INFLUENCE OF ENVIRONMENTAL CONDITIONS ON RELEASE RULES OF FERTILIZER FROM WOOD RESIDUE SLOW-RELEASE FERTILIZER SHELL

Meng-Ji Qiao

Lecturer
E-mail: qiaomengji1982@163.com

Jin-Ying Jiang

Postgraduate Student
E-mail: jiangjinying202@163.com

*Yun-Lin Fu**

Professor
Forestry College of Guangxi University
Forestry Science and Engineering Key Laboratory of Guangxi Colleges and Universities
Nanning, People's Republic of China
E-mail: fylin@126.com

(Received February 2015)

Abstract. Slow/controlled-release fertilizer is a kind of fertilizer that controls or slows down the nutrient release rate according to a specific release rate or release period. The development and application of slow/controlled-release fertilizer is highly valued all over the world because of its benefits. However, the materials used for the fertilizer coating are mostly difficult to degrade, causing many negative effects to the environment. Wood is a porous material that could be used as a coating material through which fertilizers could infiltrate. In addition, a shell glued with adhesives could degrade in soil because of the loose structure, providing another channel for infiltration of fertilizer. As a kind of environmental friendly material, a wood residue fertilizer shell could be used to provide fertilizer for trees, flowers, and other plants. *Toona sinensis* wood residues were used as the raw material to manufacture a slow-release fertilizer shell using the secondary molding method. The influence of external environmental conditions such as temperature and rainfall on the release rules of fertilizers from shells were studied through artificial rainfall simulation. Results showed that release rules were similar in three sets of rainfall. The release amount increased quickly at the early stages and then decreased gradually. Also, the release amount changed as rainfall increased. Temperature also had a major influence on release rate of fertilizer from the shell. Generally, the release rate of fertilizer in the shell increased with increase of environmental temperature. The release amount kept relatively stable at lower temperatures. This study indicated that the wood residue shell could slow down the release of fertilizer. Both rainfall and temperature had a great influence on the release rate of fertilizer from the shell.

Keywords: Wood residue, slow-release fertilizer shell, artificial rainfall simulation, rainfall, temperature.

INTRODUCTION

Slow/controlled-release fertilizer is a kind of fertilizer that delays or slows down the initial release of nutrients, thereby providing and extending the period of effective fertilizer nutrient absorption and utilization by plants (The National Fertilizer and Soil Conditioner Standardization Technical Committee 2007). One effective way to raise the fertilizer use ratio by crops is to control or slow the dissolution and release rate of fertilizer. The use of slow/controlled-release fertilizer is a developing trend all over the world, and its development and application is highly valued. This study of slow/controlled-release fertilizer mainly focuses on the choice of coating materials, release mechanism of the nutrient, and evaluation methods of fertilizers

* Corresponding author

(Feng et al 2010). Although a lot of coated fertilizers can achieve an ideal slow/controlled-release effect, the material used is usually hard to degrade, which has a detrimental effect on the environment. Therefore, to decrease the negative impact on the environment of currently used slow-released fertilizer, there should be more studies on development of environmental friendly biodegradable slow/controlled-release fertilizers at home and abroad (Hanafi et al 2002; Modabber et al 2008; Ni 2012).

Wood is a porous material that has the property of permeability through gaps in the cell wall, cell cavity, and other channels. In addition, a shell glued with adhesive becomes loose after rainfall, providing another channel for infiltration of fertilizer solution. Therefore, using wood residues as raw materials to manufacture slow-release fertilizer shells is a new approach to developing slow-release fertilizers with environmental friendly properties. The feasibility and detailed methods of manufacturing wood residue slow-release fertilizer shells were already discussed by Fu et al (2007, 2009, 2010).

In fertilizing crops with slow-release fertilizer, release characteristics are related to not only the characteristics of slow-release fertilizer itself but also to environmental factors such as soil MC, environmental temperature, and soil microbial activity (Notario et al 1995; Li 2003; Du et al 2006). Temperature, water vapor pressure, and soil MC have a significant influence on release characteristics of film-coated controlled-release fertilizer (Zheng et al 2002a, 2002b; Xiao et al 2002). The release mechanisms of film-coated slow-release fertilizers were also studied in the condition of liquid water permeability and vapor evaporation. The results showed that the release rates of fertilizer were significantly different in two different moisture conditions (Shavit et al 2003).

The release rules of fertilizer from wood residue slow-release fertilizer shells are affected by not only the characteristics of the shell but also the environmental conditions. In this study, the influence of environmental conditions such as rainfall and temperature on release rate of fertilizer from wood residue shells was studied.

