Asian Journal of Chemistry; Vol. 26, No. 17 (2014), 5750-5754

ASIAN JOURNAL OF CHEMISTRY

http://dx.doi.org/10.14233/ajchem.2014.18201

Nutrient Release Characteristics and Use Efficiency of Matrix Slow-Release Fertilizer†

ZHI-WEN CHEN*, YAN-NAN SUN, JIE LI, QING ZHANG and HUI-SHI DU

Institute of Ecological Environment, Jilin Normal University, Siping 136000, Jilin Province, P.R. China

*Corresponding author: E-mail: sdczw4489@126.com

AJC-15786

A soil column method was used in the laboratory to simulate leaching from the soil tillage layer in order to investigate nutrient release characteristics in an uncoated matrix slow-release fertilizer. Furthermore, a field test was also performed to assess the nutrient use efficiency in maize crop soil. The first three leachings contained 42 % of the total N leached from the matrix slow-release fertilizer over the experiment's duration. However, the amount of N leached on each occasion maintained stability after the fourth leaching. Compared with 60 % of the total N leached from the ordinary fertilizer in the first three leachings, the leached amounts decreased on each occasion until the end of the experiment. The field experiment showed that the amount of soil available N was lower prior to the maize's eight-leaf stage with the matrix slow-release fertilizer than the amount available with ordinary fertilizer. But after this stage, it was higher than the amount available with the ordinary fertilizer. The cumulative N uptake by maize was similar for both fertilizers until the eight-leaf stage of maize, after which the N uptake was subsequently higher with the matrix slow-release fertilizer. Over the two year-long field trial, the benefits of using matrix slow-release fertilizer became obvious; when matrix slow-release fertilizer was applied, the maize yield was significantly higher. Moreover, multiple comparisons of variance analysis showed that this difference was significant.

Keywords: Uncoated, Matrix slow-release fertilizer, Soil column leaching experiment, Field experiment.

INTRODUCTION

An uncoated slow-release fertilizer (USRF) can be produced either by using additives or by a carrier that can change the water-soluble fertilizer's nature and thus slow its nutrients' release[1,2]. The production process for these fertilizers is both simple and inexpensive. If these fertilizers were market competitive and the technology was widely used, further technological developments would take place the nutrient use efficiency would be noticeably improved and the resulting environmental effects would be reduced. Previous developments include the expansion of the uncoated slow-release fertilizer technology by using a bonding, cementation process and by adding a synergist consisting of nitrogen-rich organic compounds and modified chemical fertilizers with different decomposition rates in the soil[3]. The uncoated slow-release materials include a nitrogen fertilizer synergist, which contains an urease inhibitor, nitrification inhibitors[4], modified natural organic matter and inorganic minerals[5]. Furthermore, modifying the non-metallic mineral montmorillonte alters its water absorption, plasticity, cohesiveness and ion exchange capacity, thus enabling the effective adsorption of water and nutrients, which in turn enhances crop growth and improve soil quality[6].

Compared with coated controlled-release fertilizer, the technological advances in uncoated controlled-release fertilizer developments have been significantly less advanced in technology, material innovation and application methods. Previously, medium or low concentrations of bentonite, zeolite powder and humic acid were added to fertilizers during application. While these compounds do affect fertilizer conservation and activation, the effects are limited without any further modification. Fertilizer complex has become increasingly favored by consumers, these three materials' application rates should be restricted. Modifying these materials is necessary for achieving the goal of minimizing the amount of material used while still obtaining a good effect. In this study, the matrix materials, namely the bentonite, zeolite powder and humic acid, were treated with carbonate and then mixed with chemical fertilizers (such as nitrogen, phosphorus and potassium) in defined proportions. A catalyst and binder were also added. The purpose of this research was to investigate the nutrients' physical and chemical properties in the modified fertilizers as well as determine their effect on the regulation of soil nutrient supply, dynamic nutrient balance, utilization rate of the fertilizer and food production rate.

