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Nitrogen Release Characteristics of a Bag Controlled Release Fertilizer

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ABSTRACT

Slow release fertilizers are designed to enhance crop yield and minimizing the loss of nitrogen (N) to environment. However, N release in leaching and loss in ammonia emission from bag controlled release fertilizers have not been previously evaluated under the standardized conditions in soil. Accordingly, a laboratory study was conducted to evaluate the characteristics of N release from a bag controlled fertilizer with 1, 3, 5 and 7 rows of hole (B-1, B-3, B-5, B-7) and a kraft bag without hole (B-W). The results showed that the amount of N leaching of B-1, B-3, B-5, B-7 and B-W were significantly lower than urea fertilizer without bag (U). The maximum N release from the fertilizers followed the order: U (83.16%) > B-7 (54.61%) > B-5 (54.02%) > B-W (51.51%) > B-3 (48.87%) > B-1 (38.60%) during the experimentation. Compared with U treatment, ammonia volatilization losses were significantly decreased by B-1, B-3, B-5, B-7 and B-W treatments. Based on N release and loss, a suitable bag with holes should be considered in practice when using the bag controlled fertilizer to meet an environment good objective. The evaluation method merits further study combined with field experiment.

1. Introduction

Fertilizers are materials, which have been used widely as nutrients for plant growth^[1]. At the present, fertilizers are the necessary input material for the sustainable development of crop yield. Urea is one of the most important groups of inorganic N fertilizer used in agriculture all over the world due to its relatively low prices compared to other N fertilizers^[2]. When urea is applied to the soil surface without any incorporation, significant losses by volatilization may occur, reaching average values of 30% of the total applied N^[3]. In addition, nitrogen leaching has also become an important limitation

to improving the utilization efficiency of nitrogen in agricultural production. Nitrogen loss can both directly cause economic loss and pollute the environment, resulting in the eutrophication of surface water, excess nitrate content of groundwater and an increase in nitrous oxide release due to the misusing of chemical fertilizers in certain area.

To minimize ammonia (NH₃-N) losses of urea and maintain an adequate availability of N in soil, different strategies related to the best practices for the efficient use of fertilizers and fertilizer technologies can be used^[4-6]. The application of controlled-release fertilizers (CRF) proves to be an effective way to prevent environmental problems and reduce nutrient losses, and controlled-re-

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lease fertilizers (CRF) can make nutrient gradually release to match the nutrient requirement of plants.

Bag controlled release fertilizer is a new pattern fertilizer that changed the design idea of the grain coat of common controlled release fertilizer, and used a controlled-release bag instead to achieve controlled fertilizer release [7]. In its main method of manufacture the integrated fertilizer is enclosed into the composite paper and plastic sack and sealed. The bag is punctured with needles to generate micro-holes, which serve as points of control to achieve a controlled nutrient emission rate that will meet the nutritional requirements of plants. Compared with other types of controlled-release fertilizer, the technical process of bag-controlled release fertilizer is simple and its cost is low, making its development and utilization over large acreage favorable. However, there is still little research on bag controlled release fertilizer.

The objectives of this study were (1) to detect nitrogen release characteristics of bag controlled release fertilizer in soil incubation, and (2) to investigate the potential capability of bag controlled release fertilizer to retain ammonium nitrogen and decrease inorganic nitrogen loss, (3) to determine to what degree N volatilization can be controlled by bag controlled release fertilizer compared to water-soluble urea. The results of this study will provide practical information to guide the exploitation of a novel slow release fertilizer to improve nitrogen utilization efficiency in agricultural applications.

