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Role of polymer coated fertilizers (PCFS) an advance technology for improving nutrient use efficiency and crop productivity: A review

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Abstract

Polymer Coated Fertilisers are one of the Promising of Control release and slow release fertilizer which, when added to moist soil, uses temperature-controlled diffusion to regulate N release in matching plant demand and mitigate environmental losses. Polymer-coated fertilizers (PCF) has great potential for increasing crop production and enhancing nitrogen (N) fertilizer use efficiency, benefiting the ecosystem. Control release fertilizers are coated fertilizers that release nutrients over an extended period of time at a rate driven primarily by temperature and moisture of the root zone. It has been estimated that slow-release fertilizers comprise only 8-10% of the total fertilizers used in Europe, 1% in the USA and only 0.25% in the World. Controlled release fertilizers (CRFs) is proposed consisting of three stages:

i. A lag period during which water penetrates the coating of the granule dissolving part of the solid fertilizer in it
ii. A period of linear release during which water penetration into and release out occur concomitantly while the total volume of the granules remains practically constant
iii. A period of "decaying release", starting as the concentration inside the granule starts to decrease.

Polymer coated fertilizers are used for high value applications. Controlled-release is one of the modern application that has enhanced nutrient use efficiency. Fertilizer use efficiency can be increased by modification of fertilizer products. E.g. coated encapsulation. Controlled release fertilizers (CRFs) will bring revolution in agricultural industry in near future. In these review paper collected literature, importance of polymer coated fertilizers in agriculture production by enhancing the Nutrient Use Efficiency (NUE), Agronomic Efficiency and Physiological efficiency, they also increase the% recovery of nutrients and finally the growth and yield of crops.

Keywords: Polymer coated fertilisers (PCFS), nutrient use efficiency, productivity, profitability

Introduction

The fertilizer industry faces a continuing challenge to improve its products to increase the efficiency of their use, particularly of nitrogenous fertilizers, and to minimize any possible adverse environmental impact. This is done either through improvement of fertilizers already in use, or through development of new specific fertilizer types [Maene, 1995; Trenkel *et al*., 1988] [31, 69]. Improvement of fertilizers already in use is done through appropriate product design [Bröckel and Hahn, 2004] [4]. The product profile is determined by its chemical and physical properties, environmental safety and its stability against mechanical stress, hygrometry and temperature. With solid fertilizers new product design is mostly aimed at improving handling properties (reduction of dust formation and caking/hygroscopicity). Increasing the efficiency of mineral nitrogen (N) fertilizers use is not easy, because plants take up N normally as nitrate or ammonium ions, through their roots from the soil solution. However, ammonium-N, unlike nitrate-N_2, can be retained on soil constituents so that soil and plants compete for ammonium-N, either already available in the soil or applied. This competition for nitrogen, with the exception of nitrate-N is the main problem when it is added as mineral fertilizer to feed plants. Only a certain proportion of the N is taken up, or can be taken up, and used by the growing plants [Trenkel. 2010] [70].

Polymer-coated urea (PCU) is one promising type of CRN fertilizer that provides improved N-release timing. Soil temperature controls N release rate from certain PCU, which allows protection of N during cool periods when plants are not growing and soils are often susceptible to N losses, but then release of N as temperatures improve and plant growth and N uptake increase [Hopkins *et al*., 2008] [21]. Diffusion of N through the polymer coating is driven by an N concentration gradient-temperature being the primary regulator under irrigated conditions. Some PCU sources steadily supply plants with N for longer periods of time following application than immediately soluble forms of N, thus enhancing NUE [Hopkins *et al*., 2008; Patil *et al*., 2010; Wilson *et al*., 2010] [21, 44, 23] and leading to increased crop yield and quality [Pack and Hutchinson, 2003; Worthington *et al*., 2007; Cahill *et al*., 2010] [41, 75]. Hyatt *et al*. [2010] [23] showed that the slower release of PCU can improve economics by eliminating additional in-season N applications in potato. PCU's ability to mitigate negative environmental impacts associated with N fertilizer [Wilson *et al*., 2010; Pack *et al*., 2006; Halvorson *et al*., 2010] [73, 42, 18]. Polymer-coated urea was shown to decrease NO3-leaching [Wilson *et al*., 2010; Pack *et al*., 2006; Pack and Hutchinson, 2003; Guillard and Kopp, 2004; Du *et al*., 2006; Nelson *et al*., 2009] [74, 42, 41, 16, 11, 37], NH3 volatilization [Pereira *et al*., 2009; Rochette *et al*., 2009] [47, 48] and N2O emissions [Hyatt *et al*., 2010; Halvorson *et al*., 2008; Jassal *et al*., 2008] [23, 20, 24]. However, there have also been studies that have observed no decrease N loss compared to urea [Halvorson *et al*., 2010; Parkin and Hatfield, 2014] [19, 43].

Controlled-release fertilizers (CRF) are the newest and most technically advanced way of supplying mineral nutrients to crop plants and also nursery crops. Compared to conventional fertilizers, their gradual pattern of nutrient release better meets plant needs, minimizes leaching, and therefore improves fertilizer use efficiency [Thomas *et al*. 2009] [66]. Controlled-release fertilizers (CRFs) recently have become popular worldwide because they contain plant nutrients in a form which delays their availability for plant uptake after application, or is available to the plant much significantly longer than a more standard "rapidly available" fertilizer, such as ammonium nitrate, urea, or potassium chloride [AAPFCO. 1997] [1]. Using of CRFs may considerably reduce the energy consumption and time required to grow crops because the nutrients are slowly and gradually released throughout the growing season, hence, only one application is needed. Also consumption of natural gas and waste produced by the fertilizer industry can be reduced because of the more efficient use of nutrients [Wang. 2013; Lubkowski and Grzmil, 2008] [71, 29]. However, the use of CRFs is still limited compared with the large amount of more conventional fertilizers applied throughout the world. Relative to non-CRFs, advantages to using CRFs include the ability to obtain a better assessment of expected benefits; improving methods for production of CRFs; optimal design of the fertilizer compositions, inducing synergistic effects; a better understanding of the mechanisms which control nutrient release; and the ability to construct conceptual and mathematical models to predict the release rates and patterns under both laboratory and field conditions. All of these factors may assist growers, technicians, and environmentalists in their decision making [Shaviv. 2001; Shaviv and Mikkelsen, 1993] [55, 57]. Slowing the release of plant nutrients from fertilizers can be achieved by different methods and the resulting products are known as slow- or controlled-release fertilizers. With controlled-release fertilizers, the principal method is to cover a conventional soluble fertilizer with a protective coating (encapsulation) of a water-insoluble, semi permeable or impermeable-with-pores material. This controls water penetration and thus the rate of dissolution, and ideally synchronizes nutrient release with the plants' needs [Trenkel. 2010] [70].

Many studies have found that the application of controlled-release urea (CRU) and controlled-release potassium (CRK) greatly improved the yields and fertilizer use efficiencies of crops. Using CRUs have become a new trend to save fertilizer consumption because of the great potential for enhancing fertilizer use efficiencies [Jat *et al*., 2012] [25], reducing environmental pollution [Shaviv and Mikkelsen, 1993; Kiran *et al*., 2010] [57, 26] and saving labour and time [Zebarth *et al*., 2009] [78]. For example, nitrogen release rates of CRUs met the nitrogen requirements and improved apparent nitrogen uptake in wheat in northern China [Yang *et al*., 2011] [77]. Similarly, using CRUs increased wheat and maize yields by 12.8-14.3% and 5.5-8.1% compared with normal urea, respectively [Sun *et al*., 2010] [63]. Application of CRU also increased the yields and nitrogen use efficiencies in potatoes [Gao *et al*., 2015; Ziadi *et al*., 2011] [13, 82]. CRUs not only improved yields but also increased the protein content and reduced potential nitrogen losses compared with common urea [Zhang *et al*., 2000] [80]. The use of CRUs has shown advantages over ammonium nitrate, urea and urea ammonium nitrate, but relative performance varied with rainfall, fertilizer placement and soil texture [Nelson and Scharf, 2008] [38]. Similarly, using CRKs also showed better results compared with conventional potassium in turfgrass [Snyder and Cisar, 1992] [61]. Applications of blended CRK fertilizers may also increase the leaf potassium content in leaves and yield of tobacco [Lin *et al*., 2012] [28]. Hence, the use of CRFs should be investigated for possible extensive use in agriculture.

Control release fertilizers (CRF's) are coated fertilizers that release nutrients over an extended period of time at a rate driven primarily by temperature and moisture of the root zone. Polymer coated fertilizers (PCF's) were also a type of CRF's, which are solid or other nutrient core, coated with various polymers ("plastics"). Fertilizer use efficiency can be increased by application of polymer coated fertilizer compared to common fertilizers due to very less nutrient losses. Most common three marketed products are Nutricote, Osmocote and Polyon. Coatings are tough, resist to damage and thin. Nutrient release is due to controlled diffusion, which is fairly constant over time. Release depends on coat thickness, chemistry, temperature and moisture. These are conventional soluble fertilizer materials with rapidly plant-available nutrients, which after granulation, prilling or crystallization are given a protective, water-insoluble coating to control water penetration and thus dissolution rate, nutrient release and duration of release [Naik *et al*., 2017] [36]. AAPFCO [1995] defined them as 'products containing sources of water soluble nutrients, the release of which in the soil is controlled by a coating applied to the fertilizer'.

Naik *et al*. [2017] [36] and Trenkel [2010] [70] reported that there are three main groups of coated/encapsulated fertilizers, based on the following coating materials:

i. Sulphur,
ii. Sulphur plus polymers, including wax polymeric materials, and
iii. Polymeric/polyolefin materials.

