0.317
		214	0.683	0.035	2.023	1.877	0.199	0.370
	Twice split	0	0.320	0.260	0.940	1.187	0.147	0.190
		107	0.310	0.030	1.980	1.677	0.1707	0.33
		160	0.700	0.051	2.043	2.127	0.213	0.410
		214	0.900	0.076	2.350	2.627	0.267	0.600
LSD 0.05 for N source			0.025	0.002	0.053	0.076	0.008	0.014
Time Application			0.001	0.001	0.003	0.006	0.001	0.002
N rates			0.011	0.002	0.026	0.036	0.004	0.007
N source x T. Application			0.025	0.002	0.053	0.077	0.008	0.014
N source x N rates			0.030	0.003	0.065	0.093	0.009	0.017
N rates x T. Application			0.014	0.002	0.033	0.045	0.005	0.008
3 Factors			0.031	0.004	0.069	0.095	0.009	0.018

3.5 Effect of Application of Nitrogen Sources, Application Times, and Nitrogen Fertiliser Rates on the Availability of N, P and K in Soil at the End of the Experiment

Comment [S55]: Preferred UK spelling

The availability of N, P and K in soil at the end of the experiment is presented in Fig. 2. The application of studied treatments increased the available elements in soil. PCU was superior in increasing the elements availability in soil when compared to other studied fertilisers. The treatment of 214 kg N/ha of PCU applied through two doses provided significantly higher concentration of available elements in soil than the conventional fertiliser at 0-30 cm soil depth and the values were 93, 2.07 and 94 mg/kg for available N, P and K, respectively. Due to the slow release nature, slowly released fraction of stored urea, additionally contributed to ponded water N concentration throughout the growing season. The results were streamlined with the previous studies of Ellison *et al.* (2013) and Heiniger *et al.* (2014).

Comment [S57]: Preferred UK spelling

Comment [S56]: Preferred UK spelling

Table 4. Effect of application of nitrogen sources, application times and Nitrogen fertiliser rates on nutrients uptake in grain and straw of wheat

Comment [S58]: Preferred UK spelling

N sources	time application	N Rates	Nutrient uptake in straw kg/fed			Nutrient uptake in seeds kg/fed		
			N	P	K	N	P	K
AS	Once	0	6.41	0.47	18.26	19.19	2.39	2.76
		107	10.19	0.74	27.38	30.63	2.66	6.50
		160	13.58	0.98	36.28	40.53	3.52	8.59
		214	19.52	1.42	52.29	58.91	5.12	12.47
	Twice split	0	7.18	0.52	19.26	20.05	2.42	2.86
		107	13.58	0.99	36.46	40.48	3.52	6.50
		160	17.99	1.31	48.31	53.55	3.51	11.35
		214	25.99	1.89	69.62	77.82	6.76	16.48
AN	Once	0	6.71	0.47	18.26	19.47	2.42	2.94
		107	11.49	1.13	33.99	33.89	3.32	6.89
		160	15.23	1.50	45.04	44.84	4.39	11.00
		214	22.00	2.16	64.91	65.16	6.38	13.22
	Twice split	0	7.32	0.54	19.51	20.51	2.53	2.89
		107	12.91	1.27	38.09	40.93	4.00	8.32
		160	17.88	1.76	52.79	54.15	5.30	11.00
		214	24.26	2.38	71.49	78.69	7.71	13.23
PCU	Once	0	6.86	0.51	18.78	19.76	2.45	3.13
		107	8.54	0.56	36.42	27.34	3.22	6.01
		160	11.06	0.69	46.58	42.41	4.84	8.47
		214	16.27	1.04	59.73	53.38	5.66	10.64
	Twice split	0	7.89	0.58	20.81	20.80	2.58	3.26
		107	16.72	1.01	62.61	40.39	4.12	8.02
		160	21.49	1.56	66.09	63.61	6.38	12.29
		214	30.17	2.55	78.66	84.18	8.58	19.20
LSD 0.05 for N source			1.178	0.088	2.316	2.198	0.275	0.382
Time Application			0.578	0.040	1.628	1.114	0.120	0.211
N rates			0.852	0.072	2.317	2.325	0.245	0.444
N source x T. Application			1.372	0.100	3.050	2.583	0.312	0.460
N source x N rates			1.718	0.137	4.139	4.088	0.454	0.763
N rates x T. Application			1.190	0.096	3.262	3.053	0.323	0.583
3 Factors			2.315	0.170	6.610	6.401	0.575	1.024