2. Materials and Methods

2.1 Tested Soil Properties and Bag Controlled Fertilizer

The soil was collected from the field of Zhejiang Agriculture and Forestry University, Hangzhou city of Zhejiang, China (119°43'12"E, 30°13'48"N). Collected soil samples from the top layer (0–20cm) were air-dried and sieved to < 2mm before use. The soil is a red-yellow clay soil and has the following chemical properties as soil organic matter (SOM) 0.32%, pH 4.56, total nitrogen 0.84g.kg⁻¹, available potassium 65.96 mg.kg⁻¹, and Olsen-phosphorus 77.55 mg.kg⁻¹. In this study, the bags used in the controlled fertilizer were treated with various holes (Figure 1). The size of bag was 5 cm × 4 cm. The diameter of each hole was 0.2 mm and the interval of holes was 0.5 cm. The number of holes per row was 3. The mass of urea inside bag was 2g. The corn starch bag with holes in 1, 3, 5 and 7 rows marked as B-1, B-3, B-5 and B-7, respectively. Kraft paper bag coated with wax was marked as B-W. Urea (U) in same amount without bag was compared with other fertilizer treatments and soil without fertilizer was

set as control (CK).

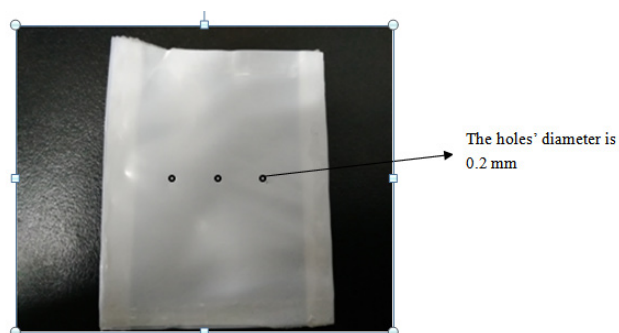


Figure 1. The bag of bag controlled release fertilizer

2.2 Leaching Experiment

The leaching column technique as described by Stanford and Smith [8] and Alva and Gascho [9] were employed in this study. The study was conducted in a greenhouse at 25 ± 2°C under intermittent leaching-incubation conditions. Columns were made from plexiglass with a size of 30 cm in length and 11.5 cm in diameter. Clean quartz sand and a slow-filtering screen ($\Phi \approx 58 \mu\text{m}$) were positioned at the end of the incubation chamber to avoid mixing clay and soil solution. The columns filled with 500g soil, and the top sealed with plastic film were positioned vertically on the 1L beaker. A 920 mg N sample of bag controlled release fertilizer or urea was placed to 3 cm below the soil surface. There was 75 g clean quartz on the top of soil for preventing water from splashing. Before starting the nitrogen leaching experiment, 200 g distilled water was added into the column to make the soil saturated. At the 2nd day the distilled water was applied to 75% of soil saturated water content ($\approx 150\text{mL}$) in each column. There was a beaker (1L) placed below the bottom of column to receive leachate. The leaching was made at an interval of 5 days during the experimentation.

2.3 Ammonia Volatilization Experiment

Soil samples (500g) were placed into incubation chambers (1L). Fertilizers were applied at a rate of 1.64 g N.kg⁻¹ in the center of the incubator and 1.5 cm into the soil where 150 mL distilled water was added. After application of fertilizer, the incubators with NH₃ collectors were placed in a greenhouse where the air temperature measured were 25 ± 2 °C. There were 50 mL plastic bottles with 20 mL 20 g.L⁻¹ Boric acid solution placed inside the collectors to capture NH₃(g) as NH₄⁺. When the solution became green, the small plastic bottle was taken away and replaced by new one. The experiments consisted of a randomized block design with three replications. There are seven

treatments comprising six fertilizers and a control without N. The intermittent leaching incubation and ammonia volatilization incubation times ranged from 1 day to 47 days and from 1 day to 57 days. The pH of the leachate and soil solution extracts (SS) and electronic conductivity (EC) from leach were determined. The total-N and $\text{NH}_4^+\text{-N}$ concentrations, as well as $\text{NO}_3\text{-N}$ concentration in the soil and the soil solution, were measured [10,11]. The collected boric acid solution was titrated by HCl (0.1M).