The most important manufactured materials are:

a. Materials releasing nutrients through either microbial decomposition of low solubility compounds with a complex/high molecular weight chemical structure, e.g.

organic-N low-solubility compounds, such as urea-aldehyde condensation products (e.g. urea-formaldehyde-UF), or chemically decomposable compounds (e.g. isobutyledenediurea-IBDU) (Shaviv, 2005) [56].

b. Materials releasing nutrients through a physical barrier, e.g. fertilizers coated with inorganic materials such as sulphur or mineral-based coatings and fertilizers coated with an organic polymer.
c. Materials releasing nutrients incorporated into a matrix, which itself may be coated, including gel-based matrices, which are still under development (Shavit *et al*., 1995; Shaviv, 2005) [54, 56]. In practice, however, matrices are only used in exceptional cases.
d. Materials releasing nutrients in delayed form due to a small surface-to-volume ratio (super-granules, briquettes, tablets, spikes, plant food sticks, etc.). [Trenkel. 2010] [70]

Thomas *et al*. (2009) [66] reported that CRF can be divided into 3 categories based on their coating and nutrient composition:

1. Uncoated, nitrogen-based fertilizers-This oldest class of CRF consists of chemically-bound urea and the release rate is determined by particle size, available water, and microbial decomposition. Urea form and IBDU are examples of uncoated, nitrogen based fertilizers.
2. Coated, nitrogen-based fertilizers-Sulfur-coated urea was one of the first CRF and nitrogen release is controlled by the thickness of the sulfur coating. Although still used in agriculture, sulfur-coated urea is rarely used in forest, conservation, and native plant nurseries.
3. Polymer-coated multi-nutrient fertilizers-Polymer-coated CRF (PCRF) are the newest and most technically sophisticated fertilizers being used in horticultural plant production, and consist of a core of soluble nutrients surrounded by a polymer coating. Each polymer-coated fertilizer particle is known as a prill" (Figure 1), and nutrient release is precisely controlled by the chemical composition and thickness of the polymer coating. Compared to the previous categories that only supply nitrogen, PCRF supply all 3 "fertilizer elements" (nitrogen [N], phosphorus [P], and potassium [K]), and many formulations include calcium, magnesium, sulfur, and micronutrients. The defining characteristic of PCRF, however, is the sophisticated polymer coatings that gradually release nutrients over extended periods; release rates can be as short as 3 months or as long as 18 months.

Types of polymer-coated controlled-release fertilizers

Polymer-coated fertilizer technologies vary greatly between producers depending on the choice of the coating material and the coating process. The Pursell Reactive Layers Coating (RLCTM) uses polymer technology, while Polyon uses a polyurethane as does Haifa (Multicote) and Aglukon (Plantacote). Chissoasahi polymer technology (Meister), Nutricote is a polyethylene; while Scotts polymer technology (Osmocote) is an alkyd resin [Naik *et al*., 2017] [36].

Osmocote® (Scott-Sierra, Marysville, OH) is one of the oldest PCRF and its coating is classified as a polymeric resin. The coating is applied in several layers, and the relative thickness determines the speed and pattern of nutrient release at 70 ^{o}F (21 ^{o}C). Osmocote fertilizers are available with release periods from as short as 3 to 4 months to as long as 14 to 16 months. A wide variety of Osmocote PCRF is available for different crops and production cycles including a "miniprill" formulation (Figure 1B) for small volume containers and mini plugs (Scotts Horticulture, 2008) [50]. Although more expensive, the smaller miniprills improved distribution between containers by 5-fold and reduced problems with uneven growth (Drahn, 2007) [9].

Apex® (J.R. Simplot, Boise, ID) uses the Polyon® Reactive Layers Coating (RLC™) process that applies 2 re active monomers over the fertilizer core in a continuous coating drum, resulting in an ultrathin polyurethane membrane coating. The result is a PCRF that delivers nutrients through a solute concentration gradient permeation process that is unaffected by soil moisture, microbial activity, or pH levels. A variety of Apex formulations are available to meet the specific needs of conifers, woody plants, and native plants (Table 1). One formulation, Apex Native, is specially formulated for plants that are sensitive to high rates of P, and therefore aids in the colonization of mycorrhizal fungi (Simplot, 2008) [60].

Multicote® and Nutricote® (Sun Gro Horticulture, Bellevue, WA) uses thermoplastic resin coatings blended with special release-controlling agents to determine the nutrient release rate and longevity. Sun Gro markets 2 brands of PCRF-Multicote® in the U.S. and Canada, and Nutricote®, which is only available in the western U.S. (Sun Gro Horticulture 2008). Multicote® is available in a wide variety of nutrient formulations with release rates from 4 to 16 months (Table 1).

Diffusion® (Green Valley Agricultural, Caledonia, MI) PCRF are customized for different temperature zones, and come in many nutrient formulations with longevities from 3 to 9 months (Green Valley Agricultural, 2008) [15].

Table 1: Macro nutrient composition (N-P-K) and longevity of polymer-coated controlled release fertilizers commonly used in forest and native plant nurseries [Source: Thomas *et al*. 2009] [66]

Longevity at 21^0c	Osmocote®	Apex®	Multicote®	Diffusion®
3 to 4 months	14-14-14 19-6-12		15-7-15	17-6-17 18-6-18 22-2-3
5 to 6 months			15-7-15	17-6-17 18-5-18 22-4-9
8 to 10 months	13-13-13 19-6-12	13-13-13 16-8-16 18-6-12 19-8-12 21-2-11	15-7-15 17-7-14 20-6-12	17-6-17 18-4-18 22-4-8
12 to 14 months	19-6-12	17-6-12	14-7-14 17-6-14 20-5-12	
14 to 16 months	19-6-12	16-5-11	14-7-14 17-5-14 20-5-10	

Huett and Gogel (2000) [22] reported that when comparing Polyon® and Osmocote® (each with a 5- to 6-month release) with 140-day Nutricote®, longevity of N, P and K was substantially less for Nutricote® than the other 2 products. Longevity of Polyon® was again greater than for Osmocote®. Release rate of N, P, and K in a variety of Osmocote®, Polyon®, and Nutricote® fertilizers increased by 13 to 19% with a 10 ∞C (18 ∞F) rise in temperature.

Thomas *et al*. (2009) [66] observed that water soluble fertilizer (Ammonium nitrate) dissolve all nutrients at once while as slow release (Urea formaldehyde) and controlled release fertilizers (Osmocote) release nutrients for a longer period in fig 1.

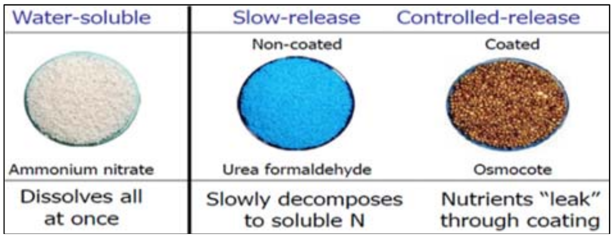


Fig 1: Different type of fertilizers [Thomas *et al*., 2009] [66]

Naik *et al*., (2017) [36] reported that Why to use PCFs:

- 70 per cent of conventionally applied fertilizer goes unutilized
- Loss of nutrients due to volatilization and leaching
- Fertilizer run-off in surface water leads to eutrophication process
- Negative environmental impacts
- Fertilizer waste through leaching increases ground water pollution
- Less fertilizer use efficiency

Thomas *et al*. (2009) [66] observed that ordinary fertilizers are affected by different types of losses viz. volatilization loss, runoff loss, leaching loss and denitrification loss, where as in slow and controlled release fertilizers nutrients delivered to root zone as plant needs them in Fig 2.

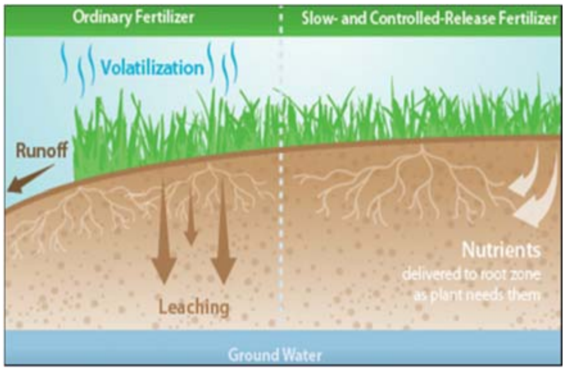


Fig 2: Difference between ordinary fertilizer and slow/controlled release fertilizer [Source: Thomas *et al*., 2009] [66]

Thomas *et al*. [2009] [66] and Naik *et al*., 2017) [36] reported that advantages of using polymer-coated controlled release fertilizers.

- Easy to adjust fertilization type and rate for different crops.
- Better fertilizer use efficiency.
- Less fertilizer pollution in wastewater.
- No rinsing required after fertilization
- Nutrients present at root initiation
- Fertilizer reserves for after sale or out planting.
- Fertilizer burn is not a problem with CRFs even at high rates of application
- Fertilizers are released at a slower rate throughout the season; plants are able to take up most of the fertilizers without waste by leaching
- Less frequent application is required
- Uniform particle size allows easier and precise mechanical distribution
- Flexibility of release periods from 40 to 360 days at 25C
- Reduced capital and labour outlay in horticultural crop production
- Reduced nutrient loss via leaching and run-off thus reducing environmental damage
- Reduced seed or seedling damage from high local concentrations of salts
- Reduced leaf burn from heavy rates of surface-applied fertilizers
- Improved storage and handling properties of fertilizer materials
- Product differentiation resulting in improved market potential
- Reduced Greenhouse Gas Emission from transportation of fertilizers
- CRFs improves NUE and in so doing reduces losses of surplus nutrients (over plant needs) to the environment [Shaviv, 2001] [55]. Consequently, high levels of fertilizer accumulation in the environment are minimized, thereby lessening several environmental problems associated with conventional fertilizer use such as eutrophication which causes O_2 depletion, death of fish, unpleasant odour to the environment, and aesthetic problems [Shaviv, 2001; Sharpley and Menzel, 1987; Clark, 1989] [55, 53, 6].