AS= ammonium sulphate AN= Ammonium nitrate PCU=polymer coated urea

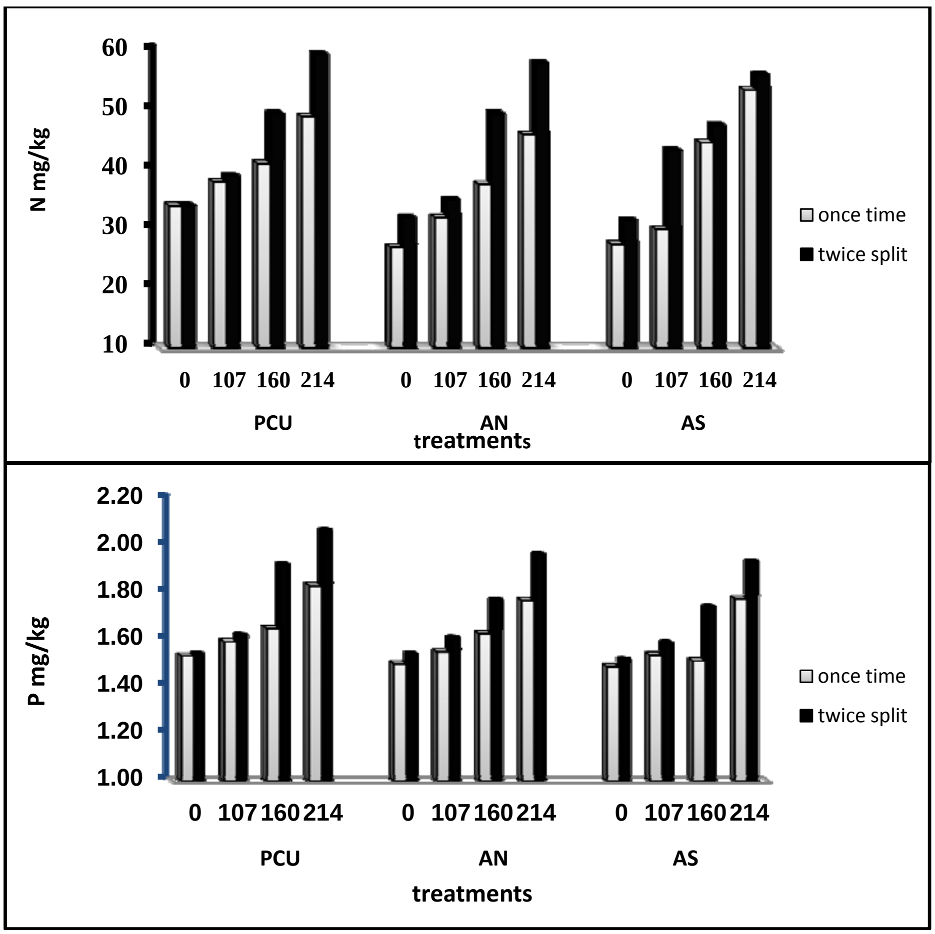
Table 5. Effect of application of nitrogen sources, application times, and Nitrogen fertiliser rates on recovery N efficiency (%), physiological efficiency and agronomic efficiency of wheat

