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A Rapid Technique for Prediction of Nutrient Release from Polymer Coated Controlled Release Fertilizers

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ABSTRACT

Controlled release fertilizers (*CRF*) *are produced with different rates and durations of nutrient release to cater to different crops with wide ranges of nutrient requirements. A rapid technique is needed to verify the label specifications of nutrient release rate and duration. Polymer-coated urea* (*PCU*) (*43% nitrogen* [*N*]) *and polymer-coated N*, *phosphorus* (*P*), *potassium* (*K*) (*PC_NPK*; 14-14-14) *fertilizer products were used in this study. Soil incubation of the above CRF products at* 25˚*C showed that* 63.6% *to* 70.8% *of total N was released over* 220 *days* (*d*). *At* 100˚*C in water* 100% *of N release occurred in about* 168 *to* 216 *hours* (*h*). *Regression equations were developed for cumulative nutrient release as a function of release time separately at* 25˚*C and* 100˚*C. Using the above regressions*, *the release duration for a given percent nutrient release at each temperature was calculated. These values were then used to establish a relationship between the release duration at* 25˚*C as a function of that at* 100˚*C. This relationship is useful to predict the release duration at* 25˚*C of an unknown CRF product by conducting a rapid release test in water at* 100˚*C. This study demonstrated that a rapid nutrient release test at* 100˚*C successfully predicted nutrient release rate and duration at* 25˚*C*, *for polymer coated fertilizers. Therefore*, *this rapid test can be used to verify the label release rate and duration of most CRF products.*

Keywords: *Nutrient Requirement*, *Nutrient Management*, *polymer Coated Fertilizer*, *Slow Release Fertilizer*

1. Introduction

Potential benefit of controlled release fertilizers (CRF) is the ability to manipulate the rate and duration of nutrient release, so that the product can be applied once a year to supply the nutrient requirement over the entire annual growing period [1,2]. The duration of nutrient release can vary for several months depending on the coating specification and duration of crop growth. Although coating can be applied on any nutrient granules, much of the interest and justification for coating is on nitrogen (N) source. This is due to the complexity of N transformations in the soil that ultimately produces nitrate (NO_3-N) form, which is highly vulnerable to leaching down the soil profile if not taken up by the plant roots. Under conditions that favour downward transport of water below the root zone, the NO_3-N can be carried by leaching water deeper into the vadose zone and can contaminate surficial aquifer. Hence, there is a need to develop techniques to mitigate NO_3-N leaching below the rootzone. Most of the studies on nutrient release by the CRF products are based on the N release [3,4]. In a coated N, phosphorus (P), potassium (K) fertilizer the release of N was faster than that of P and K [4].

Verification of nutrient release pattern of CRF is critical for evaluation of effectiveness of these fertilizers for supplying plant nutrients according to the crop needs and the duration of crop growth. Despite a variety of prediction models and methods to evaluate the nutrient release [5-10] being developed in the past, there is no consistent and standardized method being recognized to date [10-12]. However, these predictions were relying heavily on the characteristics of the coating materials. Nutrient release of polymer-coated CRF is primarily temperature dependent [4,13-16]. However, verification of nutrient release pattern and total duration at the ambient soil temperature is not feasible due to the prolonged duration of release expected for most CRF, *i.e.*, 3 to 6 months. Medina *et al.* [17] used a laboratory procedure to predict N release rate of several slow release fertilizers. The method include extractions in 0.2% citric acid solution at 4 temperatures; *i.e.* 2 h at 25˚C, 2 h at 40˚C, and 20 h at 50˚C, and 50 h at 60˚C. They reported that the above accelerated laboratory extraction procedure was successful in predicting N release rate of some slow release fertilizers. However, this method was not satisfactory for some other type of slow release fertilizers. Hence the need for a rapid nutrient release evaluation for verification of the product label nutrient release duration. An alternate approach is desirable to establish correlation between the nutrient release at high temperature (in a few d) vs. that at prevailing soil temperature during the growing season (several d to months). This correlation can be used to predict the rate and duration of nutrient release at ambient soil temperature by using the nutrient release measurement over a short duration at high temperature.