2.4. Statistical Analysis

Analysis of variance (ANOVA) and mean separation tests (Duncan's multiple-range test and the least significant difference test) were performed using Statistical Product and Service Solution (SPSS) version 19.0. The figures shown in this article were generated using Sigma Plot 12.5 and Microsoft Excel 2010.

3. Results

3.1 pH of Leachate

pH of leachate from different treatments by the intermittent leaching incubation was shown in Figure 2. As for the control of soil, pH increased from slightly the initial to final stage during the incubation. pH of the urea treatment had the highest value as 9.0 in the first time of leaching and showed a relative stable value at the rest time. The treatment of B-W also had a higher pH firstly and slight increased to a relative stable value. Other treatments of B-1, B-3, B-5 and B-7 had a similar initial pH about 4.76 as the control, and then increased with time. However, the increase rate with time was dependent on the rows of hole in the bag. More rows of the bag, much faster the pH increased with time.

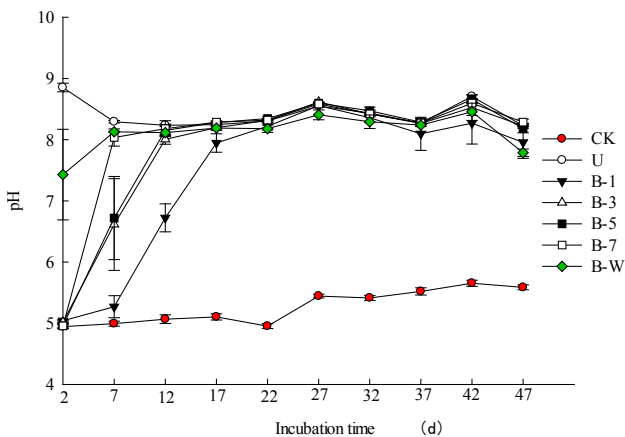


Figure 2. pH of leachate varied with incubation time

3.2 Electronic Conductivity of Leachate

As shown in Figure 3, EC of the control decreased with the incubation time. All other treatments showed a peak shape of EC with time. The urea treatment and B-W had the first peak time at the 7th day (first time of leaching). The peak time of other treatments increased with the holes in bag from 2 to 22 days.

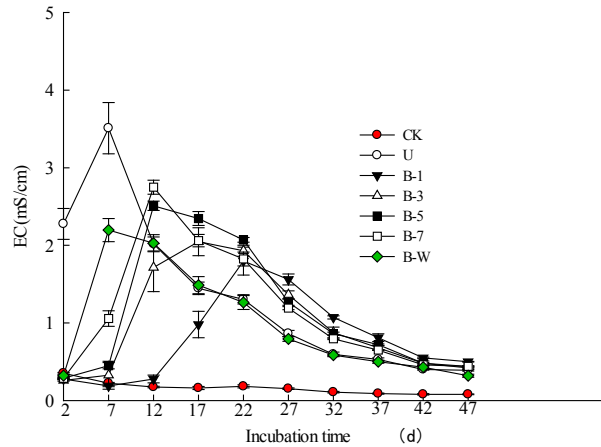


Figure 3. Electronic conductivity of leachate varied with incubation time

3.3 Ammonium Nitrogen in Leachate

The variation of concentration of $\text{NH}_4^+\text{-N}$ in the eluent from the six fertilization treatments was consistent throughout the leaching process (Figure 4). In the first week of leaching, the concentration of Urea treatment was the highest followed by B-W treatment. After 7 days, $\text{NH}_4^+\text{-N}$ concentration in the eluent of treatments of B-1, B-3, B-5, B-7 and B-W was higher than that of urea treatment. The concentration in the eluent of those treatments showed a trend of peak shape with time, and the peak time had a certain delay with the hole number on the bag.