Comment [S59]: Preferred UK spelling

N sources	time application	N Rates	Recovery efficiency	Physiological efficiency	Agronomic efficiency
			(%)	(kg grain/kg N uptake)	(kg grain/kg N applied)
AS	once	0	0.00	0.00	0.00
		107	6.93	20.23	1.05
		160	8.65	24.40	1.58
		214	12.03	24.61	2.23
	twice split	0	0.00	0.00	0.00
		107	12.22	24.00	2.23
		160	13.46	24.56	2.50
		214	17.44	23.32	3.07
AN	once	0	0.00	0.00	0.00
		107	8.74	23.10	1.52
		160	16.57	25.19	3.12
		214	22.36	24.55	4.11

N sources	time application	N Rates	Recovery efficiency (%)	Physiological efficiency (kg grain/kg N uptake)	Agronomic efficiency (kg grain/kg N applied)
	twice split	0	0.00	0.00	0.00
		107	11.85	24.74	2.30
		160	21.61	25.01	4.11
		214	27.54	23.58	5.03
PCU	once	0	0.00	0.00	0.00
		107	9.05	44.40	3.29
		160	17.50	42.68	6.30
		214	21.03	33.42	5.49
	twice split	0	0.00	0.00	0.00
		107	27.79	33.45	6.41
		160	36.77	28.94	8.08
		214	41.88	22.95	7.11

AS= ammonium sulphate   AN= Ammonium nitrate   PCU=polymer coated urea



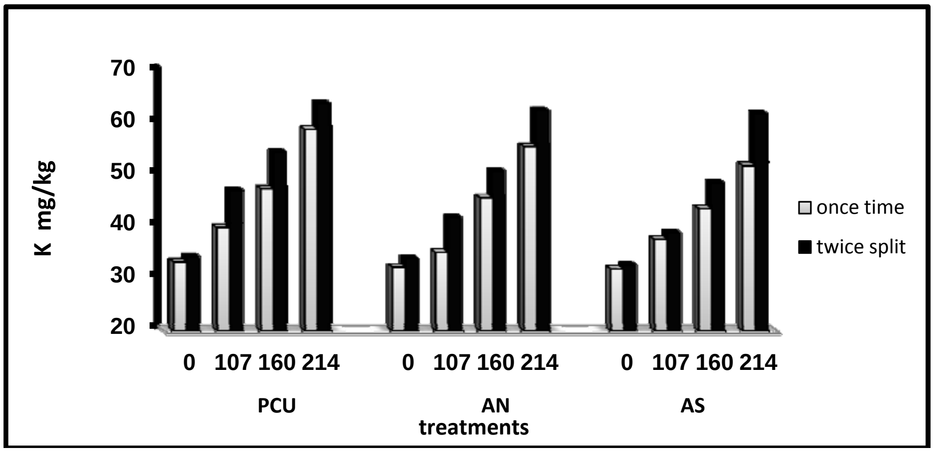


Fig. 2. Effect of application of nitrogen sources, application times, and Nitrogen fertiliser rates on nutrient availability in soil

