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RESEARCH ARTICLE

NUTRIENT RELEASE PERFORMANCE OF STARCH COATED NPK FERTILIZERS AND THEIR EFFECTS ON CORN GROWTH

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ABSTRACT

One way to control or slow down the nutrient release rate from fertilizer is by a coating technique. Nowadays the use of biodegradable coating materials for slow-release fertilizer (SRF) is preferable because of environmental issues. This research was aimed to make SRF using starches and cellulose as the coating materials and to test the release rate of the nutrients. Five kinds of starches (cassava, corn, sago, wheat, and glutinous rice) and carboxymethyl cellulose (CMC) were used as coating material for granulated NPK fertilizer. The coated fertilizers (NPK SRF) were tested for their leaching rate in the soil by percolation experiment. The results showed that the kind of starch used influenced the release rate of the NPK SRFs. The NPK SRF coated with sago starch exhibited slow release rate and low leached nutrients which also resulted in slow growth of corn plant, as expected of SRF. The use of starch and CMC as biodegradable coating materials in this research has a possibility to affect the microbial activity in the soil so that the nutrient release became faster than the uncoated NPK fertilizer.

Keywords: biodegradable coating, environmental issue, leaching, percolation, slow-release fertilizer

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INTRODUCTION

Nutrient losses in fertilization have often become a problem that causes the low efficiency and environmental pollution issues. About 40-70% of nitrogen, 80-90% of phosphorus, and 50-70% of potassium of the applied fertilizers are lost to the environment and cannot be absorbed by plants (Wu & Liu, 2008). The losses of these nutrients from the soil can be caused by leaching (washing off) by the rainfall, irrigation water, and runoff. Besides causing economic losses, nutrient losses by leaching especially for N and P may lead to environmental issues like pollution, groundwater contamination, and eutrophication in the aquatic environment.

One way to minimize those environmental hazards, while improving the efficiency of nutrient use, is by using slow-release or controlled-release fertilizers (Shaviv & Mikkelsen, 1993). Slow-release fertilizers are made to release their nutrient contents gradually and coincide with the nutrient requirement of a plant. Thereby, they can minimize the pollution of soil and water associated with fertilizer overdosage and leaching.

Coating is one of the methods to produce slow-release fertilizer (SRF). Physically, SRF can be prepared by coating granules of

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conventional fertilizers with materials that slow down their dissolution rate. Thus, the release and dissolution rates of SRFs depend on the coating materials. However, the use of coating material such as synthetic polymers/plastics to produce SRF also contribute to environmental pollution, because after nutrients' release there is still a considerable amount of plastic residues left in the soil, estimated around 50 kg ha^{-1} per year (Trenkel, 2010). Furthermore, use of those polymer coating materials may result in high production costs. Therefore, researches in inexpensive and biodegradable coating materials for SRF become an important focus to solve these problems. Some natural and biodegradable coating materials and their modification have been observed, such as lignin (Mulder, Gosselink, Vingerhoeds, Harmsen, & Eastham, 2011), chitosan (Wu & Liu, 2008), alginate (Rashidzadeh & Olad, 2014), and rubber with modified starch (Riyajan, Sasithornsonti, & Phinyocheep, 2012).

Starch is one of the most abundant renewable materials. It is a natural polymer derived from various kinds of plants. Besides its low cost and easily available, starch also fully biodegradable polymer. Starch films and coatings have been used for various food and pharmaceutical applications. Recently, the starch-based material also increased an interest in agriculture and agrochemical industries, for example for encapsulating urea and other fertilizer (Chen, Xie, Zhuang, Chen, & Jing, 2008; Han, Chen, & Hu, 2009) and controlled-released agent or carrier of fungicide (Bai et al., 2015). Based on the plant, there are various kinds of starch such as cassava starch, corn starch, sago starch, glutinous rice starch, and wheat starch. All of them are potential to be used and developed in the making SRF coating. Yet, each of them may have different characteristics as fertilizer coating.

Another biopolymer that can be used as the biodegradable coating material is cellulose. Cellulose has been widely used as raw material for biodegradable plastics and coatings. It is also known to be degraded slowly by soil microbes. Carboxymethyl cellulose (CMC) is a cellulose derivative that is non-toxic, renewable, available in abundance and biodegradable. The CMC also can be used to make a good biodegradable film (Tongdeesoontorn, Mauer, Wongruong, Sriburi, & Rachtanapun, 2011).