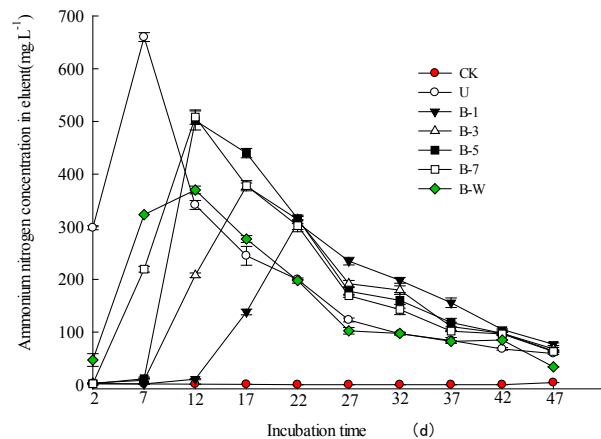


Figure 4. $\text{NH}_4^+\text{-N}$ concentration of leachate varied with time

3.4 Nitrate Nitrogen in Leachate

The nitrate (NO₃⁻-N) concentration in leachate from fertilization treatments showed a fluctuation with time but their trend of variation was similar (Figure 5). In this experiment, the nitrate concentration was lower than the ammonium concentration in the leachate.

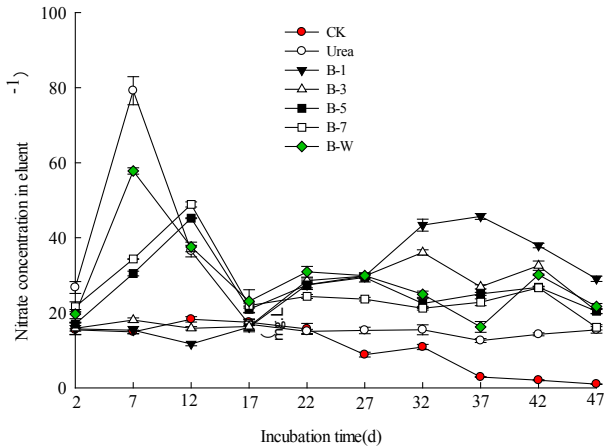


Figure 5. NO₃⁻-N concentration with time in leachate

3.5. Total Nitrogen in Leachate

Total nitrogen in leachate with time from all treatments was present in Table 1. Obviously, total nitrogen in leachate decreased with time in all treatments. However, there was a peak shape with time in all treatments. The trend of total nitrogen was similar with the ammonium because ammonium was the major N form in leachate. At the first time, total nitrogen leached from U, B-1, B-3, B-5, B-7 and B-W were 23.38%, 0.98%, 0.94%, 1.07%, 1.13%, and 2.69%, respectively.

Table 1. Nitrogen release rates for different fertilizer treatments

Treatment Leaching event	Total nitrogen release rate (%)					
	U	B-1	B-3	B-5	B-7	B-W
1	23.38 a	0.98 b	0.94 b	1.07 b	1.13 b	2.69 b
2	23.65 a	0.51 e	1.80 de	2.62 d	5.40 c	13.21 b
3	11.38 b	1.37 e	3.58 de	9.12 c	14.34 a	11.83 b
4	8.47 c	3.58 d	14.32 a	14.6 a	11.10 b	7.50 c
5	4.98 cd	5.83 bc	8.60 a	9.84 a	6.81 b	3.95 d
6	3.31 d	8.52a	6.59 b	5.39 c	4.90 c	3.38 d
7	2.35 d	6.02a	4.51 b	3.83 bc	3.56 c	2.30 d
8	2.88 cd	4.56a	4.38 a	4.26 ab	3.74 abc	2.78 d
9	1.04 d	4.37a	2.01 b	1.37 cd	1.71 bc	2.10 c
10	1.72 c	2.86a	2.14 b	1.92 bc	1.92 bc	1.77 c
Total	83.16 a	38.60 d	48.87 c	54.02 b	54.61 b	51.51 bc

Note: *Letters indicate the significant difference at 5% level.