†Presented at 2014 Global Conference on Polymer and Composite Materials (PCM2014) held on 27-29 May 2014, Ningbo, P.R. China

EXPERIMENTAL

Test time and location: Field tests were conducted in Gaojia, Lishu, Jilin Province from 2009 to 2010. The laboratory tests were conducted in the soil laboratories and meteorological laboratory at Jilin Normal University, China.

Fertilizer raw materials: The urea (containing 46.3 % nitrogen) was produced by Shanxi Fengxi Fertilizer Industry Co. Ltd. The monoammonium phosphate (containing 50 % phosphorus and 10 % nitrogen) was produced by Yunnan Red Phosphorus Chemical Co. Ltd. Potassium chloride (containing 60 % potassium) was obtained from Russia. The slow-release materials were composed of Jilin Liu Fangzi bentonite, Jilin Jiutai zeolite powder and Huolinhe humic acid with the addition of carbonate-modified agent A, catalyst B and adhesive C, all of which were purchased in the market. The added amount of modifier A was 1.5-2 % of the fertilizer amount. Material B was added as a catalyst at a rate of 0.2 % in the fertilizer. The soil was collected from Gaojian, Lishu Town in the Jilin Province. The basic agricultural soil properties were as follows: density, 1.1 g/cm^3; pH 6.9; organic matter content, 18.4 g/kg; nitrogen (N), 133.4 mg/kg; phosphorus (P), 10.7 mg/kg; and potassium (K), 162.5 mg/kg.

Fertilizer leaching test: The following three treatments were set up and then replicated four times: Treatment 1: No fertilizer; Treatment 2: Ordinary fertilizer N, P_2O_5 and K_2O at 600, 270 and 210 mg/kg, respectively; and Treatment 3: Matrix slow-release fertilizer (MSRF) with N, P_2O_5 and K_2O at the same rates as in Treatment 2. Soil columns were constructed according to Duan's method[7] but were packed with soil to simulate topsoil instead of sand. First, a filter cloth with 0.75 mm apertures was placed across the end of a plastic tube with a diameter of 4.5 cm and a height of 30 cm. Next, about 25 g of sand was placed onto the filter cloth at the bottom of the tube to prevent the washout of soil particles. Then, the tube was filled to a height of approximately 10 cm and a density of 1.1 g/cm^3 with 200 g of soil, which had been previously passed through a 2 mm sieve. Another 20 g of sand was added on top of the soil in order to prevent the soil surface from being disturbed when water is added. The soil columns for Treatments 2 and 3 were similarly prepared for the same density using 200 g of sieved soil mixed with fertilizer. Approximately 120 mL of water was added to the soil in each column to bring it close to saturation at the beginning of the test. Another 80 mL of water was added and the leachate from the columns was collected over the next 24 h. After the water was added, a plastic film with small holes was placed across the opening of the tubes to minimize evaporation and allow free drainage. The soil columns were allowed to drain to acclimatize for 3 d before leaching again with another 80 mL of water and the subsequent collection of the leachate over 24 h. This cycle of 1 d of leaching followed by a 3 d interval was repeated for a total of 30 d. The leachate samples were analyzed for their total N content and the N leached from the fertilizer treatments was calculated by subtracting the N leached from the treatment without fertilizer.

Field manure trial: For this trial, the following three treatments were set up and then replicated four times: Treatment 1: No fertilizer; treatment 2: Ordinary fertilizer with 200 kg/hm^2 N, 90 kg/hm^2 P_2O_5 and 70 kg/hm^2 K_2O; and Treatment 3: matrix slow-release fertilizer with N, P_2O_5 and K_2O at the same rates as in Treatment 2.