MATERIALS AND METHODS

Wood Residues and Fertilizers

The raw material was sawdust of *Toona sinensis* wood residue, which was dried and screened to an average particle size of 0.64 to 1.4 mm. Urea-formaldehyde resin, which was commercially available, was used as the adhesive. Monobasic potassium phosphate was used as the fertilizer.

Instruments and Equipment

A hot press machine was used for pressing boards. A biochemical incubator was used for controlling environmental temperature in the experiment. A flame photometer was used for analyzing the concentration of potassium.

Shell Manufacture

The shell was manufactured with a secondary molding method. Urea-formaldehyde adhesive was mixed with wood residues at a mass ratio of 1:6. After being stirred well, the mixture was spread on the hot press template, whereas the thickness of the boards was controlled by the thickness gauge. The hot press time was 7 min with pressure of 1.4-2.1 MPa and temperature of 130°C. After cooling down, the boards were cut into small pieces and glued into a 60- × 60- × 60-mm cube shell with hot melt adhesive. Shell density was 550 kg m^{-3}, and thickness was 8 mm.

Artificial Rainfall Simulation

With respect to the randomness of natural rainfall, artificial rainfall simulation was used to study the influence of rainfall and temperature on release rules of fertilizer from the shell. According to the average annual rainfall in Nanning and the factors of the forest canopy and topsoil interception, the amount of artificial rainfall was set to three groups of 400, 600, and 800 mL.

A total of 200 g monobasic potassium phosphate (KH_2PO_4) was loaded in every shell. Shells were placed in a plastic barrel filled with quartz sand to simulate the soil environment. In the outdoor test (the effect of different rainfall on release content of fertilizer), barrels with diameter of 0.33 m and depth of 0.30 m were used. In the indoor test (the effect of different temperature on release content of fertilizer), barrels with diameter of 0.24 m and depth of 0.20 m were used. All barrels were filled with quartz sand, and the surface of the sand was about 20 mm below the edge of the barrels. Only one shell was put in every barrel, and the shell was in the middle of the barrel.

Water was dropped from a top bottle and infiltrated into the shell through the quartz sand. Under the influence of water seepage, the fertilizers dissolved into aqueous solution and flowed to the bottom of the barrel. A drainage pipe was inserted into the bottom of the barrel, and another side of the pipe was attached to a plastic bottle receiving the liquid. The surface of the barrel was covered with plastic wrap to prevent moisture evaporation. The concentration of potassium was measured after 2 da when the top bottle was empty and there was no more water flowing into the bottle. Test parameters and factor level settings are shown in Table 1.

Table 1. Parameters list of the test.

	Test number	Artificial rainfall amount (mL)	Temperature (°C)
Rainfall test	1-3	400	Natural condition
	4-6	600	
	7-9	800	
	10-12 (control)	600	
Temperature test	13-15	600	10
	16-18	600	20
	19-21	600	30

Determination of Potassium Content

Artificial rainfall simulation was carried out every 15 da in this study. Details on determination of potassium concentration were conducted according to the Chinese Forestry Science Academy of Forestry Research Institute (1987). After filtering, the liquid samples were diluted before measuring because the concentration of potassium was far greater than the test range of the flame photometer. The measured values were converted to the final concentration of potassium according to the dilution ratio. The water samples in this study were referred to as the fertilizer solution taken from the receiving bottle during the 15 da between two samplings. The total content of potassium was referred to as the product of the potassium concentration and the sample volume. The change of potassium content was used to study the release rules of fertilizer from the shell.

$$\text{Release rate} = \frac{\text{The nutrient release content during the experiment}}{\text{Total nutrient content loaded in the shell}} \times 100\%$$

RESULTS AND DISCUSSION

The Influence of Rainfall on Release Rate of Fertilizer

The influence of rainfall on release rules of fertilizer was studied according to the change of potassium content in the collected water samples. The results of total potassium contents with different rainfall during 240 da are shown in Table 2, whereas a variation of that is shown in Fig 1. The figures presented in Table 2 and Fig 1 are the average of three samples.