According to the result of N release from bag fertilizers, the cumulative N released with time could be fitted

by Logistic equation: $N = \frac{a}{1 + e^{-k(t-t_c)}}$, where *a* is the maximum cumulative N release (mg), *k* is the N release rate constant (*d*⁻¹), *t* is the incubation time (*d*), and *t_c* is the time at the inflection point (*d*).

Table 2. Parameters of Logistic equation of total N accumulation with time

Parameter Treatment	a	t _c	k	R ²
U	78.06	6.79	0.243	0.954**
B-1	39.45	27.07	0.156	0.998**
B-3	52.02	20.52	0.189	0.995**
B-5	51.64	17.41	0.200	0.993**
B-7	51.73	15.39	0.189	0.987**
B-W	47.67	11.64	0.199	0.975**

Note: ** indicates significant difference at 1% level (n=11)

3.6 Ammonia Volatilization

Ammonia volatilization occurred at the first day when urea was applied to soil and the volatilized rate of U treatment was much greater than other treatments (Figure 6). After three days, ammonia volatilization occurred in the B-W treatment. Other treatments had delayed time in occurrence of ammonia volatilization as B-1, B-3, B-5 and B-7. There was almost no ammonia volatilization detected from the control of soil. The rate of ammonia volatilization from B-1, B-3, B-5, B-7, and B-W to control were 23.78%, 18.21%, 16.82 %, 13.46% and 17.81%, respectively (Figure 7). B-7 treatment had the least ammonia volatilization rate.

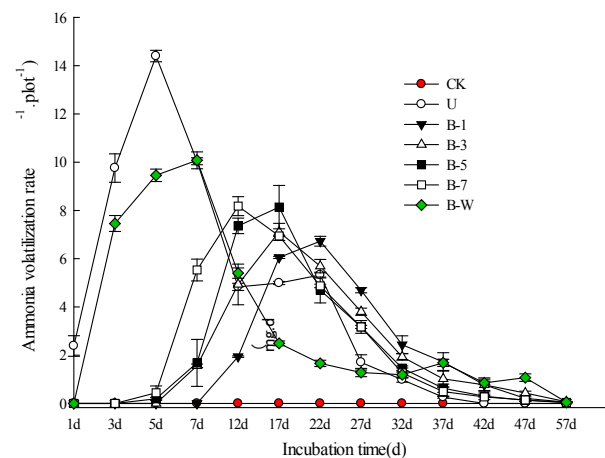


Figure 6. Ammonia volatilization rates with time in soils. Vertical lines at each data point represent the standard error of the mean

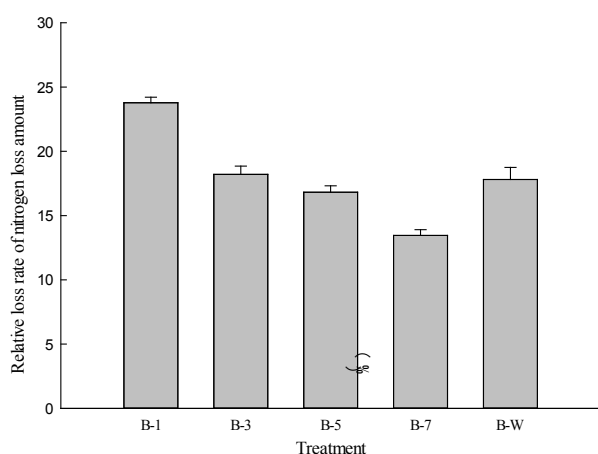


Figure 7. Percentage of ammonia volatilization from treatments to the control

The ammonia volatilization from all treatments with time could be fitted well by a non-linear equation of first-order kinetics: $N_t = N_0(1 - e^{-kt})$, where a is the maximum cumulative ammonia volatilization (mg), k is the ammonia volatilization rate constant (d^{-1}), t is the incubation time (d). The parameters were listed in Table 5.