Experimental plots (7 m long by 6 m wide) were set up and cultivated to a depth of 15 cm; maize was then planted into the plots (Qiule Zhengdan 958) in rows 60 cm apart with 25 cm plant spacing. Fertilizer was applied at a rate of 182 kg/hm^2 N, 52 kg/hm^2 P_2O_5 and 52 kg/hm^2 K_2O, separated from the seeds by 10-12 cm at the time of cultivation and then again at a rate of 18 kg/hm^2 N, 38 kg/hm^2 P_2O_5 and 18 kg/hm^2 K_2O, separated from the seeds by 3 cm to 5 cm at the time of planting. Maize samples were taken from the middle four lines of each plot's harvest area at the following time points: the 8-leaf stage, 12-leaf stage, silking stage, 15 d after silking, 30 d after silking and from the mature stem, leaf and ear of the plants. Samples were dried at 105 and 80 ºC, weighed and then crushed for analysis. Soil samples were simultaneously collected from 20 cm below the surface. Four rows in the middle of each plot were taken at harvest season (the whole area is 12 m^2) and both sides were reduced by 1 m. The yield was then calculated and the seed quality was determined.

Test methods: Soil samples used for the leaching test were extracted with an alkali solution to determine the available N, 0.5 mol/L $NaHCO_3$ to determine the available P and 1 mol/L ammonium acetate to determine the available K. The chromium powder reduction distillation method (with hydrochloric acid heating) was used to determine the total N in the leached solutions. Maize samples from the field trial were digested with H_2SO_4-H_2O_2 and the digests were analyzed for N, P and K using the Kjeldahl method, colorimetric method and atomic absorption, respectively[8-12]. Deionized water and analytical grade chemicals were used for the entire test.

Both ANOVA and determination of the test data's statistical significance were carried out using SPSS (v. 17.0) statistical analysis software.

Nitrogen use efficiency (NUE) calculation: The NUE of the maize plants was calculated using the following equation: NUE (%) = [(Plant uptake of nitrogen treatment – Plant uptake of no fertilizer treatment)/Nitrogen applied] × 100 %.

Nitrogen leaching: As illustrated in Fig. 1, the amount of N that leached from the matrix slow-release fertilizer (Treatment 3) resulted in a slow downward trend over the first three leachings. These results accounted for about 42 % of the total N leached over the experiment's duration. The amount of N that leached from the ordinary fertilizer (Treatment 2) was significantly higher in the first two leachings; in fact, this fertilizer's first three leachings accounted for 60 % of the total N leached. The amounts of N in the first three leachings from Treatments 2 and 3 were similar to each other. From the first four leachings onward, the amounts of N that leached from Treatment 3 remained constant, whereas the amounts of N that leached from Treatment 2 steadily decreased until the trial's completion. The leaching of N from the matrix slow-release fertilizer was significantly lower than that of the ordinary fertilizer in the first two leachings but was significantly higher than that of the ordinary fertilizer. These results show that the matrix slow-release fertilizer has superior advantages. It could reduce N leaching as well as provide a stable supply of N for a longer period than ordinary fertilizer.

