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ORIGINAL ARTICLE

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Utilization of waste paper for an environmentally friendly slow-release fertilizer

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Abstract To help address the physical, chemical, and biological degradation of agricultural soils resulting from indiscriminate use of chemical fertilizers, we developed a slow-release fertilizer from waste paper and urea. This approach has the advantage of a slow-release fertilizer in that it avoids surface runoff or leaching of nutrients, while providing an excellent medium for the recycling of waste paper. The successful impregnation of urea into waste paper was confirmed by scanning electron microscopy. This study also evaluated the release patterns of N from impregnated waste paper using a simulated soil solution and distilled water as leaching solutions. The release patterns of N were examined in both static and continuous-flow conditions for 720 h. Release of N from impregnated waste paper was found to be slow and steady, although the release rate of N was lower in distilled water than soil solution under both conditions.

Key words Waste paper · Slow-release fertilizer · Urea · Impregnation

Introduction

Environmental pollution resulting from fertilizer losses, industrial wastes, and domestic waste is one of the biggest problems facing the human race. Much concentrated effort is being put into solving this problem on a worldwide basis in advanced and less advanced countries. Mismanagement of fertilizer used in conventional agriculture is a well-known inefficiency of plant nutrient use, which leads to financial losses for farmers, poses a risk to the environment, and represents a waste of energy.[1,2]

In what might be considered an unrelated problem, waste paper is one of the major recyclable materials even though there is a severe lack of waste paper for papermaking worldwide. The development of slow-release fertilizer by using waste paper will contribute to proper management of fertilizer and reduce environmental pollution. In addition, application of waste paper for N fertilizer could provide high crop yields while also reducing N leaching losses, possibly due to N immobilization after use of waste paper.[3] Slow-release fertilizers are excellent alternatives to soluble fertilizers. Because nutrients are released at a slower rate throughout the season, plants are able to take up most of the nutrients without waste by leaching. A slow-release fertilizer is more convenient, because less frequent application is required. Fertilizer burn is not a problem with slow-release fertilizers even at high rates of application; however, it is still important to follow application recommendations. In the past two decades, several types of slow-release fertilizer have been developed and tested.[4]

There are 16 essential nutrients required for plant growth. Among them, N, P, K, Ca, Mg, and S are macro nutrients and the others are considered micro nutrients.[5] In particular, N fertilization is considered a main source of N_2O and NO emission from agricultural soils.[6–9] The most widely used N fertilizer is urea, which accounts for about 40% of the total global N application. Although urea has greatly contributed to the increase in crop productivity that subsequently alleviates food shortages around the world, considerable and rapid loss of applied urea has led to serious air and water pollution. It has been a great challenge to enhance urea efficiency without any adverse effects on the environment.

Urea decomposition in soils is mediated by various physical and chemical factors such as sunlight and high temperature. Its reaction products, CO_2 and NH_3, are rapidly volatized into air unless they are captured by soils and plants. Subsequently, urea efficiency as a N fertilizer greatly

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Table 1. Chemical components of slow-release N fertilizer made from waste paper

N (%)	P (%)	K (%)	Ca (%)	Mg (%)	As (mg/kg)	Cd (mg/kg)	Cr (mg/kg)	Cu (mg/kg)	Pb (mg/kg)	Zn (mg/kg)
28	0.05	0.02	0.58	0.20	ND	ND	18.1	151.0	10.3	54.8

ND, not detected

depends on agricultural practices like timing and method of fertilization and cropping systems.[9] These kinds of practices are difficult to conduct mainly because of economical aspects such as high labor costs. However, recent attention has focused on development of slow-release fertilizers mostly from urea. This approach has been compromised by two persistent drawbacks; it is extremely difficult to control the nutrient release property for time-dependent crop demand, and there is still doubt over compatibility with natural environments. Urea has been the most preferred nitrogen fertilizer with fast effectiveness. To our knowledge, there are no alternative nitrogen fertilizers to date. Therefore, it is highly desirable to prevent urea from undergoing rapid loss from soils without any influence on its fast effectiveness. This would lead to improvement of urea efficiency and consequently to reduction of nutrient losses from agricultural soils.