Dai and Fan [18] and Dai *et al.*, [19,20], evaluated the nutrient release from two resin-coated N, P, K fertilizers (Trincote 1 and 2) at 25˚C, 50˚C, 60˚C, 70˚C, 80˚C and 90˚C. They used the calibration of nutrient release at 80˚C and 25˚C as a model to predict the nutrient release rate at 25˚C (in d) using the release results at 80˚C (in h). The objective of this study was to develop and validate a rapid test for prediction of nutrient release at 25˚C from polymer coated CRF products by using the measured nutrient release rate at 100˚C temperature.

2. Materials and Methods

Two CRF products used in this study included: polymer-coated urea (PCU); 43% N and polymer-coated N, P, K (14-14-14) (PC_NPK) fertilizers. Nitrogen release from these products was determined in water over 220 d at 25˚C, and 220 h at 100˚C.

2.1. Nutrient Release at 100˚C

A constant temperature extractor (Model HKQT, assembled at Shandong Agricultural University, Taian, China) was used to determine the nutrient release characteristics from the above two CRF products in deionized water at 100˚C. The extractor consisted of air-tight incubation chambers (500 ml), stainless steelwire mesh containers, water bath, and temperature and pressure regulators. Ten grams of each CRF was placed in one of six wire mesh containers which submerged into 250 ml deionized water in incubation chamber in three replications. The incubation chamber was preheated to 100˚C at 100 kPa. The extractions (50 ml) were collected at various time intervals from 1 to 220 h following incubation for analysis of total N in the extract using a total N analyzer (Liqui-TOCII, Elementar Americas, Inc., Mt. Laurel, NJ). At each sampling, the remaining extract was depleted and another 250 ml deionized water was added for the subsequent extraction.

2.2. Incubation at 25˚C

Nutrient release characteristics from CRF products in free water at 25˚C was evaluated by following the procedure described by Dai *et al.* (2006). Ten grams of CRF product was weighed, sealed in nylon mesh bags, placed into plastic bottles containing 250 ml deionized water, and bottles were incubated at 25˚C. Each treatment was replicated three times. Nutrient release at various sampling time, over 220 d, was measured by sacrificing three bottles per treatment at each sampling time. Total N in an aliquot of the total extract was measured, as described above, and total N released from ten grams of the product at each sampling time was calculated.

2.3. Model Development

Total duration for over 90% release of nutrients at 100˚C is in the range of several h or few d as compared to several d or months for similar magnitude of nutrient release at 25˚C. Therefore, a calibration between the nutrient release rates at 100˚C and 25˚C can be used to predict the nutrient release rate at 25˚C by measuring the release rate at 100˚C. This can be accomplished by the following steps:

Determine nutrient release rates in water for a given CRF product at 100˚C and 25˚C, until at least 80% to 90% of total nutrients are released at the respective temperatures.

Develop relationship between the cumulative nutrient release as percent of total nutrients in the product (Y) and time (X) at each temperature:

$$Y_1 = A_1 + B_1 X_1 + C_1 X_1^2 \quad [1]$$

where Y_1 = cumulative release at 100˚C; X_1 = release time (in h); A_1, B_1, and C_1 are constants

$$Y_2 = A_2 + B_2 X_2 + C_2 X_2^2 \quad [2]$$

where Y_2 = cumulative release at 25˚C; X_2 = release time (in d); A_2, B_2, and C_2 are constants.

From the above equations, we can calculate the time required for release of different percentages (P_1, P_2, P_3, P_4 and P_5 etc.) of total nutrients as Z_{21}, Z_{22}, Z_{23}, Z_{24} and Z_{25} etc. (in d) at 25˚C; and Z_{11}, Z_{12}, Z_{13}, Z_{14}, and Z_{15} etc. (in h) at 100˚C. Notice that the percent of total nutrient released is similar for a given pair of release times at two different temperatures, *i.e.*, Z_{21} and Z_{11}, Z_{22} and Z_{12} and so on.

Using the above paired values, we can then establish relationship between the nutrient release time at 25˚C as a function of that at 100˚C as follows:

$$Z_2 = P + MZ_1 + NZ_1^2 \quad [3]$$

where Z_2 = release time (in d) at 25˚C; Z_1 = release time (in h) at 100˚C;

P, M, and N are constants.