Mechanisms of nutrient release in polymer-coated controlled-release fertilizers

a) Soil moisture penetrates the polymer coating within a week and activates the encapsulated nutrients. No nutrient is released.
b) Nutrients slowly diffuse through the polymer coating over the next several months when triggered by soil temperature.
c) The polymer coating microbially decomposes into naturally occurring soil elements after complete release of nutrients & nbsp; [Fig 3].

Fig 3: Mechanisms of nutrient release (Source: [Source: http://www.mvjinter.com/fertilizer/polymer-coated-fertilizer/])

Guo *et al*. [2006] [17] proposed the mechanism of nitrogen release from urea-formaldehyde (UF) slow-release fertilizer granules based on three steps. Step one: the coating materials become swollen by absorbing water from the soil and so get transformed into hydrogels which contribute to increasing the orifice size of the 3D network of the coating materials so that it benefits the diffusion of the fertilizer in the core of the gel network. As a result, a layer of water between the swollen coatings and the UF granule core is formed. Step two: water slowly diffuses into the cross linked polymer network and dissolves the soluble part of UF; consequently the soluble part of the fertilizer gets slowly released into the soil through the swollen network with the dynamic exchange of the water in the hydrogel and the water in the soil. Step three: the soil microorganisms penetrate through the swollen coatings and assemble around the UF granule thereby degrading the insoluble part of nitrogen in UF granule into urea and ammonia which in turn is slowly released into the soil via dynamic exchange explained in fig 4 & 5. Such steps have also been described as lag period, linear stage, and decay period by other researchers [Du *et al*., 2006] [12].

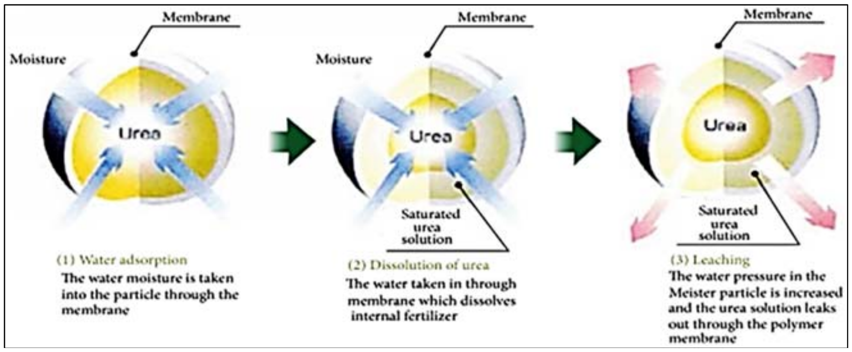


Fig 4: Release of nitrogen from polyolefin coated urea in water at 25 ⁰C. [Source: Sempho *et al*. 2014].

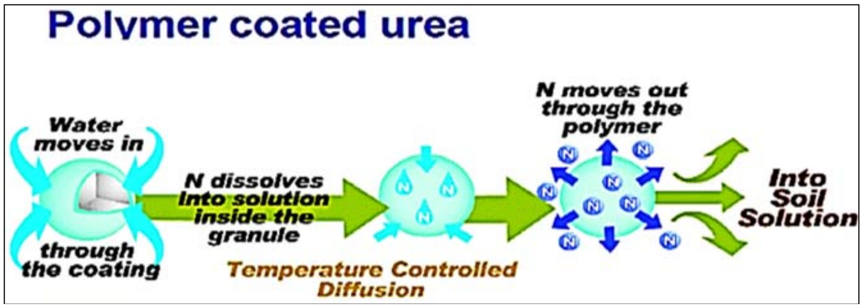
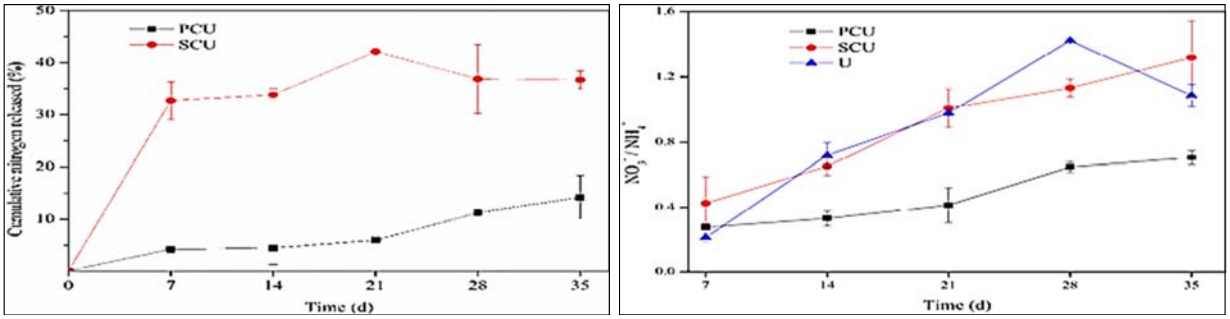


Fig 5: Mechanism of nitrogen release from polymer coated urea [Source: https://www.turfmagazine.com/services/controlled-release-ferts-offer-many-advantages/]

Effect of polymer-coated controlled release fertilizers for enhancing nutrient use efficiency

Tong *et al*. (2018) [68] observed that the cumulative N release rate curves of controlled release urea with two different coatings were significantly different in Fig. 6(a). At the beginning of the experiment, N release of SCU was faster than that of PCU. In the later stage, the cumulative release rate of SCU gradually stabilized, while PCU increased with a significantly higher growth trend than that of SCU. Initially in the experiment, the cumulative N release rate of SCU soared rapidly and was linearly released before the end of seven days. After that, the cumulative N release rate increased more slowly. By contrast, the cumulative N release rate of PCU increased steadily before 21 days, but the N was considered to release faster in later period because of the large slope of the curve. CRU can reduce concentrations of NO_3^- and NH_4^+, and PCU was more effective in maintaining lower soil NO_3^-/ NH_4^+ ratios than SCU and U in Fig 6(b).



(a) **(b)**

Fig 6(a): Nitrogen release from polyurethane-coated urea (PCU) and sulfur-coated urea
Fig 6(b): Dynamic changes of the NO_3^-/ NH_4^+ ratio (SCU) [Source: Tong *et al*. 2018] [68].

Yang *et al*. (2016) [76] reported that the contents of NO_3^--N and NH_4^+-N found 0-20 cm deep in the soil were significantly affected by fertilization. The control treatment showed the lowest quantities, which generally decreased in all treatments throughout the cotton growing season (Fig. 1). In the squaring stage, the contents of NO_3^--N and NH_4^+-N were each significantly higher in urea than in the PCU treatments, but the concentration decreased rapidly and later became lower than the urea treatment. However a relatively steady nitrogen supply was provided by the PCU treatments during the entire growing season. The contents of NO_3^--N and NH_4^+-N were each highest during the full boll stage (57.1 mg kg^{-1} and 44.9 mg kg^{-1}, respectively). The potassium fertilizer treatments showed no significant effects on the contents of NO_3^--N and NH_4^+-N, which had higher concentrations resulting from the PCPC80 than from the PCPC40 or PCPC120 treatments. The soil available potassium content decreased during the growing season (Fig. 7). For each kind of nitrogen fertilizer, the available potassium concentration increased as the input potassium rate increased. In addition, the levels of soil available K from the PCU treatments were markedly higher than from the urea treatments. Throughout the growing season, the lowest potassium content was observed in the control treatment.

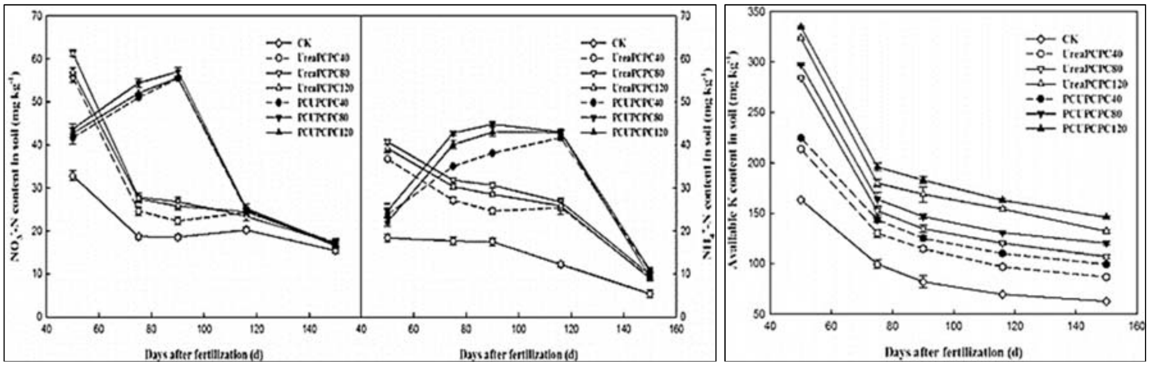


Fig 7: Changes of NO_3^--N and NH_4^+-N contents and available K content in soil in cotton crop [Source: Yang *et al*., 2016] [76].