By impregnation of urea fertilizer into waste paper, macro nutrient supply can be provided to the plant at a slow rate. The recycling of waste papers to develop a slow-release fertilizer, rather than dumping it in landfills, is an environmentally friendly practice. Waste papers also add organic matter to the soil, provide a form of weed control, utilize a recyclable material, and retain moisture in the soil. The main advantage of using fertilizer impregnated into waste paper is that there is no temperature requirement for its release.

Materials and methods

In this study, old newspapers (ONPs) were used as raw material due to ease of availability. Briefly, ONPs were first cut into pieces and mixed in 1%–2% alum solution at 30°–40°C using a defibrator to obtain pure pulp slurry. After secondary fibers were produced from deinked pulp slurry, fibers were placed into a deckle box measuring 30 × 30 cm and were dried at 100° ± 5°C in a dry oven. Urea-saturated solution was fully impregnated into fiberboards, which were then dried at 75° ± 5°C for 24 h. The resulting fertilizer materials were finally manufactured at 100 kPa at 50°C through a thermal press and then uniformly sliced. The ultra structure of the secondary fiber surface and fertilizer impregnated into secondary fibers was observed by scanning electron microscopy (S-4200, Hitachi, Japan). Chemical components of prepared slow-release fertilizer using waste paper are presented in Table 1. Total N content of the prepared slow-release fertilizer was measured by Kjeldahl's method and the contents of P, K, Ca, Mg, As, Cd, Cr, Cu, Pb, and Zn were determined by inductively coupled plasma-atomic emission spectroscopy (ICP-AES).

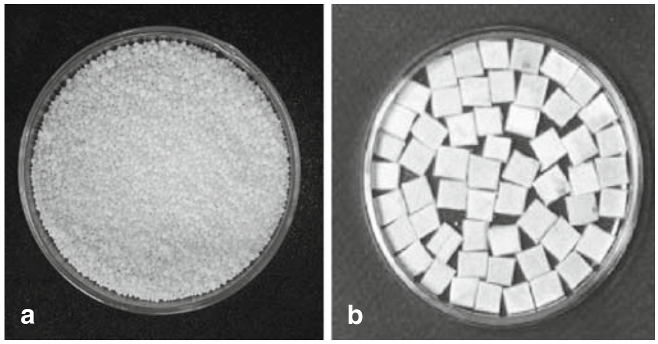

Fig. 1. **a** Urea (46% N) and **b** slow-release N fertilizer made from waste paper (28% N)

Two different solutions, distilled water and a simulated soil solution, were used as leaching solutions to examine the ion-release patterns from impregnated waste paper. The simulated soil solution consisted of 5 mM $CaCl_2$, 1 mM $MgCl_2$, and 0.25 mM KCl.[10] The ion release was examined under two different conditions: static and continuous flow. Under the static condition, samples were immersed in 500 ml of the leaching solution. The concentrations of the ions released into the solution were monitored with immersion time. Under the continuous-flow condition, other test pieces of the same samples were loaded to a glass column. A separating funnel was placed at the top end of the glass column as a reservoir of leaching solution. The leaching solution was continuously eluted through the column at a flow rate of 10 ± 2 ml/h, which was controlled by an adjustable knob. Fractions were collected at immersion or effluent times of 1, 2, 3, 6, 9, 12, 24, 48, 72, 96, 120, 240, 360, 480, 600, and 720 h for determination of concentration of released ions. Release of N into the solutions was determined with an elemental analyzer (Vario EL III). All samples were analyzed in triplicate.

Results and discussion

Chemical components and structure of fertilizers

The contents of chemical components of the slow-release N fertilizer prepared using waste paper are shown in Table 1. The contents of N, P, and K were 28%, 0.05%, and 0.02%, respectively. Toxic metals like Cr, Cu, Pb, and Zn were also detected and the contents were considerably lower than the limits set in the standard for Korean fertilizer regulation. In addition, As and Cd were not detected in the prepared slow-release N fertilizer. The structures of urea and the