Therefore, once we know the release time at 100˚C for a given percent release of nutrients from an unknown CRF product, we can use equation #3 to calculate the release time at 25˚C for the same percent release.

3. Results and Discussion

3.1. Release Characteristics of Two CRF Products at 25˚C and 100˚C

At 100˚C (**Figure 1**), 100% of total N in PCU and PC_NPK was released in about 220 hours. In contrast, at 25˚C only 63.6% to 70.8% of total N from the above two products were released over a period of 220 d. At 100˚C, percent N release from PCU was generally greater than that from PC_NPK at any given time throughout the incubation, except the initial 7 h. At 25˚C, percent N release was greater from PCU than that from PC_NPK during first 100 d. Subsequently, however, the trend was reversed until the end of 216 d incubation period. The percent release of N increased at a rapid rate during the first 56 d at 25˚C, followed by a slow rate during the rest of incubation.

3.2. Predicting Total N release at 25˚C by Using Measured Release at 100˚C

The relationship between cumulative percent release of N and release time is described by quadratic or cubic functions both at 25˚C and 100˚C for both products (**Table 1**). The regression equations are highly significant with $R^2 > 0.98$. Using these regressions, the times required for a different percent release of total N were calculated at both 25˚C and 100˚C (**Table 2**).The Z_1 and Z_2 values for each CRF product were then used to establish regressions between release time at 25˚C as a function of that at 100˚C for each product (**Table 1**). These regressions were also highly significant with $R^2 > 0.998$.

3.3. Application of the above Model to Predict Total N Release at 25˚C

If we have an unknown coated product of somewhat similar coating characteristics, a fast release test can be conducted at 100˚C. The release time for a given percent of total N at 100˚C can then be used in either equation in **Table 1** (depending on PCU or PC_NPK) to predict the time required to release the similar percent of total N in soil at 25˚C. Thus, the nutrient release pattern at 25˚C can be predicted by using a fast nutrient release test at 100˚C within h or a few d.