It can be seen from this study that the shell delayed the release of fertilizer. Early in this study, the release quantity of potassium was significantly higher in the control group without a

Table 2. Total potassium release content in different rainfall conditions during 240 da.[a]

	Potassium content (mg)			
Time (da)	400 mL rainfall	600 mL rainfall	800 mL rainfall	Control group
15	230.50	663.00	1023.83	2407.50
30	979.58	1425.00	2562.29	4178.50
45	1277.58	2100.00	3146.71	4961.00
60	2657.67	3971.67	4056.25	8593.92
75	2270.83	3806.25	4464.00	7501.25
90	2899.67	4271.25	5395.08	7527.08
105	2606.67	3246.25	3727.50	5379.17
120	2474.92	3071.25	3570.63	4183.13
135	2417.50	3306.67	3321.67	3043.25
150	2453.29	2747.58	2532.25	2165.63
165	3026.63	2966.08	2444.50	1860.00
180	1971.25	2290.31	1841.15	1593.75
195	2226.17	2212.08	2029.27	1235.00
210	2476.98	2866.35	2320.00	1125.00
225	3005.40	2766.54	2444.73	1155.21
240	1324.08	1677.71	1500.00	345.40
Total content (mg)	35,298.71	44,388.00	48,379.85	57,254.77
Release rate (%)	59.75	75.59	80.80	99.75

[a] 200 g KH_2PO_4 contained 57.4 g potassium calculated from the molecular formula.

shell than in the other three groups. After reaching the maximum release quantity at 60 da, the release quantity stayed at a high level for the following 30 da and then gradually became smaller. Because of the early loss of fertilizer, the release quantity of potassium in the control group became smaller than that in the other groups after 135 da. Therefore, the shell could have delayed the release of fertilizer and kept the release quantity at a relatively stable level.

Rainfall had a major influence on release rate of fertilizer from the shell. In three rainfall sets, the release of potassium from the shell increased at the beginning of the study and then decreased gradually. The release quantity reached a maximum value at 90 da and then became slower. In the 400-mL rainfall group, the release quantity stayed more stable than the other two groups with 600 and 800 mL rainfall.

In the control group, the total content of potassium was 57.255 g at 240 da, which accounted for 99.75% of the total amount of fertilizer (57.4 g K in 200 g KH_2PO_4). Therefore, the effective time of fertilizer without the shell was

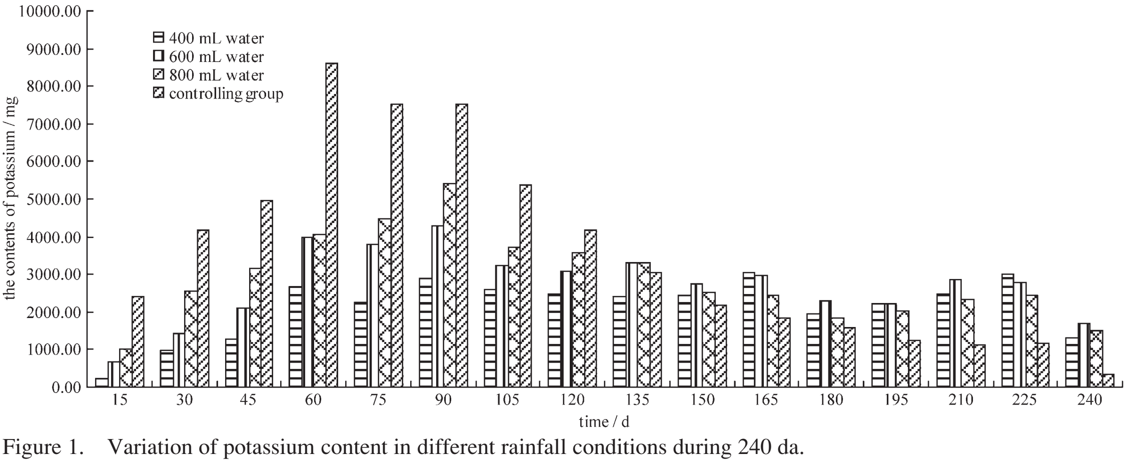

Figure 1. Variation of potassium content in different rainfall conditions during 240 da.

Table 3. Total potassium release content at different temperatures during 180 da.[a]

Time (da)	Potassium content (mg)		
	10°C	20°C	30°C
15	6.71	25.50	105.40
30	1830.88	2714.25	3191.25
45	1901.08	4392.00	6076.78
60	2792.50	4713.00	5854.38
75	2632.13	4631.00	5583.38
90	2185.38	4183.38	4818.00
105	1800.00	3989.50	5207.00
120	1987.50	3645.00	5030.00
135	2726.81	3581.00	4073.50
150	2145.88	2944.69	3357.25
165	2334.94	2705.88	2954.69
180	2331.88	1944.25	3194.75
Total content (mg)	24,675.7	39,469.4	49,446.36
Release rate (%)	43.0	68.8	86.1

[a] 200 g KH_2PO_4 contained 57.4 g potassium calculated from the molecular formula.

about 8 mo. Compared with the control group, the release rate of fertilizer from the shell was smaller. At rainfall amounts of 400, 600, and 800 mL in this study, release rate was 59.75, 75.59, and 80.80% at 240 da, respectively. This study showed that the wood residue slow-release fertilizer shell had a significant slow release effect and that the release rate of fertilizer was higher with an increase in rainfall.