Table 5. First-order kinetic equation parameters of cumulative nitrogen loss amount from ammonia volatilization

Parameter Treatment	N_0 (mg)	$k(d^{-1})$	R^2
U	170.75	0.074	0.989**
B-1	275.43	0.013	0.911**
B-3	204.93	0.023	0.930**
B-5	178.94	0.031	0.923**
B-7	157.11	0.060	0.949**
B-W	135.31	0.065	0.990**

Note: ** indicates significant at $P < 0.01$ level ($n=13$)

4. Discussion

Evaluating the N of leachate released from fertilizers is crucial in determining the most effective release patterns and chemical reactions that affect N use efficiency of urea fertilizers under field conditions. In this study, N released from the various bag fertilizers was determined. Electrical conductivity (EC) and pH were determined as well. The results showed that the electrical conductivity of leachate showed as a peak shape with time of all treatments. Such a result was consistent with the similar studies [12,13]. However, the variation of pH with time was not the same as those reported that might be a high amount of fertilizer and different soil used in this study.

Ammonium nitrogen is an important form of N loss under leaching conditions [14]. The direct use of urea in soil could result in a rapid release of urea in leachate and showed a sharp increase in pH and conductivity in the first time of leaching. Differently with the U treatment, the bag-controlled slow-release urea (B and B-W) could delay the release of N and reduce the leaching rate in the beginning stage. Compared with ammonium N, nitrate N in leachate was lower because there was a high pH value of leachate that is not suitable for the growth of nitrifying bacteria [15]. At the same time, the high concentration of ammonium could also limit the nitrification reaction, which was consistent with the study of Lv et al. [16].

The product of urea hydrolysis by urease enzyme is ammonium (NH_4^+) that can remain in the soil solution or be retained by the soil. The chemical change from NH_4^+ in the soil solution can diffuse to the atmosphere by ammonia volatilization [17]. Under a favorable environmental condition, N of broadcast urea-based fertilizer may lose 30 to 50% of applied N [18-20], and sometimes, as high as 60% [21]. The largest losses for NH_3 volatilization for urea occurred between 1 day and 7 days after application that was in agreement with other reports [22,23]. According to Junejo et al.(2011), the highest percentage of ammonia losses was determined by the soil's pH and microbial activity [24]. When the fertilizer disconnected with soil, ammonia volatilization could be avoided. Our results showed that N loss from ammonia volatilization could be reduced after urea was accommodated in a bag. Junejo et al. (2011)also reported when urea was encapsulated with the coating material, it delayed its reaction in the soil, which positively affected its losses from the soil. The ammonia release from bags had a high solubility in water that could be absorbed by the paper with strong water absorption performance from the B-W treatment. That was the main reason of B-W showed a different pattern of ammonia volatilization from other bag-controlled release fertilizer treatments.

The pattern of various bag control release fertilizers in N release was related to the hole-number on the bag. The less number could delay N release through leaching and ammonia volatilization. Accordingly, it could be a simple and reliable method to adjust the hole number on bag to meet the nutrient demand by plant growth [25]. Simultaneously, N loss can be reduced when using a suitable bag control release fertilizers.

5. Conclusions

The current work verified distinct release patterns of N from bag controlled release fertilizer, which changed the N dynamics in the soil. The maximum N released

by leaching from the fertilizers followed the order: U (83.16%) > B-7 (54.61%) > B-5 (54.02%) > B-W (51.51%) > B-3 (48.87%) > B-1 (38.60%). Fertilizer bagged could effectively decrease and delay NH₃ emission. Accordingly, the method of fertilizers with bag control was a potential measure in practice. Moreover, the bag controlled release fertilizers merit further study to develop strategies in different soil, climate, and cropping systems for decreasing N losses and improving N-uptake efficiency.

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