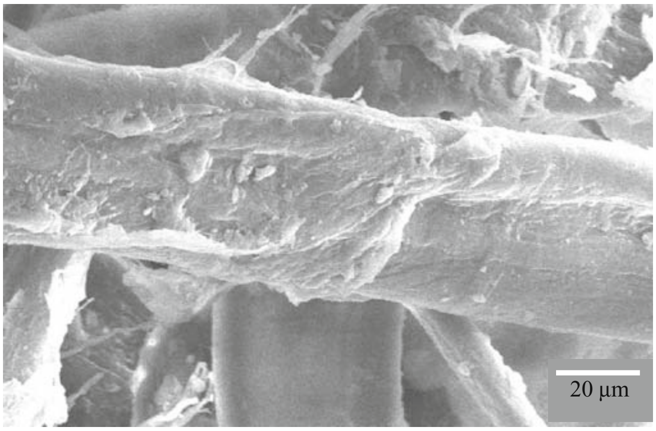

Fig. 2. Micrograph of secondary fiber surface

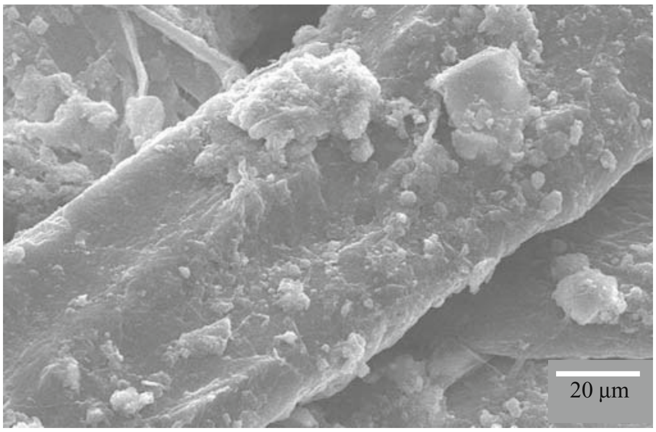

Fig. 3. Micrograph of secondary fiber surface impregnated with N fertilizer

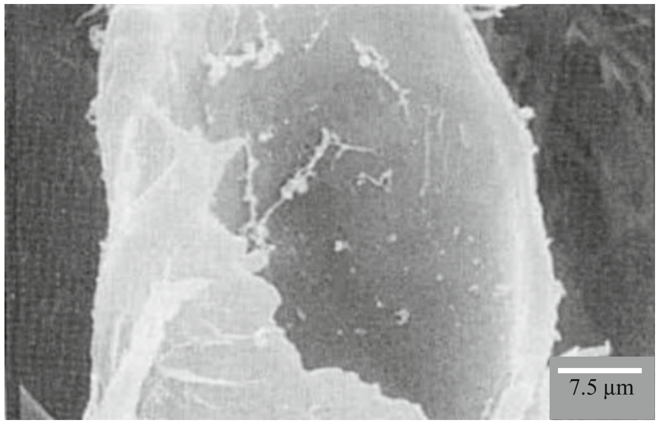

Fig. 4. Micrograph of secondary fiber (inner side)

Fig. 5. Micrograph of secondary fiber (cross section) with N fertilizer impregnated into micropores

slow-release N fertilizer prepared in this work are shown in Fig. 1. Urea fertilizer was made up of small round-shaped granules in which nitrogen content was 46%. On the other hand, the slow-release N fertilizers were flat forms with approximate dimensions of $0.5 \times 0.5 \times 0.2$ cm (length × width × thickness) and N content was 28%.

SEM observations

Figure 2 shows a SEM micrograph of secondary fibers used in this study. The fibers are long, thick, and continuous. Also, the fiber consists of adhered fiber.[11] Figure 3 shows a micrograph of a secondary fiber surface impregnated with urea fertilizer. It was observed that the surface on the fibers was uniformly filled with crystalline structures of fertilizer, indicating that the fertilizer had been successfully attached to the surface of secondary fibers. Vacant spaces were located within the inner side of secondary fibers (Fig. 4), and the urea depositions are clearly observed in micropores of secondary fiber (Fig. 5). An impregnation technique has also been developed through which fertilizing materials fill the capillary spaces derived from degradation of lignin and hemicellulose present in pulp.[12,13]

Release patterns of N from fiber matrix

Static method Soil solution and distilled water were used as solutions to determine the release amount of N from fertilizer-impregnated fiber mat and the samples were collected at different times. Figure 6 shows the release patterns of N in the presence of soil solution and distilled water, respectively. The release rate of N in soil solution was found to be low and steady in the early stages but gradually increased with immersion time. This type of release pattern was also observed for distilled water. Release of N in both liquids came close to equilibrium after 600 h. Release of N continued after 720 h. Both the cumulative released amount was much higher in the soil solution than in distilled water. However, dissolution occurred when N was released in both liquids. The release rate of N from the urea powders as shown in Fig. 1 is much higher than from the fiber matrix.