Li *et al* [2015] [27] reported that the NUE, NAE and PFPN were affected by N fertilizer type and N input level (Table 2). Total N uptake at harvest was affected by N fertilizer type and N input level. Averaged over years, the POCU had the highest total N uptake (100.7, 90.3 and 191.0 kg ha^{-1} for early rice, late rice and total year), and followed by NCU (86.0, 80.1 and 166.1 kg ha^{-1} for early rice, late rice and total year) and control (47.7, 41.6 and 89.2 kg ha^{-1} for early rice, late rice and total year). Total N uptake increased with increasing N input levels until reaching a peak value and also followed the quadratic model [Baker *et al*., 2004; Chen *et al*., 2012] [2, 5]. Total N uptake were greater under POCU than under NCU and then than under control. Compared to NCU, POCU application had significantly higher NUE, NAE and PFPN (Table 3). Averaged over years and N rates, the NUE was greater under POCU than under NCU in early rice (52.3% from POCU, 36.5% from NCU), late rice (47.8% from POCU, 35.3% from NCU) and annual (50.0% from POCU, 35.9% from NCU). The NAE was greater under POCU than under NCU annual (22.1 kg grain kg^{-1} N from POCU, 15.7 kg grain kg^{-1} N from NCU), but similar in early (26.2 kg grain kg^{-1} N from POCU, 17.7 kg grain kg^{-1} N from NCU) and late rice (18.0 kg grain kg^{-1} 1 N from POCU, 13.7 kg grain kg^{-1} N from NCU). The PFPN was greater under POCU than under NCU in early rice (61.2 or 52.8 kg grain kg^{-1} N from POCU or NCU), late rice (54.7 or 50.5 kg grain kg^{-1} N from POCU or NCU) and annual (58.0 or 51.6 kg grain kg^{-1} N from POCU or NCU) respectively.

Table 2: Plant N uptake, nitrogen use efficiency (NUE), nitrogen agronomic efficiency (NAE) and partial factor productivity of applied N (PFPN) under different fertilization treatments in Rice crop [Li *et al*., 2015] [27]

Treatments	**N uptake (kg N ha⁻')**			**NUE (%)**	**NAE (g grain kg⁻' N)**		**PFP$_N$ (kg grain kg⁻' N)**	
	2002	**2003**	**2002**	**2003**	**2002**	**2003**	**2002**	**2003**
				Early rice				
Control	42.8±2.0d	52.5±3.4e	—	—	—	—	—	—
NCU-75	75 3+-3 5c	85.5±1.4b	43.3±3.4b	44.0±3.2b	27.8±2.6b	14.7±2.1b	66.7±3.6b	69.2±1.1b
NCU-150	89.1±2.8b	94.1±2.4a	30.9±1.7c	27.7±2.4c	19.9±1.1c	8.6±2.3b	39.3±0.6d	35.9±2.0c
POCU-75	96.0±2.8b	100.5±0.7a	71.0±4.1a	64.0±5.0a	47.4±0.9a	22.3±3.4a	86.4±2.5a	76.8±2.2a
POCU-150	113.0±2.1a	93.4±3.2a	46.8±2.0b	27.3±4.3c	27.6±2.3b	7.3±1.4b	47.0±1.8c	34.6±0.2c
				Late rice				
Control	38.6±1.3c	44.6±2.4e	—	—	—	—	—	—
NCU-75	62.7±1.2b	78.5±4.5b	32.2±1.0b	45.2±4.2b	10.4±1.5b	17.4±2.8b	51.3±1.0b	74.6±4.3b
NCU-150	80.8±1.3a	98.3±2.5a	28.1±12bc	35.8±1.9b	10.0±0.8b	17.0±1.6b	30.4±0.4e	45.6±1.2c
POCU-75	80.7±1.3a	94.6±5.2a	56.2±1.7a	66.7±7.8a	17.9±0.6a	35.1±6.0a	58.7±1.0a	92.3±5.1a
POCU-150	76.8±3.5a	108.9±3.7a	25.5±31k	42.9±3.1b	2.4±0.9c	16.5±2.3b	22.8±1.3d	45.1±1.5c
				Total				
Control	81.4±2.8d	97.1±1.6c	—	—	—	—	—	—
NCU-75	138.0±4.7c	164.014:7b	37.8±1.5b	44.6±2.8b	19.1±0.9b	16.0±1.0b	59.0±2.0b	71.9±1.6b
NCU-150	169.9-12.81)	192.4±4.2a	29.5±0.9c	31.8±1.8c	15.0±0.6c	12.8±1.8b	34.9±0.3c	40.7±1.5c
POCU-75	176.7±3.2b	195.1±5.8a	63.6±1.3a	65.3±4.8a	32.7±0.5a	28.7±4.0a	72.5±1.3a	84.5±3.5a
POCU-150	189.8±2.9a	202.3±5.4a	36.1±1.4b	35.1±2.3bc	15.0±0.9c	11.9±1.0b	34.9±1.0c	39.8±0.8c

Data were means ±SE (n =3) and different letters (a, b, c, d) within a column refer to significant differences ($P<0.05$) among treatments in the same rice season

Abbreviations: NAE, nitrogen agronomic efficiency; NUE, nitrogen use efficiency; NCU, non-coated urea; POCU, polyolefin-coated urea; PFPN, Partial factor productivity of N.

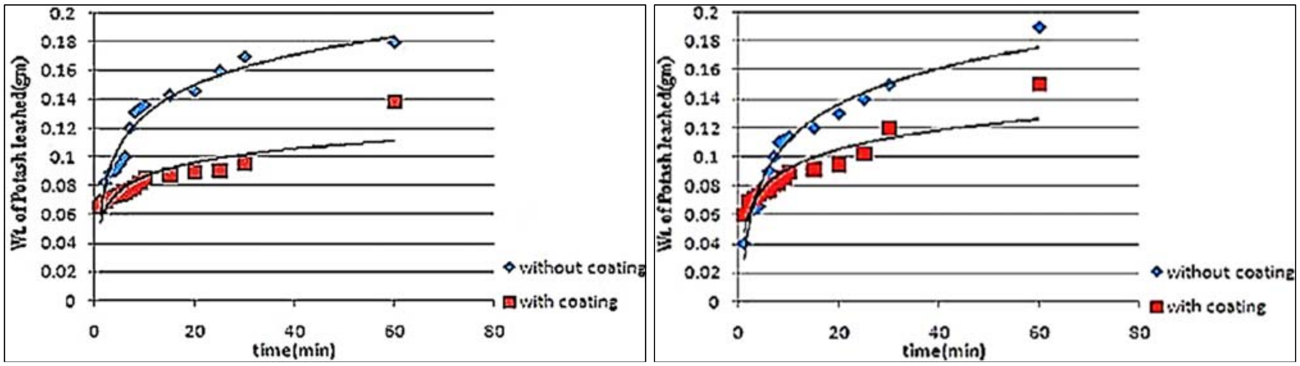
Wiatrak and Gordon [2014] [72] at Kansas, USA reported that application of nitrogen @ 270 kg/ha by urea with Nutrisphere-N in winter and spring corn recorded highest ear-leaf N% (3.01, 3.0%), grain N% (1.44, 1.41%) respectively over urea without Nutrisphere-N. Treating urea with Nutrisphere-N, increased corn yields on average by 15% with winter N application and 16.3% with N applied in the spring over urea without Nutrisphere-N (Table 3).

Table 3: Influence of urea with and without Nutrisphere-N applied in the winter and spring on ear-leaf and grain N of corn. [Source: Wiatrak and Gordon, 2014] [72]

Treatments	**N rates (kg ha^{-1})**	**Ear-leaf N%**	**Grain N%**
Control	**0**	**1.67**	**1.12**
Winter applied N			
Urea	90	2.95	1.22
Urea	180	2.53	1.26
Urea	270	2.63	1.34
Urea with Nutrisphere-N	90	2.82	1.27
Urea with Nutrisphere-N	180	2.94	1.38

Urea with Nutrisphere-N	270	3.01	1.44
Spring applied N			
Urea	90	2.30	1.21
Urea	180	2.62	1.27
Urea	270	2.68	1.33
Urea with Nutrisphere-N	90	2.87	1.29
Urea with Nutrisphere-N	180	2.93	1.38
Urea with Nutrisphere-N	270	3.00	1.41
LSD (0.05)		0.09	0.05

Subbarao *et al*. [2013] [62] at Andhra Pradesh reported that in the absence of coating, 0.18 gms out of 0.25 gms of potash could be leached in one hour where as in presence of coating, 0.11 gms of potash could be leached when the potash pellet is surrounded by 100 ml water. He also found that when pellet is surrounded by 200 ml water, 0.19 gms out of 0.25 gms of potash could be leached in uncoated potash while only 0.12 gms potash leached in coated potash shown in fig 8.



(a) **(b)**

Fig 8: Solubility of potash pellet with and without coating in (a)100 ml water (b)200 ml water [Source: Subbarao *et al*., 2013] [62]

Ma *et al*. [2007] [30] found that ammonia volatilization is influenced by soil type and that N losses from conventional fertilizers are greater than those from controlled-release fertilizers. Zhang *et al*. [2001] [81] found in N leaching experiments with various fertilizers in soil columns that, in addition to other positive aspects, controlled-release fertilizers had less influence on changes of the soil pH than conventional fertilizers. Dou and Alva [1998] [8] studied the effect of several controlled-release fertilizers compared to urea on citrus rootstock seedlings in a sandy soil. They demonstrated that, for a given N application rate, the total N uptake by the seedlings was greater for controlled-release fertilizers than for urea and they concluded that N losses would Slow- and controlled-release and stabilized fertilizers therefore be less when using controlled-release fertilizers as an N source compared to a soluble N fertilizer.