Comment [S60]: Preferred UK spelling

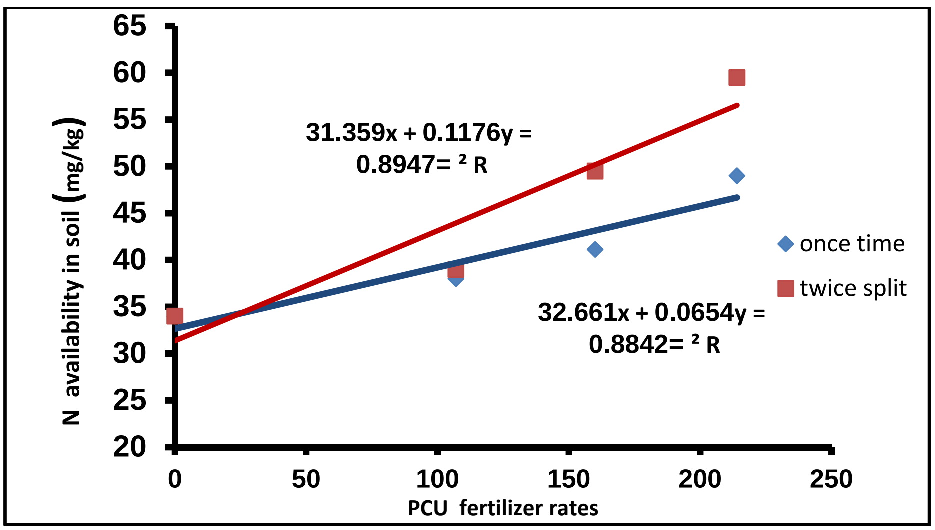


Fig. 3. Interaction between polymer-coated urea (PCU) fertiliser and nitrogen availability in soil

Comment [S61]: Preferred UK spelling

The linear regression showed a value of 31.359 by adding N fertiliser at one time (Fig. 3). However, this value increased to 32.661 when N fertilizer was spllited at heading stage, this indicate that application of PCU had a potentiality to increase N content. This slowly released and steady supply of N may be responsible for greater use efficiency in PCU as reported by Tang *et .al.* (2007). Yang *et al.* (2012) endorsed that using controlled-release urea (CRU) in rice without additional fertiliser application during the growing season significantly increased N availability in the soil and improved yields by 13.6%–26.5%

Comment [S62]: Preferred UK spelling

4. CONCLUSIONS

Present study shows that the use of PCU is much better than conventional fertilisers; as the application of PCU plays an important role for increasing crop productivity. Yield components, nutrients content and uptake by wheat were increased by using the PCU, compared to other fertilisers. Also, split application of fertilisers is

Comment [S64]: Preferred UK spelling

Comment [S63]: Preferred UK spelling

Comment [S65]: Preferred UK spelling

Comment [S66]: Preferred UK spelling

more effective than one time application. The apparent recovery efficiency of N increased significantly by using the PCU source. Using only a rate of 50 or 75% of the recommended rate from PCU source gave recovery efficiency of N higher than applying 100% of the conventional source, with almost similar or higher yield. It is concluded that using PCU fertilisers can reduce the amount chemicals wastage and hence, minimises the pollution hazard. It can be recommended to cultivate wheat crop with 214 kg N/ha of PCU under two equal doses of split application to get the highest nutrients uptake and productivity under sandy soil of Sinai region, Egypt.

COMPETING INTERESTS

Author has declared that no competing interests exist.

REFERENCES

Agrium,Inc.,(2005).How the Technology Works. http://www.agrium.com/ESN/docs/How_Technology_Works_Can.pdf. Agrium, US, Inc. Denver, CO.

Agrium,Inc.,(2011).Agrium advanced technologies.ESN Smart Nitrogen product information. Agrium,Inc.,Calgary,AB.[Online]Available:http://www.smartnitrogen.com/environmentally-smart-nitrogen-fertilizer-product-overview.aspx.

Analytical software, (2008). Statistix Version 9, Analytical Software, Tallahassee, Florida, USA.

Bernard G., Noura Z., and Cynthia, G.(2012). Urea fertilizer forms affect grain corn yield and nitrogen use efficiency. . Can. J. Soil Sci. (2012) 92: 341_351

Blackshaw, R.E.; Hao, X.; Brandt, R.N.; Clayton, G.W.; Harker, K.N.; O'Donovan, J.T.; Johnson, E.N.; Vera, C.L.(2011). Canola response to ESN and urea in a four-year no-till cropping system. Agron. J., 103, 92–99; doi:10.2134/agronj2010.0299.

Blaylock, A.D., Kaufmann, J. and Dowbenko R.D.(2005). Nitrogen Fertilizer Technologies. In: W.B. Stevens (ed.). Proceedings of the Western Nutrient Management Conference, Vol. 6:8-13. Salt Lake City, UT. Potash and Phosphate Institute, Manhattan, KS.