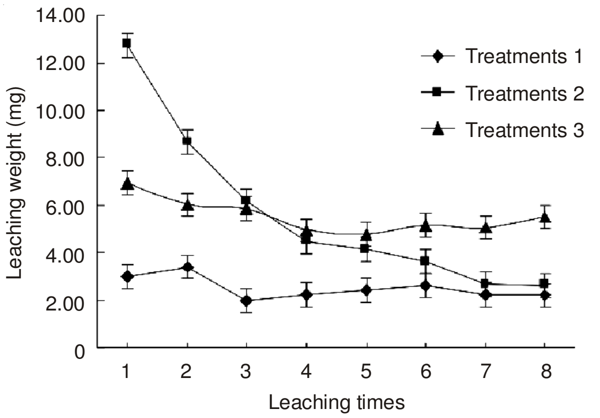

Fig. 1. Graphs of fertilizer leaching change under different treatments

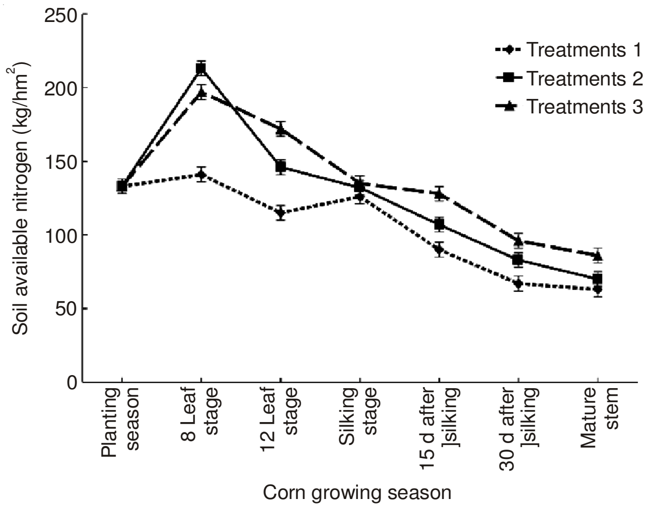

Fig. 2. Changes in the soil available nitrogen in different fertilizer treatments under corn in 2009

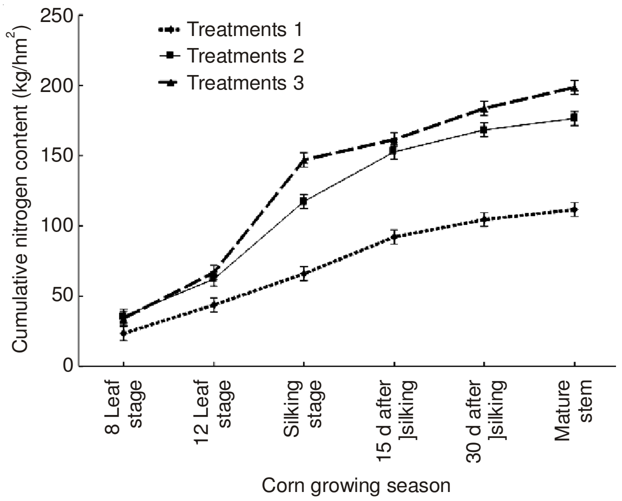

Fig. 3. Cumulative changes in corn's nitrogen content in different fertilizer treatments in 2009

Uptakes of N, P and K by maize: The results indicate that nutrient uptakes of N, P_2O_5 and K_2O in both the seed and stem were significantly higher when matrix slow-release fertilizer was applied (Treatment 3) rather than ordinary fertilizer (Treatment 2) (Table 1). In the maize grain, the nutrient uptake of N, P_2O_5 and K_2O over the trial's two years was higher in Treatment 3 than in Treatment 2 by an average of 9.03, 4.70 and 3.66 kg/hm^2, respectively. In the maize stalks, the nutrient uptake of N, P_2O_5 and K_2O over the trial's two years was again higher in Treatment 3 than in Treatment 2 by an average of 12.92, 5.27 and 1.00 kg/hm^2, respectively. Finally, in the whole maize plants, the nutrient uptake of N, P_2O_5 and K_2O over the trial's two years was also higher in Treatment 3 than in Treatment 2 by an average of 21.95, 9.97 and 4.66 kg/hm^2, respectively.

Fig. 2 shows that the available nitrogen in the soil changed slightly between planting and silking in Treatment 1. The absorbed nutrients increased during maize growth. The available nitrogen in the soil decreased until late silking but then stabilized until the corn reached maturity. The soil available nitrogen content in Treatments 2 and 3 peaked when the maize reached the 8-leaf stage. As the maize absorbed the nitrogen, the soil available nitrogen content consequently decreased. For each of the maize's growth stages, except for the sowing and 8-leaf period, the soil available nitrogen content in Treatment 3 was significantly higher than in Treatment 2.