Masuda *et al*. [2003] [32] studied the decrease in nitrate leaching when polymer-coated N fertilizers were applied to sugarcane and showed that N fertilizer use could be decreased by about 40% without causing a reduction in sugar yield. Nitrogen absorption was estimated at 57.7% and 90.9% with conventional and controlled-release fertilizers, respectively. Tachibana [2008] [65] gives the percentage reduction in the recommended N rate when controlled-release fertilizers replace conventional fertilizers. This saves labour and energy costs, and greater N-use efficiency will minimize possible nitrate leaching losses. Maximizing NUE requires programmed fertilization using controlled-release fertilizers (e.g. such as Meister®), best fertilizer placement, and soil conditions favourable to plant growth. Innovative farming systems as well as using controlled-release fertilizers contribute to the improvement of the agro-environment [Shoji. 2005] [59]. For example, appropriate controlled-release fertilizers in no-till rice culture can effectively improve the water, atmospheric and biological environments of rice fields.

Effect of Polymer-Coated Controlled Release Fertilizers on crop productivity

Murphy and Sanders [2007] [34] showed that polymer coated mono ammonium phosphate (MAP) was more effective than uncoated MAP. Application of mono ammonium phosphate (MAP) with phosphate enhancer (Avail) applied in band produced highest wheat yield (76.9 bu/acre) compared to control (46.7 bu/acre) and MAP without Avail (54.7 bu/acre) shown in table 4. The largest increase was with banded P applications but broadcast P applications, widely recognized as less efficient, were also consistently increased by Avail coating of MAP. He also found that polymer coated mono ammonium phosphate (MAP) was more effective than uncoated MAP. Application of mono ammonium phosphate (MAP) with polymer as banded apply recorded the highest corn yield (157 bu/acre) and lowest corn yield with MAP without polymer as broadcast (132 bu/acre) shown in table 5.

Table 4: Effect of source and method of application of phosphorus on wheat yields [Source: Murphy and Sanders, 2007] [34]

Treatment	Yield (bu / acre)
Control	46.7
MAP banded	54.7
MAP + polymer, banded	76.9
MAP +broadcast	58.2
MAP + polymer, broadcast	65.6
MAP +seed, broadcast	55.1
MAP + polymer +seed, broadcast	68.3
LSD (0.05)	7.5

30 lb P2O5/A. Low soil P, pH 7 Palmer, University of Arkansas

Table 5: Corn responses to enhanced P availability [Source: Murphy and Sanders, 2007] [34]

Treatment	Grain yield (bu/acre)
Control, No P	135
MAP, broadcast	132
MAP + polymer, broadcast	151
MAP, banded	132
MAP + polymer, banded	157
LSD (0.05)	16

20 lb P2O5/A. Soil test Bray P-1: 7 ppm pH: 5.9 Blevins, Univ. of Missouri

Naik *et al*. [2017] [36] reported that grain yield of lowland rice from a single application of PCU was equivalent to or better than 3-4 well-timed split urea application. Fertilizer recovery with PCU was 70-75 per cent compared with 50 per cent with prilled urea (PU). The higher recovery of N from two PCU products was related to N release and subsequent N uptake by rice during the post anthesis stage. A one-time application of PCU may have distinct advantages over prilled urea, not just in terms of labour saving, but also because PCU may provide a more stable and sustained N release in rainfed crop systems where well-timed split N applications may not be feasible due to variability in rainfall and soil moisture. Coated urea also performed better than regular fertilizers by promoting increased grain yield and N uptake in rice in Spain, winter wheat in China, peanuts in Japan, potatoes in the USA, and maize in Japan.

Yang *et al*., [2016] [76] reported that the number of bolls, yields of seed cotton and lint were all affected by the type of nitrogen fertilizer and the PCPC rates and their interactions (Table 6). All PCU treatments produced significantly higher cotton yields and numbers of bolls compared with the urea treatments. Treatment with PCUs led to significantly higher lint yields (by 15.8-19.1%) compared to urea treatments. Generally, the PCU × PCPC80 treatment produced the highest lint yields for both years, when there were also no significant differences between PCU ×PCPC40 and PCU ×PCPC120. Meanwhile, the PCU treatments increased the number of bolls by 4.9-35.3% compared with the urea treatments. However, the weights of single bolls showed no significant differences among the fertilization treatments, and the control was the numerically lowest treatment each year. In addition, the lint percentage was not affected by the types of nitrogen fertilizers, rates of potassium fertilizers (except in 2015), or their interactions. Lint percentages persistently remained 43.5 to 44.8% among the different treatments. Fiber quality appeared to be significantly improved by N and K fertilization compared with the control treatment (Table 7). Based on measurements of fiber length, uniformity, and strength, there were obvious significant differences among the N-fertilized treatments, especially with PCU significantly higher than the urea treatments. Fiber qualities were all affected by N × K interaction results, except for fiber elongation. Fiber lengths and strengths in the PCPC80 and PCPC120 treatments were markedly increased compared with PCPC40.

Table 6: Main and interaction effects of N and K application on cotton yield and its components in cotton crop [Source: Yang *et al*., 2016] [76].

Ii-t--f r-›-Ti;	**2014**					**2015**				
	Bolls	**Boll weight**	**Seed cotton yield**	**Lint percentage**	**Lint yield**	**Bolls**	**Boll weight**	**Seed cotton yield**	**Lint percentage**	**Lint yield**
	(no. pot')	**(g)**	**(g pot^{-I})**	**(%)**	**(g por I)**	**(no. pot$^{-'}$)**	**(g)**	**(g pot$^{-'}$)**	**(%)**	**(g pot^{-1})**
Types of *N* fertilizers										
Urea	13.2 b	5.66 a	74.73 b	44.49 a	33.2613	16.3 b	6.55 a	107.40 b	44.39 b	47.69 b
PCU	15.7a	5.51a	86.23a	44.66a	38.51 a	19.4a	6.56a	127.29a	44.61 a	56.79a
PCPC fertilizer rates										
PCPC40	13.5 b	5.59 a	75.39 b	44.53 a	33.58 b	17.013	6.39 b	108.88 b	44.34 b	48.3013
PCPC80	15.0 a	5.60 a	83.68 a	44.70 a	37.42 a	18.5 a	6.54 ab	120.97 a	44.62 a	54.00 a
PCPC120	14.8 a	5.56 a	82.38 a	44.49 a	36.65 a	18.2 a	6.74 a	122.20 a	44.54 a	54.43 a
N x K interaction										
Control	11.0f	5.23 a	57.59 f	43.47 c	25.03 *f*	11.3 e	5.23 c	59.34 e	43.38 d	25.74 e
Urea x PCPC40	12.0 e	5.69 a	68.26 e	44.36 b	30.28 e	15.0 d	6.28 b	94.10 d	44.21 c	41.60 d
Urea x PCPC80	13.3 d	5.70 a	75.85 d	44.57 ab	33.81 d	16.7 c	6.52 ab	108.54 c	44.45 b	48.25 c
Urea x PCPC120	14.3 c	5.60 a	80.10 c	44.55 ab	35.68 c	17.3 c	6.90 a	119.5713	44.52 b	53.24 b
PCU x PCPC40	15.0 be	5.50 a	82.52 k	44.70 ab	36.89 k	19.013	6.51 ab	123.66 b	44.48 b	55.0013
PCU x PCPC80	16.7 a	5.35 a	90.88 a	44.79 a	40.71 a	20.3 a	6.46 b	132.43 a	44.80 a	59.76 a
PCU x PCPC120	15.3 b	5.53 a	84.67 b	44.43 ab	37.62 b	19.013	6.58 ab	124.83 b	44.56 b	55.63 b
Source of variance										
N	<0.0001	0.2878	<0.0001	0.1593	<0.0001	<0.0001	0.8847	<0.0001	0.0013	<0.0001
K	0.001	0.9742	0.0006	0.2621	0.0004	0.0037	0.0585	0.0002	0.0027	0.0001
N x K	0.0054	0.9034	0.0067	0.2284	0.0037	0.0131	0.1299	0.0005	0.061	0.0004

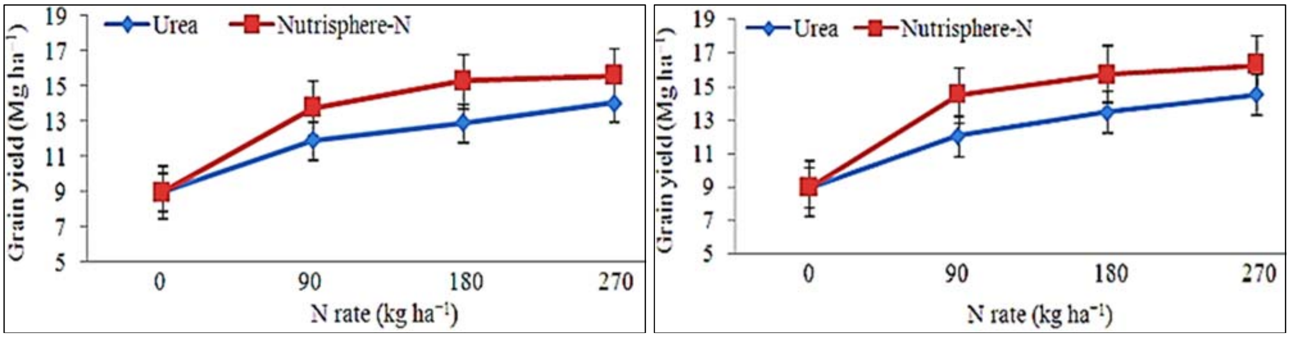
Note: PCU-polymer coated urea, Urea-common urea fertilizer, PCPC-polymer coated potassium chloride. Means followed by a same lowercase letter in the same column was not significantly different by Duncan's test in the same year (*P*<0.05).