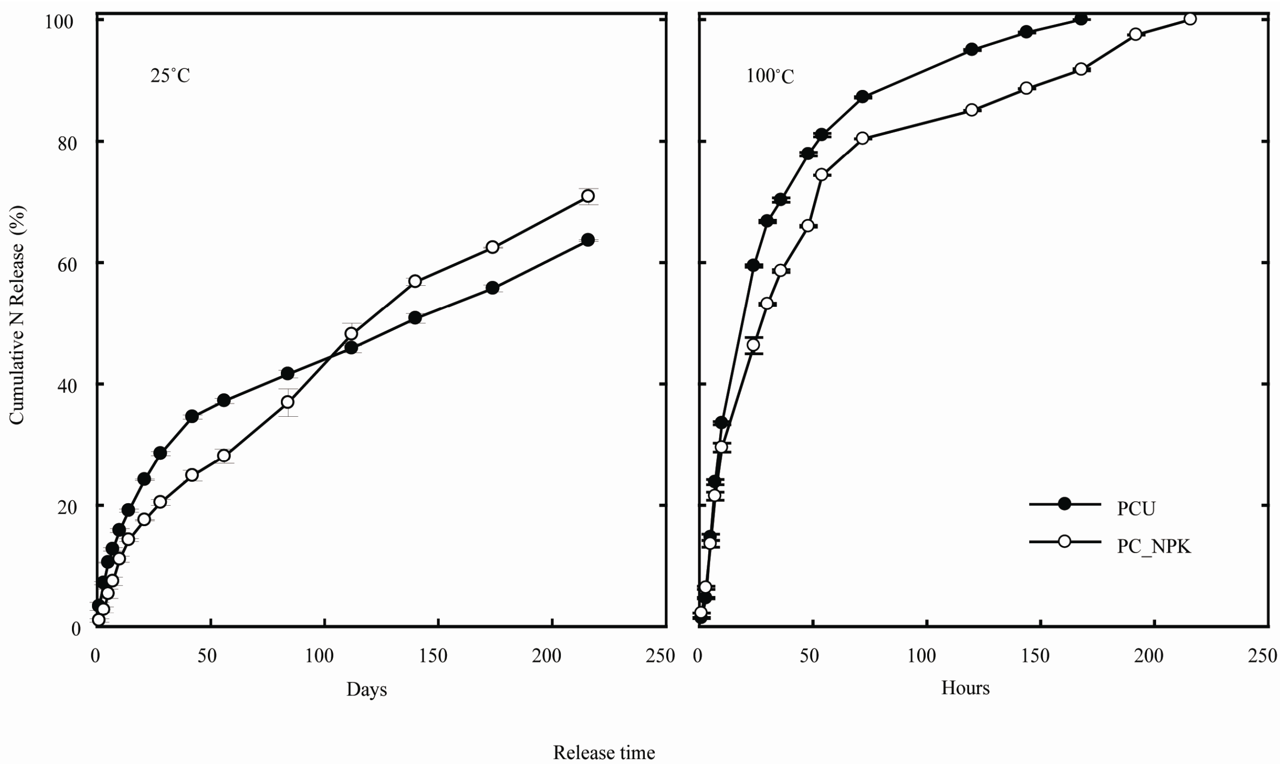

Figure 1. Cumulative release of nitrogen (N) as percent of total N from polymer-coated urea (PCU) and Polymer-coated N, phosphorus (P), potassium (K) product (PC_NPK) in water at 25˚C and 100˚C.

Table 1. Relationship between cumulative percent release of total nitrogen (Y_1 and Y_2) and time (in days (X_2) for 25˚C and in hours (X_1) for 100˚C), and equation for calculation of nutrient release at 25˚C using the release time at 100˚C for any given percent release.

Fertilizer	Temp.	Cumulative percent release of total N vs. time	R^2	Release time at 25˚C as a function of that at 100˚C	R^2
PCU	25˚C	$Y_2 = 6.381 + 0.874X_2 - 0.006X_2^2 + 0.00002X_2^3$	0.988	$Z_2 = -12.897 + 3.431Z_1 + 0.198Z_1^2$	0.998
	100˚C	$Y_1 = 3.446 + 2.618X_1 - 0.025X_1^2 + 0.00007X_1^3$	0.984		
PC_NPK	25˚C	$Y_2 = 4.408 + 0.492X_2 - 0.001X_2^2$	0.990	$Z_2 = -45.908 + 14.424Z_1 - 0.510Z_1^2 + 0.007Z_1^3$	0.998
	100˚C	$Y_1 = 5.471 + 1.920X_1 - 0.014X_1^2 + 0.00003X_1^3$	0.989		

PCU = Polymer-Coated Urea; PC_NPK = Polymer Coated N, P, K fertilizer; All regressions are significant at $P \le 0.001$.

Table 2. Calculated time (from Equations 1 and 2) for different cumulative release of N (as percent of total N) for two controlled release fertilizers.

Cumulative release of N (percent of total N)	Time required for respective release			
	PCU		PC_NPK	
	100˚C	25˚C	100˚C	25˚C
	h	d	h	d
10	3.4	4.5	4.4	9.6
20	6.7	14.5	6.9	27.6
30	9.0	31.2	11.1	64.9
40	13.4	73.6	19.3	92.1
50	20.1	136.1	27.7	116.9
60	25.2	198.5	37.7	160.0
	Z_1	Z_2	Z_1	Z_2

PCU = Polymer coated area; PC_NPK = Polymer coated N, P and K.

Unlike the past methods of prediction of nutrient release from CRF products, the method described in this study is rapid, reproducible, and requires no chemicals for extractions. This method also integrates the properties of coating material in determining the nutrient release at ambient temperature in the soil. No tedious extraction and analytical technique are required, except analysis of total N in the water. Therefore, the proposed method can be readily adapted by the fertilizer manufacturer or distributors for accurate labelling of the CRF release rate and duration.

4. Conclusions

This study demonstrated that 100˚C nutrient release test in water was useful for prediction of nutrient release rate and duration at 25˚C. Therefore, a quick test done at 7 to 10 d is useful to predict the CRF release characteristics at 25˚C.

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