Flow method Figure 7 presents the release patterns of N in soil solution and distilled water under continuous-flow conditions. These release patterns are comparable to those for the static condition.

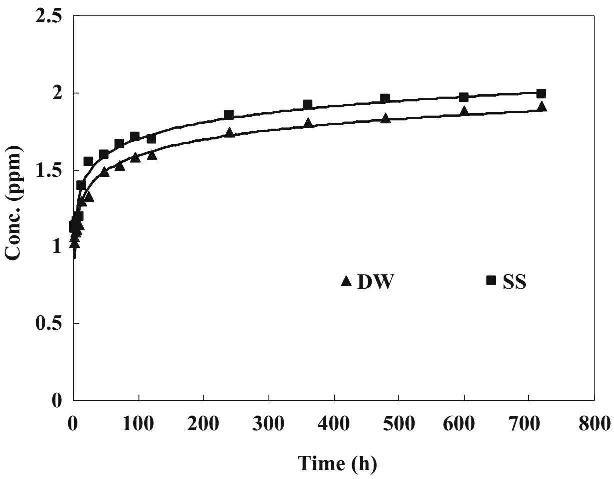

Fig. 6. Release patterns of N from secondary fiber by soil solution (*SS*) and distilled water (*DW*) for static test method

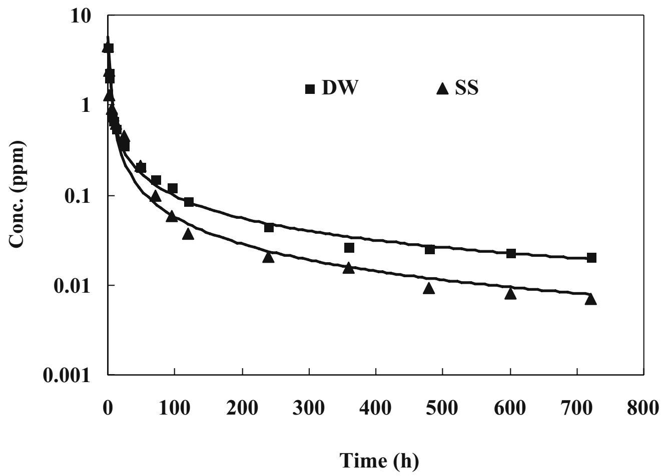

Fig. 7. Release patterns of N from secondary fiber by soil solution and distilled water for continuous-flow method

As shown in Fig. 7, the release rate of N from secondary fibers decreased in soil solution and in distilled water with elution time. For the soil solution, the release rate was higher in the first 120 h of the experiment and thereafter the release rate slowed. However, the release rate was also high (although lower for distilled water than for soil solution) for the first 120 h for distilled water and release continued up to 720 h. The difference in the release amount of N for the two liquids is due to the presence of counter ions in the soil solution. In addition, N fertilizer impregnated into the surface and micropores of secondary fibers where large numbers of hydroxyl groups are present as part of the cellulose structure. This introduces the possibility of hydrogen bonding between urea and the hydroxyl groups at the C_6 position, which means that fertilizer impregnated into waste paper could function as a slow-release fertilizer with maximum uptake and utilization of the nutrients.

Conclusions

Using scanning electron microscopy, urea fertilizer was found to have impregnated into the surface and micropores of secondary fibers. The release rate of N from impregnated fiber matrix was low and steady, and the release rates were higher in soil solution than distilled water in static and continuous-flow conditions. Both ion exchange and dissolution occurred when N was released to soil solution. On the other hand, only dissolution occurred in test using distilled water. In summary, it is suggested that waste paper impregnated with urea fertilizer could act as a benign slow-release fertilizer that permits maximum uptake and utilization of the nutrients.

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