Table 7: Main and interaction effects of N and K application on fiber qualities in cotton crop [Source: Yang *et al*., 2016] [76].

Treatment	Fiber length (mm)	Fiber uniformity (%)	Micronaire	Fiber elongation (%)	Fiber strength (cN ter ')
Types of N fertilizers					
Urea	27.5 b	83.4 b	5.5 a	6.8 a	28.3 b
PCU	27.7a	83.9a	5.5a	6.8a	29.3a
PCPC fertilizer rates					
PCPC40	27.4 b	82.9 b	5.5 b	6.8 a	27.8 b
PCPC80	27.7a	84.2a	5.6a	6.8a	29.4a
PCPC120	27.7 a	83.8 b	5.6 a	6.8 a	29.3 a
N x K interaction					
Control	26.7 e	81.3 e	5.2 d	6.7 b	25.2 e
Urea x PCPC40	27.3 d	82.3 d	5.4c	6.8 a	27.0d
Urea x PCPC80	27.5c	83.6 c	5.5 b	6.8 a	28.6c
Urea x PCPC120	27.8b	84.2b	5.6a	6.8a	29.4b
PCU x PCPC40	27.6 c	83.4 c	5.5 b	6.8 a	28.6 c
PCU x PCPC80	27.9 a	84.8 a	5.6 a	6.8 a	30.2 a
PCU x PCPC120	27.6c	83 5 c	5.5b	6.8a	29.2b
Source of variance					
N	<0.0001	<0.0001	0.0706	0.195	0.0001
K	<0.0001	<0.0001	0.0005	0.2798	<0.0001
N x K	<0.0001	<0.0001	0.0006	0.6243	0.0002

Note: PCU-polymer coated urea, Urea-common urea fertilizer, PCPC-polymer coated potassium chloride. Means followed by a same lowercase letter in the same column was not significantly different by Duncan's test in the same year ($P < 0.05$).

Li *et al*. [2015] [27] reported that grain yield of rice were influenced by N fertilizer type and N input level. Averaged over years and N levels, greater annual grain yields were significantly ranked as under POCU > under NCU > under control (11.4, 10.6 and 7.2 Mg ha^{-1}, respectively). Grain yields increased with increasing N rates until reaching a peak value, following the quadratic model [Baker *et al*., 2004; Chen *et al*., 2012] [2, 5]. Wiatrak and Gordon [2014] [72] at Kansas, USA reported that highest grain N was recorded with application of urea coated with Nutrisphere-N at 270 kg N ha^{-1} in the winter and spring. Grain N improved with Nutrisphere-N application by 4.1%, 9.5% and 7.5% for winter applications over untreated control at 90 kg, 180 kg and 270 kg N ha^{-1} respectively (fig. 9a). Grain N improved with Nutrisphere-N application by 6.6%, 8.7% and 6.0% over untreated control at 90 kg, 180 kg and 270 kg N ha^{-1} applied in the spring, respectively in (fig. 9b). Grain N improved on average by at least 7% with winter N applications using urea coated with Nutrisphere-N compared to uncoated urea.



(a) (b)

Fig 9: Influence of N application rate in the form of urea with Nutrisphere-N applied in the (a) winter and (b) spring on grain yields of irrigated corn.

Said *et al*. [2014] [49] at Malaysia observed that regardless of N sources and time of application, significantly higher yield components and grain yields were recorded from PCSCU, WSCU, U+S (6%), U+S (17%) without coating @ 120 N kg ha^{-1} fertilizers, applied as basal or split than the lower rates of N. However, lowest grain yields were recorded when crop was fertilized with lower N rates @ 60 N kg ha^{-1}. The result for N application time showed that splitting urea, U+S (6%) and U+S (17%), in equal doses during crop growth, enhanced grain yield of rice, and whereas all coated fertilizers showed no statistical yield difference in terms of N application timing. Pawel [2013] [45] at USA reported that application of seed coating treatments significantly increased dry matter production, N and P uptake compared to the untreated seeds. Seed treatment applications at 265, 395 and 530 ml 100 kg^{-1} seeds increased dry matter production by 13.4, 22.6 and 20.7%, N uptake by 13.9, 24.6 and 19.3% and P uptake by 16.0, 23.3 and 21.3% over control, respectively. However, Cu, Mn and Zn content in plant biomass was not affected by the seed coating treatment and he also found that application of seed coating at 395 and 530 ml 100 kg^{-1} seeds produced significantly higher grain yields of winter wheat compared to control. Grain yields increased by 2.1% at 395 ml seed application and 5.0% at 530 ml 100 kg^{-1} seeds of seed coating application. Grain N significantly increased by 5.0% with seed application treatment of 265 ml 100 kg^{-1} seeds. Highest grain P content was recorded at 265 ml and 395 ml 100 kg^{-1} seeds and for untreated control, while the highest seed treatment application had lower P content. Grain Cu content was highest for the control and treatment with seed coating application at 395 ml 100 kg^{-1} seeds. Seed coating treatment did not significantly affect plant height, grain weight and Mn and Zn content in grain. He also reported that the compared to the untreated control, application of polymer seed coating at 265 and 395 ml 100 kg^{-1} seeds significantly increased soybean yields by 8.1% and 14.0%, respectively. Although there was no significant difference, plant LAI improved by 2.0 and 1.5% over control at 8 weeks after soybean planting and 6.9 and 5.3% at 12 weeks following planting with application of seed coating at 265 ml and 395 ml 100 kg^{-1} seeds, respectively. Compared to control, application of seed coating at 265 ml and 395 ml 100 kg^{-1} seeds increased plant height by 3.5 and 4.8%, respectively, but difference was not significant.

Nelson *et al*. [2012] [39] reported that application of nitrogen @ 120 kg/ha by polymer coated urea (PCU) with non-coated urea (NCU) in the ratio of 75:25(PCU: NCU) recorded the highest wheat grain yield (5370 kg/ha) and lowest with ammonium nitrate (5110 kg/ha) shown in table 8.

Table 8: Winter wheat grain yields analysed at 130 g kg^{-1} moisture by N rate and fertilizer sources [Source: Nelson *et al*., 2012] [39]

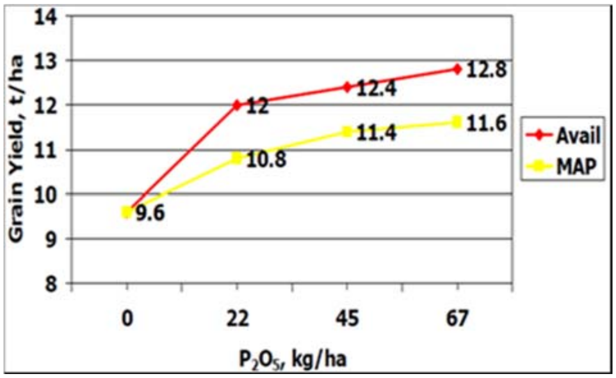
Rate (kg/ha)	N fertilizer source				
	100%	**100%**	**100%**	**75:25%**	**50:50%**
	AN	**NCU**	**PCU**	**PCU/ NCU**	**PCU / NCU**
	--------------------Grain yield (kg ha^{-1}) ------------------				
0	3550	-	-	-	-
84	4880	4800	5030	4960	4900
112	5110	5120	5340	5370	5290
LSD (0.05)	--------------------------------178-------------------------				
AN=Ammonium nitrate, NCU=Non coated urea, PCU=Polymer coated urea					

Palmer *et al*. [2011] at Columbia reported that application of monoammonium phosphate with polymer (MAP + Polymer) produce healthy plant and vigorous growth of the maize plant compared to uncoated mono ammonium phosphate (Uncoated MAP) in fig 10a. He also found that application of Avail (phosphate enhancer) produced highest corn grain yield (12.8 t/ha) compare to mono ammonium phosphate (MAP) (11.6 t/ha) in fig 10b. Gordon and Tindall (2006) at USA reported that application of phosphorus fluid starter with polymer recorded highest corn yield (223.5 bu/acre) and ear leaf phosphorus concentration (0.26%) compared to starter alone (215 bu/acre, 0.24%) and check (195 bu/acre, 0.20%), respectively.

MAP+ Polymer **Uncoated MAP**

(a)

Fig 10a: Effect of polymer coated MAP and uncoated MAP on growth of maize.



(b)

Fig 10b: Effect of Avail (polymer coated phosphorus) on corn grain yield [Source: Palmer *et al*., 2011]

Dong and Wang [2007] [7] reported that application of polymer coated nitrogen fertilizer recorded the highest Nitrogen Use Efficiency (70.54%), Nitrogen Agronomic Efficiency (32.56 kg/ha) and Nitrogen Physiological efficiency (46.16 kg/ha) compared to uncoated common fertilizers in rice crop.

Zhang [2007] [30] reported that crop yields were larger when using a controlled-release fertilizer, than when using conventional fertilizers although the amount of nutrient applied was a third or a half less with the controlled-release fertilizer. The quality of the crops and food products was also improved. In addition to the increase in N-use efficiency, N volatilization and leaching losses were considerably reduced through the application of controlled-release fertilizers. Zhang [2007] [30] concluded that, in regions where there was excess application of conventional fertilizers, the increase in severe non-point pollution could be reduced considerably by using controlled-release fertilizers. Shao *et al*. [2007] [52] confirmed similar beneficial results with the application of controlled-release fertilizers on apple trees; controlled-release fertilizers promoted tree growth and increased yield and quality.