Chen J., Fangbo C.; Hairong X.; Min H., Yingbin Z., and Yuanfu X.(2017). Effects of single basal application of coated Compound fertilizer on yield and nitrogen use Efficiency in double-cropped rice. Crop. J. 5, 2 6 5 – 2 7 0

Cottenie, A.;Verlso M.; Kilkens L.; Velghe G. and Camerlynck R., (1982) Chemical Analysis of Plants and Soils. Lab. Agroch. State Univ. Gent, Belgium

Dhank, W.C. and Johnson G.V. (1990). Testing soils for available nitrogen. In :soil testing and plant analysis, 3rd ed., SSSA book series No.3, R.L. Westerman (ed.). Madison, WI: Soil Sci. Soc. of Am. J., 127-139.

Ellison E.; Blaylock, A. Sanchez,C. and Smith, R.(2013). Exploring controlled release nitrogen fertilizers for vegetable and melon crop production in california and arizona.Western Nutrient Management Conference.. Vol.10.17-22.

Engelsjord, M.E.; Fostad, O., and Singh, B.R.(1997). Effects of temperature on nutrient release from slow-release fertilizers. Nutrient Cycling in Agroecosystems. 46:179-187.

Geng, J..; Ma, Q.; Zhang, M.; Li, C.L.; Liu, Z.G.; Lyu, X.X. and Zheng, W.K., (2015). Synchronized relationships between nitrogen release of controlled release fertilizers and nitrogen requirements of cotton. Field Crop. Res. 184, 9–16.

Geng, J.; Mac, Q.; Chenb, J.;Zhang, M.; Lia, C.; Yanga, Y.;nYanga,X.; Zhanga, W. and Liu, Z. (2016). Effects of polymer coated urea and sulfur fertilization on yield, nitrogen use efficiency and leaf senescence of cotton. Field Crops Research 187, 87–95

Heiniger, R.W.; Smith, T.A. and Wiatrak, P. (2014). The impact of the polymer coating nutrisphere™ in increasing Nitrogen use efficiency and corn yield. American Journal of Agricultural and Biological Sciences 9 (1): 44-54.

Henry, D.C.; Mullen, R.W.; Dygert, C.E.; Diedrick, K.A.and Sundermeier, A.(2010). Nitrogen contribution from red clover for corn following wheat in western Ohio. Agron. J., 102, 210–215.

Hopkins, B. G., Rosen, C. J., Shiffler, A. K. and Taysom, T. W. 2008.. Enhanced efficiency fertilizers for improved nutrient management: potato (Solanum tuberosum). Crop Manage. doi:10.1094/CM-2008-0317-01-RV.

Hou, Z.; Li, P.; Li, B.; Gong, J. and Wang, Y. (2007). Effects of fertigation scheme on Nuptake and N use efficiency in cotton. Plant Soil 290, 115–126.

Comment [S67]: Preferred UK spelling

Comment [S68]: Preferred UK spelling

Comment [S69]: Unnecessary space deleted

Comment [S70]: Unnecessary space deleted

Jackson, M. L. (1973). Soil Chemical Analysis, Prentice hall, England, U.K.

Khan, A.Z.; Ali, B.; Afzal, M.; Wahab, S.; Khalil, S.K.; Amin, N.; Ping, Q.; Qiaojing, T. and Zhou, W. (2015). Effects of sulfur and urease coated controlled release urea ondry matter yield, N uptake and grain quality of rice. J. Anim. Plant Sci. 25 (3),679–685.

Kawakami, E.M.; Oosterhuis, D.M.; Snider, J.L. and Mozaffari, M., 2012. Physiologicaland yield responses of field-grown cotton to application of urea with theurease inhibitor NBPT and the nitrification inhibitor DCD. Eur. J. Agron. 43 (3):147–154.