Influence of Temperature on Release Rate of Fertilizer from Shells

Influence of temperature on release rules of fertilizer was studied according to the change of potassium content in the water samples. The results of total potassium content with different temperatures during 180 da are shown in Table 3, and a variation of that is shown in Fig 2. The figures presented in Table 3 and Fig 2 are the average of three samples.

The results showed that the environmental temperature had an impact on release rate of fertilizer. There was a sharp rise of the release quantity at the beginning of the test. Then, the maximum release quantity appeared at 45 da in the 30°C group. The release quantity kept a stable level in the following 30 da and then decreased gradually. The greatest release quantity appeared at 60 da in the 20°C group, and the trend was the same as the 30°C group in the rest of the time. The release quantity of the 10°C group was lower than the other two groups and more stable during the whole experiment. At the end of the experiment, the release quantity of the three groups was at about the same level. From what has been previously discussed, the release quantity of the fertilizer in the shell increased with increase in environmental temperature and kept relatively stable at lower temperatures. These results were related to the faster molecular motion at higher temperatures. With the same condition of 600-mL rainfall, the release rate was 75.59% in total in the previous rainfall experiment, compared with 68.76% at 20°C and 86.14% at 30°C in this study. This result was consistent with the local environmental condition of Nanning, which is about 22°C.

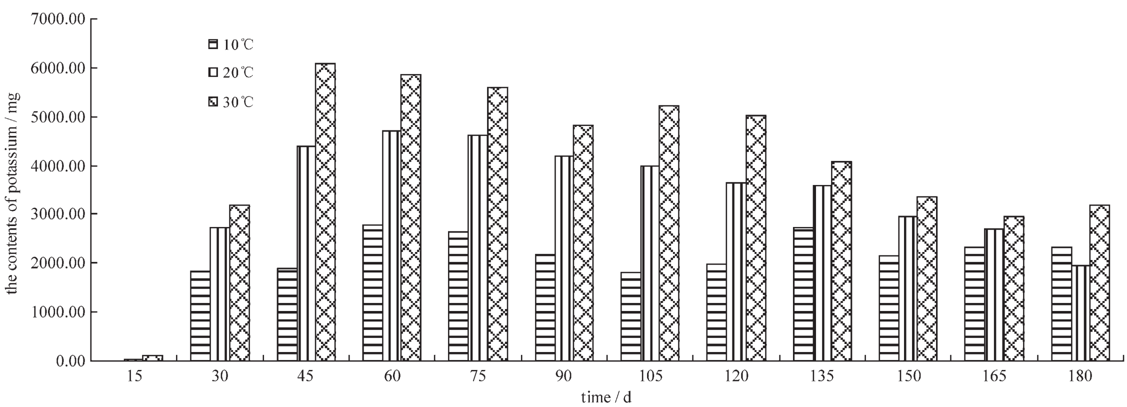

Figure 2. Variation of potassium content at different temperatures during 180 da.

CONCLUSIONS

This study showed that the wood residue shell had an effect on slow release. The release amount of fertilizer first became high, then stayed stable or decreased gradually. However, in the control group without the shell, the release amount of fertilizer stayed very large in the beginning and then decreased rapidly, which was more than that in the experiment groups. The release rules were about the same in the three sets of rainfall; release rate increased quickly early on and then decreased gradually. Also, the release quantity changed more significantly with larger rainfalls. Temperature also had a great impact on the release rate of fertilizer from the shell. Generally, the fertilizer release amount in the shell increased as ambient temperature increased. The release rate quantity kept relatively stable at lower temperatures.

Based on the experimental results, wood residue shell could have potential to be a suitable shell for fertilizer that could allow time for actual fertilization work according to change of climate and plant growth requirements. This study also provided a theoretical basis for the preparation of controlled-release fertilizer shells made from wood residues.

ACKNOWLEDGMENTS

This work was supported by the National Natural Science Foundation of China (31160144) and the Scientific Research and Technology Project of Guangxi (14122005-39). The authors thank the Forestry Science and Engineering Key Laboratory of Guangxi Colleges and Universities for support of this research.

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