Drost and Koenig [2002] [10] at Utah, U.S. studied that there is significant difference in onion yield due to different sources of nitrogen fertilizer and different rate of application. Application of polymer coated urea @ 224 kg/ha recorded the highest onion yield (82.7, 97.3 Mg/ha) and lowest in urea without polymer coating @ 112 kg/ha (63.4, 68.3 Mg/ha), respectively in both the years of study.

Nyborg *et al*. [1995] [40] reported that application of mono ammonium phosphate (MAP) with thin polymer coating in barley pot study recorded highest Plant yield (24.4 g/pot) and highest Apparent phosphorus recovery (44%) at 52 days after sowing compared to application of MAP without polymer coating and thick coating. Mortvedt [1994] [33] reported that uptake value of micronutrients from coated Fe, Mn and Zn in sorghum were highest (6.8, 2.3, and 1.2 mg/pot) compared to non-coated Fe, Mn and Zn.

Conclusion

Polymer Coated Fertilizers (PCFs) an advance technology not only has the potential to improve crop yields and farmer profits but also has positive implications on possible environmental footprint of fertilizer use. The application of polymer coated fertilizers increase the Nutrient Use Efficiency (NUE), Nitrogen Agronomic Efficiency and Nitrogen Physiological efficiency, they increase the% recovery of nutrients and finally the growth and yield of crops. Prolonged nutrient release may provide more uniform plant nutrition, better growth and improved plant performance and crop yields. Most common three marketed products are Nutricote, Osmocote and Polyon. Coatings are tough, resist to damage and thin. Nutrient release is due to controlled diffusion, which is fairly constant over time. Release rate mainly depends on coat thickness, chemistry, temperature and moisture. Of the 3 types of controlled-release fertilizers, polymer coated products are most commonly used in forest, conservation, crop plants and native plant nurseries. Depending on the type of coating and temperature of the medium, these fertilizers release their nutrients over periods from 3 to 18 months. CRU can reduce concentrations of NO_3- and NH_4+ accumulation in black soils, thereby reducing harmful gas emissions compared with conventional urea. PCU was more effective in maintaining lower soil NO_3-/NH_4+ ratios, indicating that nitrification was slower with PCU treatment, which meant PCU was more suitable for crop growth than SCU and U. PCRF afford many advantages, including ease of adjusting fertilizer rate for many crops better fertilizer use efficiency, and less concern about potential groundwater pollution, therefore maintain high grain yield and farmer's income, increase Nutrient use efficiency and ultimate improve crop production potential.

References

1. Association of American Plant Food Control Officials (AAPFCO): Official publication No. 50, T-29. Published by Association of American Plant Food Control Offials, Inc.; West Lafayette, Indiana, USA, 1997.
2. Baker DA, Young DL, Huggins DR, Pan WL. Economically Optimal Nitrogen Fertilization for Yield and Protein in Hard Red Spring Wheat. Agron. J. 2004; 9:116-123.
3. Bröckel U, Hahn C. Product design of solid fertilizers. Chemical Engineering Research and Design. 2004; 82(A11):1453-1457.
4. Cahill S, Osmond D, Weisz R, Heiniger R. Evaluation of alternative nitrogen fertilizers for corn and winter wheat production. Agron. J. 2010; 102:1226-1236.
5. Chen C, Neill K, Burgess M, Bekkerman A. Agronomic benefit and economic potential of introducing fall-seeded pea and lentil into conventional wheat-based crop rotations. Agron. J. 2012; 104:215.
6. Clark R. Marine Pollution, Clarendon Press, Oxford, UK, 1989.
7. Dong Y, Wang ZY. Release characteristics of different nitrogen forms in an uncoated and coated slow release fertilizers. Agric. Sci. 2007; 6(3):330-337.
8. Dou H, Alva AK. Nitrogen uptake and growth of two citrus rootstock seedlings in a sandy soil receiving diffrent controlled-release fertilizer sources. Biology and Fertility of Soils. 1998; 26(3):169-172.
9. Drahn SR. Propagating with Controlled Release Fertilizer. Presentation at 2007 Western IPPS Regional Meeting. Salem, OR. URL: http://www.ippswr.org/home/ippsna/2007/Presentations/Drahn.pdf (accessed 8 Dec 2008), 2007.
10. Drost D, Koenig R. Nitrogen use efficiency and onion yield increased with a polymer coated nitrogen source. Hort. Sci. 2002; 37(2):338-342.
11. Du CW, Zhou JM, Shaviv A. Release characteristics of nutrients from polymer-coated compound controlled release fertilizers. J Polymers Environ. 2006; 14:223-230.
12. Du CW, Zhou JM, Shaviv A. Release characteristics of nutrients from polymer-coated compound controlled release fertilizers, Journal of Polymers and the Environment. 2006; 14(3):223-230.
13. Gao X *et al*. Controlled release urea improved the nitrogen use efficiency, yield and quality of potato (Solanum tuberosum L.) on silt loamy soil. Field Crops Res. 2015; 181:60-68.
14. Gordon WB, Tindall T. Fluid phosphorus performance improved with polymers. Fluid J., 12-13, 2006
15. Green Valley Agricultural. Diffusion controlled release fertilizers. URL: http://www.diffusionfertilizer.com/7128.html (accessed 11 Dec 2008).
16. Guillard K, Kopp KL. Nitrogen fertilizer form and associated nitrate leaching from cool-season lawn turf. J Environ. Qual. 2004; 33:1822-1827. PMID: 15356243
17. Guo M, Liu M, Liang R, Niu A. Granular urea-formaldehyde slow-release fertilizer with superabsorbent and moisture preservation, Journal of Applied Polymer Science. 2006; 99(6):3230-3235.
18. Halvorson AD, Del Grosso SJ, Alluvione F. Tillage and inorganic nitrogen source effects on nitrous oxide emissions from irrigated cropping systems. Soil Sci. Soc. Am. J. 2010; 74:436-445.
19. Halvorson AD, Del Grosso SJ, Alluvione F. Nitrogen source effects on nitrous oxide emissions from irrigated no-till corn. J Environ. Qual. 2010; 39:1554-1562. PMID: 21043261.
20. Halvorson AD, Del Grosso SJ, Reule CA. Nitrogen, tillage, and crop rotation effects on nitrous oxide emissions from irrigated cropping systems. J. Environ. Qual. 2008; 37:1337-1344. doi: 10.2134/jeq2007.0268 PMID: 18574163.
21. Hopkins BG, Rosen CJ, Shiffler AK, Taysom TW. Enhanced efficiency fertilizers for improved nutrient management: Potato (Solanum tuberosum). Online. Crop Manage, 2008. doi: 10.1094/CM-2008-0317- 01-RV.
22. Huett DO, Gogel BJ. Longevities and nitrogen, phosphorus, and potassium release patterns of polymer-coated controlled release fertilizers at 30 ∞C and 40 ∞C. Communications in Soil Science and Plant Analysis. 2000; 31:959-973.
23. Hyatt CR, Venterea RT, Rosen CJ, McNearney M, Wilson ML, Dolan MS. Polymer-coated urea maintains potato yields and reduces nitrous oxide emissions in a

Minnesota loamy sand. Soil Sci. Soc. Am. J. 2010; 74:419-428.