Kiran, J.K.; Khanif, Y.M.; Amminuddin H and Anuar, A.R.(2010). Effects of controlled release urea on the yield and nitrogen nutrition of flooded rice, Commun. Soil Sci. Plant Anal. 41 :811–819.

Malhi, S. S.; Soon, Y. K.; Grant, C. A.; Lemke, R. and Lupwayi, N. (2010). Influence of controlled-release urea on seed yield and N concentration, and N use efficiency of small grain crops grown on Dark Gray Luvisols. Can. J. Soil Sci. 90: 363-372.

McKenzie, R. H.; Middleton, A. B.; Pfiffner, P. G. and Bremer, E. (2010). Evaluation of polymer-coated urea and urease inhibitor for winter wheat in southern Alberta. Agron. J. 102: 1210-1216.

Nelson, K.A. ; Motavalli, P.P. and Nathan, M. (2014).Nitrogen Fertilizer Sources and Application Timing Affects Wheat and Inter-Seeded Red Clover Yields on Clay pan Soils. Agronomy , 4, 497-513

Piper, C. S. (1950). Soil and plant analysis, Waite Agric. Res. Inst., Adelaide, S.A., Australia.

Raun, W.R. and Johnson, G.V. (1999). Improving nitrogen use efficiency for cereal production. Agron. J. 91:357-363.

Rehab H. Hegab (2013). Bioavailability of some nutrients in Soil treated with organic wastes, PhD, (Soil Science) Ain shams university.

Salvagiotti, F. and Miralles, D.J. (2008). Radiation interception, biomass production andgrain yield as affected by the interaction of nitrogen and sulfur fertilization inwheat. Eur. J. Agron. 28 (3):282–290.

Shehab El-Din, T.M. and El-Shamy, M.E.M., (2003). Wheat production in Egypt. Ministry of Agriculture, Egypt.

Soltanpour, P.N. (1985). Use of ammonium bicarbonate - DTPA soil test to evaluate elemental availability and toxicity. Commun. Soil Sci. Plant Anal., 16 (3): 323-338.

Subbarao, Ch. V. ; Kartheek, G. and Sirisha, D.(2013). Slow Release of Potash Fertilizer Through Polymer Coating Int. J. Appl. Sci. Eng., 2013. 11, 1 25

Tang, S.; Yang, S.; Chen, J.; Xu, P.; Zhang, F.; Ai, S.and Huang, X. (2007). Studies on the mechanism of single basal application of controlled release fertilizers for increasing yield of rice (oryza sativa L.). Agric Sci China 6:586–596

Trent, W. T.; Hopkins, B. G; Shiffler, A.K. and Stephens, S. Ch.(2007). Polymer coated urea in potato production. Western Nutrient Management Conference. Salt Lake City, UT. 7, 169-175.

Wilson, M. L.; Rosen, C. J. and Moncrief, J. F. (2010). Effects of polymer-coated urea on nitrate leaching and nitrogen uptake by potato. J. Environ. Qual. 39: 492-499

Wilson, M. L.; Rosen, C. J. and Moncrief, J. F.(2009). Potato response to a polymer-coated urea on an irrigated, coarse textured soil. Agron. J. 101: 897-905.

Yadvinder, S.; Bijay, S.; Ladha, J.K.; Khind, C.S.; Khera, T.S. and Bueno, C.S., (2004). Effects of residue decomposition on productivity and soil fertility in rice-wheat rotation. Soil Sci. Soc. Am. J., 68 (3): 854-864.

Yang, Y.C.; Zhang, M.; Li, Y.C.; Fan, X.H and Geng Y.Q.(2012). Controlled release urea improved nitrogen use efficiency, activities of leaf enzymes, and rice yield, Soil Sci. 76 : 2307–2317.

Ziadi, N.;Grant, C.; Samson, N.; Nyiraneza, J.; Be´langer, G. and Parent, L.E´.(2011). Efficiency of controlled-release urea for a potato production system in Quebec, Canada. Agron. J. 103: 60-66.