Treatment 3's sustained-release effect extended the period over which the N was available to the growing corn plants. This finding indicates that nitrogen was being released and made available precisely when the maize required many nutrients in order to maintain a high growth rate in the late growth stages. The maize's cumulative nitrogen content in different growth stages and treatments is shown in Fig. 3. Compared toTreatment 1, fertilization significantly increased N uptake by the maize. The N uptake in Treatment 3 was significantly higher than that in Treatment 2 after the 8-leaf stage. This result shows that the slow release of N in Treatment 3 lead to an increase in the N uptake by the maize in the middle and late stages of growth and thus improved the efficiency of the use of nitrogen fertilizer.

Maize production in the field experiment: The values for maize production in the field experiment are shown in Table-2. In 2009, 10,337 kg/hm^2 of maize were produced in Treatment 3, which was 10.8 % higher than the 9,328 kg/hm^2 produced in Treatment 2. In 2010, 10,408 kg/hm^2 of maize were produced, which was 10.3% higher than the 9,434 kg/hm^2

TABLE-1
DIFFERENT CORN TREATMENTS ASSIMILATE DIFFERING AMOUNTS OF NITROGEN, PHOSPHORUS AND POTASSIUM (kg/hm^2)

Test years	Treatment	N			P_2O_5			K_2O		
		Seed	Haulm	Sum	Seed	Haulm	Sum	Seed	Haulm	Sum
2009	1	76	35	111	44	35	79	24	86	110
	2	120	56	176	53	44	97	34	111	145
	3	130	69	199	58	49	107	38	112	150
2010	1	77	36	113	42	35	77	24	87	111
	2	121	57	178	53	44	97	34	112	146
	3	130	70	200	58	49	107	38	113	151

TABLE-2
MAIZE YIELD IN DIFFERENT TREATMENTS

Treatment	2009			2010			Average (kg/ hm²)
	Yield (kg/ hm²)	Increase (%)		Yield (kg/ hm²)	Increase (%)		
		Treatment 1	Treatment 2		Treatment 1	Treatment 2	
Treatment 1	6946	–	–	6807	–	–	6877
Treatment 2	9328	34.29	–	9434	38.59	–	9381
Treatment 3	10337	48.82	10.82	10408.	52.90	10.32	10372

produced in Treatment 2. Statistical analysis of the data showed that the differences between the treatments were highly significant in both years and no significant differences were observed between the two years or between the replicates. Over the trial's two years, the average maize yield was 991 kg/hm^2, which was 10.6 % higher when matrix slow-release fertilizer, rather than just ordinary fertilizer, was applied.

The results of the statistical analysis for maize production in the field experiment data are shown in Table-3. Significant differences were noted between different treatments, which indicates that the compound had good sustained nutrient release properties and consequently had significantly improved the maize yield.

RESULTS AND DISCUSSION

Lu *et al.*[9] used a polymer that incorporated fertilizer swelling and blending to prepare a hybrid slow-release fertilizer that had better release characteristics than ordinary fertilizer. Furthermore, Zhang *et al.*[10] used 10 types of organic and inorganic stromal to prepare a stromal fertilizer and then studied its release characteristics using a sand leaching method. This demonstrated the slow-release effect of oxidized starch and lignin in an organic matrix and the even slower release properties of bentonite in inorganic stromal. In the present study, we produced a compound of bentonite, zeolite powder and humic acid with modified nutrient physical and chemical properties. Both the soil column leaching trial and the maize field trial demonstrated that the compound had good sustained nutrient release properties and thus significantly improved the maize yield.

The matrix slow-release fertilizer particles that were used in this study had large surface area and pore volume. Furthermore, the material had strong adsorption properties and could retain ammonium and potassium ions. Thus, when matrix slow-release fertilizer was applied to the soil, the available soil N retained a steady state. This finding corresponded to how the crops required more fertilizer at the early development stages but less at the later stages[6].