24. Jassal RS, Black TA, Chen BZ, Roy R, Nesic Z, Spittlehouse DL, Trofymow JA. N2O emissions and carbon sequestration in a nitrogen-fertilized Douglas fir stand. Online. J Geophys. Res. 2008; 113:G04013, doi: 10.1029/2008JG000764.
25. Jat RA *et al*. Recent approaches in nitrogen management for sustainable agricultural production and eco-safety. Arch. Agron. Soil Sci. 2012; 58:1033-1060.
26. Kiran JK *et al*. Effects of controlled release urea on the yield and nitrogen nutrition of flooded rice. Commun. Soil Sci. Plant Anal. 2010; 41(7):811-819.
27. Li D, Xu M, Qin D, Shen H, Sun N, Hosen Y, He X. Polyolefin-coated urea improves nitrogen use efficiency and net profitability of rice-rice cropping systems. Int. J Agric. Biol. 2015; 17:1083-1090.
28. Lin C *et al*. Effect of blended controlled release potassium fertilizer on yield and potassium content of flue-cured tobacco cultivation. Journal of Huazhong Agricultural University (in Chinese). 2012; 31(06):720-724.
29. Lubkowski K, Grzmil B. Controlled release fertilizers. Pol. J Chem. Technol. 2008; 9(01):83-84.
30. Ma L, Yang L, Zhang M, Yang YCH, Chen BCH. Volatilization of nitrogen of coating controlled-release fertilizer and common fertilizer. (Chinese) Acta Pedologica Sinica, 2007.
31. Maene LM. Changing Perception of Fertilizer Worldwide. Fertilizer Industry Round Table, 1995.
32. Masuda T, Katsuta Y, Sugahara K, Banzai K, Shibano K. Improved sugarcane cultivation in the subtropical islands of Japan using controlled-release N-fertilizers. JIRCAS Research Highlights 2003.
33. Mortvedt JJ. Needs for controlled-availability micronutrient fertilizers. Fertilizer Research. 1994; 38:213-221.
34. Murphy L, Sanders L. Improving N and P use efficiency with polymer technology. Indiana CCA Conference Proceedings, 2007, 1-13.
35. MVJ International Coal, Biofuels, Oil & Gas, Energy. http://www.mvjinter.com/fertilizer/polymer-coated-fertilizer/
36. Naik M, Rajeswar, Kumar B, Kranthi, Manasa K. Polymer coated fertilizers as advance technique in nutrient management. Asian J Soil Sci. 2017; 12(1):228-232: DOI : 10.15740/HAS/AJSS/12.1/228-232.
37. Nelson KA, Paniagua SM, Motavalli PP. Effect of polymer coated urea, irrigation, and drainage on nitrogen utilization and yield of corn in a claypan soil. Agron. J. 2009; 101:681-687.
38. Nelson KA, Scharf PC. Agricultural Management of Enhanced-Efficiency Fertilizers in the North-Central United States. Crop Management 7(1), 2008.
39. Nelson KA, Nash PR, Motavalli PP, Meinhardt CG. Effects of polymer-coated urea application ratios on wheat. Agron. J. 2012; 104(4):1074-1084.
40. Nyborg M, Solberg ED, Pauly DG. Coating of phosphorus fertilizers with polymers increases crop yield and fertilizer efficiency.Better Crops. 1995; 79(3):8-9.
41. Pack J, Hutchinson C. Potato (Solanum tuberosum L.) Tuber yields, specific gravities, and nitrate leaching under polymer coated urea and ammonium nitrate fertilizer program. Hort Science. 2003; 38: 719-720.
42. Pack JL, Hutchinson CM, Simonne EH. Evaluation of controlled-release fertilizers for northeast Florida chip potato production. J Plant Nutr. 2006; 29:1301-1313.
43. Parkin TB, Hatfield JL. Enhanced efficiency fertilizers: Effect on nitrous oxide emissions in Iowa. Agron. J. 2014; 106:694-702.
44. Patil MD, Das BS, Barak E, Bhadoria PBS, Polak A. Performance of polymer-coated urea in transplanted rice: Effect of mixing ratio and water input on nitrogen use efficiency. Paddy Water Environ. 2010; 8:189-198.
45. Pawel W. Effect of polymer seedcoating with micronutrients on soybeans in South Eastern coastal plains. American J Agric. Bio. Sci. 2013; 8(4):302-308.
46. Pawel W. Infuence of seed coating withmicronutrients on growth and yield of winter wheat in South-Eastern coastal plains. American J Agric. Bio. Sci. 2013; 8(3):230-238.
47. Pereira HS, Leao AF, Verginassi A, Carneiro MAC. Ammonia volatilization of urea in the out-of-season corn. Revista Brasileira De Ciencia Do Solo. 2009; 33:1685-1694.
48. Rochette P, MacDonald JD, Angers DA, Chantigny MH, Gasser MO, Bertrand N. Banding of urea increased ammonia volatilization in a dry acidic soil. J Environ. Qual. 2009; 38:1383-1390. doi: 10.2134/jeq2008.0295 PMID: 19465713.
49. Said FNB, Yusop MK, Oad FC. Nutrient uptake, pH changes and yield of rice under slow release sulfur-coated urea fertilizers. Australian J Crop Sci. 2014; 8(10):1359-1366.
50. Scotts Horticulture. Controlled release fertilizers. URL: http://the-scotts-exchange.com/products/fertilizers/osmocote.cfm accessed 3 Dec 2008), 2008.
51. Sempeho SI, Kim HT, Mubofu E, Hilonga A. Meticulous Overview on the Controlled Release Fertilizers. Review Article. Advances in Chemistry, 2014, 1-16.
52. Shao L, Zhang M, Chen XS, Wang LX. Effects of Controlled-Release Nitrogen Fertilizer on Yield and Nitrogen Content of Soil and Apple Tree. (Chinese) Acta Horticulturae Sinica. 2007; 34(1):43-46.
53. Sharpley AN, Menzel RG. The impact of soil and fertilizer phosphorus on the environment. Advances in Agronomy. 1987; 41:297-324.
54. Shavit U, Shaviv A, Zaslavsky D. Solute diffusion coefficient in the internal medium of a new gel based controlled release fertilizer. Journal of Controlled Release 37, Elsevier Science B.V., Amsterdam, Th Netherlands, 1995.
55. Shaviv A. Advances in controlled-release fertilizers. Adv. Agron. 2001; 71:1-49.
56. Shaviv A. Controlled Release Fertilizers. IFA International Workshop on Enhanced-Efficacy Fertilizers, Frankfurt. International Fertilizer Industry Association Paris, France, 2005.
57. Shaviv A, Mikkelsen RL. Controlled-release fertilizers to increase efficiency of nutrient use and minimize environmental degradation-A review. Fertile. Res. 1993; 35(1-2):1-12.
58. Shaviv A. Advances in controlled-release fertilizers. Advances in Agronomy. 2001; 71:1-49.
59. Shoji S. Innovative use of controlled availability fertilizers with high performance for intensive agriculture and environmental conservation. Science in China Ser. C. Life Sciences. 2005; 48:912-920.

60. Simplot. Apex nursery fertilizer: a higher standard in plant nutrition. URL: http://www.simplot.com/turf/apex/index.cfm (accessed 3 Dec 2008), 2008.
61. Snyder GH, Cisar JL. Controlled-release potassium fertilizers for turfgrass. J Am. Soc. Hortic. Sci. 1992; 117(3):411-414.
62. Subbarao V, Kartheek G, Sirisha D. Slow release of potash fertilizer through polymer coating. Int. J Applied Sci. Engg. 2013; 11(1):25-30.
63. Sun K *et al*. Study on the effect of the control released urea in the wheat-corn rotation system. Chin. J Soil Sci. (in Chinese). 2010; 41(5):1125-1129.
64. Sungrow Horticulture. Nutricote controlled release fertilizer. URL: http://www.sungro.com/ products_displayProBrand.php?brand_id=6 (accessed 3 Dec 2008), 2008.
65. Tachibana M. Chissoasahi Fertilizer Co., Ltd: Personal report, 2008.
66. Thomas DL, Andis, Kasten Dumroese R. Using Polymer-coated Controlled-release Fertilizers in the Nursery and After Outplanting. Forest Nursery notes. Winter, 2009, 5-12.
67. Thomas D, Landis R, Kasten D. Using polymer-coated controlled-release fertilizersin the nursery and after outplanting. Forest Nursery Notes, winter, 2009, 5-12.
68. Tong X, He X, Duan H, Han L, Huang G. Evaluation of Controlled Release Urea on the Dynamics of Nitrate, Ammonium, and Its Nitrogen Release in Black Soils of Northeast China. Int. J Environ. Res. Public Health. 2018; 15(119):1-13. doi:10.3390/ijerph15010119.
69. Trenkel ME, Wichmann W, Kummer KF. New Challenges for the World Fertilizer Industry with Regard to Agriculture. IFA Agro-Economics Committee, Monte Carlo, 1988.
70. Trenkel ME. Slow-and Controlled-Release and Stabilized Fertilizers: An Option for Enhancing Nutrient Use Efficiency in Agriculture. International Fertilizer Industry Association (IFA) Paris, France, 2010.
71. Wang S *et al*. Effects of controlled-release urea application on the growth, yield and nitrogen recovery efficiency of cotton. Agri. Sci. 2013; 4(12):33-38.
72. Wiatrak P, Gordon WB. Effect of urea with nutrisphere-N polymer in fall and spring nitrogen applications for corn. American J Agric. Bio. Sci. 2014; 9(1):89-93.
73. Wilson ML, Rosen CJ, Moncrief JF. Effects of polymer-coated urea on nitrate leaching and nitrogen uptake by potato. J Environ. Qual. 2010; 39:492-499. doi: 10.2134/jeq2009.0265 PMID: 20176822.
74. Wilson ML, Rosen CJ, Moncrief JF. Effects of polymer-coated urea on nitrate leaching and nitrogen uptake by potato. J Environ. Qual. 2010; 39:492-499. doi: 10.2134/jeq2009.0265 PMID: 20176822.
75. Worthington CM, Portier KM, White JM, Mylavarapu RS, Obreza TA, Stall WM, Hutchinson CM. Potato (Solanum tuberosum L.) yield and internal heat necrosis incidence under controlled-release and soluble nitrogen sources and leaching irrigation events. Am. J of Potato Res. 2007; 84:403-413.
76. Yang X *et al*. Cumulative release characteristics of controlled-release nitrogen and potassium fertilizers and their effcts on soil fertility, and cotton growth. Sci. Rep. 2016; 6(39030):1-11. doi: 10.1038/srep39030.
77. Yang Y *et al*. Controlled release urea improved nitrogen use efficiency, yield, and quality of wheat. Agron. J. 2011; 103(2):479-485.
78. Zebarth BJ *et al*. Opportunities for improved fertilizer nitrogen management in production of arable crops in eastern Canada: a review. Can. J Soil Sci. 2009; 89(2):113-132.
79. Zhang M. Effect of coated controlled-release fertilizer on yield increase and environmental significance. (Chinese) Ecology and Environment, 2007.
80. Zhang M *et al*. Yield and protein content of barley as affected by release rate of coated urea and rate of nitrogen application. J Plant Nutr. 2000; 23:401-412.
81. Zhang QL, Zhang M, Tian WB. Leaching characteristics of controlled release and common fertilizers and their effects on soil and ground water quality. (Chinese) Soil and Environmental Sciences. 2001; 10(2):98-103.
82. Ziadi N *et al*. Efficiency of controlled-release urea for a potato production system in Quebec. Canada. Agron. J. 2011; 103:60-66.