In the early stages of maize growth, the available nitrogen in the soil for the plants in Treatment 3 was low, which reduced nitrogen loss. Conversely, nutrients were rapidly released into the soil from the ordinary fertilizer in Treatment 2. At the 8- and 12-leaf stages, the nitrogen contents of the two treatments were similar to one another. The maize plants' nitrogen content in Treatment 3 was significantly higher than in Treatment 2 after the 12-leaf stage. When matrix slow-release fertilizer was used in the middle and last stages of maize growth (the stages in which the plants require more nitrogen), more nitrogen was available and taken up and, therefore, utilized by the plants. This coordination between the soil supply and the demand from the plants improved the use of nitrogen and lead to an increased maize production[11].

In the fertilizer leaching trial, the leachate contained the following nitrogen compounds: amide, ammonium and nitrate. Analysis of these compounds involved reducing nitrate to ammonium using chromium powder and hydrochloric acid. Additionally, amide was converted to ammonium using sulfuric acid and catalyst. The total ammonium was then measured by adding sodium hydroxide and distilling the sample[10]. The distillate was trapped in sulfuric acid and then titrated with sodium hydroxide[13].

The absorption characteristics of nitrogen, phosphorus and potassium into the corn revealed the superiority of matrix slow-release fertilizer in growing more desirable plants. The results revealed that the regulated release process of nutrients from matrix slow-release fertilizer could improve maize growth compared to using just ordinary fertilizer, thereby providing more luxuriant plants and a higher grain yield.

ACKNOWLEDGEMENTS

This research is supported by the National Science and Technology Research during the 12th Five-Year Plan Period (No. 2013BAD07B02) and the Technology development project of Jilin Province (No. 20100213).

TABLE-3
STATISTICAL ANALYSIS FOR THE MAIZE YIELD UNDER DIFFERENT TREATMENTS

Variation	Sum of squares	df	Variance	F	P
Correction model	5.212×10^7	6	8686343.924	160.855	0.000
Intercept	1.891×10^9	1	1.891×10^9	35022.918	0.000
Treatment	5.193×10^7	2	2.596×10^7	480.809	0.000
Replicate	188855.615	3	62951.872	1.166	0. 352
Interannual	918.844	1	918.844	0.017	0. 898
Deviation	918016.448	17	54000.968	–	–
Sum	1.944×10^9	24	–	–	–
Total correction	5.304×10^7	23	–	–	–

REFERENCES

1. N. Xiaoyu, W. Yuejin, W. Zhengyan, W. Lin, Q. Guannan and Y. Lixiang, *Biosystems Eng.*, **115**, 274 (2013); .
2. L.H. Xie, M.Z. Liu, B.L. Ni, X. Zhang and Y. Wang, *Chem. Eng. J.*, **167**, 342 (2011); .
3. Y. Dong and Z.Y. Wang, *Scientia Agric. Sinica*, **39**, 960 (2006).
4. L. Fu, Y.L. Shi, Z. Su and L.L. Wang, *Chinese J. Soil Sci.*, **42**, 923 (2011).
5. P.X. Wu, Z.W. Liao and X. Feng, *Acta Petrolog. Mineral.*, **22**, 442 (2003).
6. Z.W. Chen, Q. Zhang and X.Q. Li, *J. Agro-Environ. Sci.*, **24**, 158 (2005).
7. P. Duan, *Phosphate Compound Fertilizer*, **15**, 21 (2000).
8. R.K. Lu, Methods of Soil and Agrochemistry Analysis, Chinese Agricultural Science and Technology Press, Beijing (2000).
9. Q.M. Lu, X. Feng, K.J. Sun et al., *Plant Nutrition Fertilizer Sci.*, **25**, 62 (2009).
10. X.D. Zhang, C.Y. Shi, X.Y. Sui and X.G. Cheng, *Trans. CSAE*, **25**, 62 (2009).
11. C. Hu, Z.P. Cao, J. Hu and S.L. Li, *Acta Ecol. Sin.*, **29**, 2080 (2009).
12. GB/T8572-2001, Test Methods of Evaluating the Properties of Wood-Based Panels and Surface Decorated Wood-Based Panels.
13. HJ 636-2012, The Technical Guide for Printing and Publishingo Environmental Standard.