The comparisons among starches as fertilizer coating are scarce. Therefore, it is important to be well aware of the nutrient release characteristics and potential differences among comparable starches and CMC as fertilizer coating. Thus, the objectives of this study are to: (1) make slow-release fertilizers (SRF) using starches and CMC as the basic coating material, (2) compare the nutrient release rate and leaching from the coated fertilizers (SRFs) by percolation experiment, and (3) examine the effect of SRFs on the vegetative growth of corn plant in the greenhouse.

MATERIALS AND METHODS

Materials

Granular NPK fertilizer 15:15:15 were provided by Nusa Palapa Gemilang Ltd., Indonesia. Cassava starch, corn starch, sago starch, wheat starch, glutinous rice starch, carboxymethyl cellulose (CMC) and polyethylene glycol (PEG) were purchased from the market in Indonesia. Commercially available polymer-coated fertilizer Osmocote® 14:14:14 was used as the SRF standard. Percolation test and plant growth experiment were conducted using soil material of Latosol Dramaga as media. Corn (*Zea mays*) was used in the plant growth experiment.

Preparation of NPK SRF

Six kinds of coating solutions were prepared. Each coating solution was made from 2% w/v of starch (or CMC) and 1 gram PEG, then 30 ml of distilled water was added to the mixture at room temperature and stirred until homogenous. Except for CMC, the coating solution also heated to let the starch gelatinized. After being dyed, the coating solution is ready to use. Preparation of coating solution was modified from Suherman & Anggoro (2011).

The coating process was done in the laboratory scale using pan granulator under a dryer tool. About 30 ml of the coating solutions was sprayed onto the 100 g of granular NPK fertilizer. The coated fertilizer then dried in a 50 °C oven for one hour. The final products, starch-coated and CMC-coated NPK fertilizers, then called as NPK SRF and were given codes as follow: C1 (cassava starch-coated SRF), C2 (corn starch-coated SRF), C3 (sago starch-coated SRF), C4 (wheat starch-coated SRF), C5 (glutinous rice starch-coated SRF), C6 (CMC-coated SRF)

Nutrient Release Test

The test for nutrient release was done by percolation experiment using cylinder column (7.4 cm inner diameter and 29 cm high) containing 1 kg of air-dried soil (< 2 mm). The fertilizer samples were given in equal to 1000 mg N for each column and were placed 3 cm below the soil surface. The initial amount of phosphorus and potassium were following the result of an analysis based on the given nitrogen. There were 8 treatments: K (control without fertilizer application), C0 (uncoated NPK fertilizer), C1 (cassava starch-coated SRF), C2 (corn starch-coated SRF), C3 (sago starch-coated SRF), C4 (wheat starch-coated SRF), C5 (glutinous rice starch-coated SRF), C6 (CMC-coated SRF), and C7 (SRF standard/Osmocote®). All treatments were replicated three times and observations were taken over a month period. During the experiments, soil columns were incubated at room temperature. Watering was applied weekly using distilled water in conformity with the average rainfall (326 ml column^{-1}) and the leachates (percolates) were collected in plastic bottles. Nutrients leached were measured from the percolate weekly. Nitrogen in the form of ammonium-N and nitrate-N were analyzed using steam distillation method with MgO and Devarda's alloy (Mulvaney, 1996). Phosphorus (P) in the percolate was analyzed using a spectrophotometer and potassium (K) was analyzed using flame photometer. The average value was reported as the result.

Evaluation of Plant Growth with NPK SRF

This experiment was carried out in order to test the effect of NPK SRF on plant vegetative growth. Plant growth experiment was performed in the greenhouse conditions using sweet corn plant. Polybags were used as media container, filled with air-dried soil equal to 5 kg of soil dry weight (< 5 mm). There were 8 treatments which were the same as the nutrients release experiment, three replicates for each treatment. Corn seeds were planted two seeds per polybag, then only one plant was chosen in the first week after planting. Fertilizers were given in accordance to the N requirement of the corn plant (120 kg N ha^{-1} or 0.3 g N per polybag) and were given on the day of planting.

Plants were grown for seven weeks. Plant growth was observed weekly for the height, leaf number, leaf width, and stem diameter. At the end of that period, the dry weight of the plants was determined. The dry weight of the tested plants was determined after drying at 60 °C until a constant weight.

The experimental data were analyzed using SAS software version 9.1.3 for Windows , as a completely randomized design with three replicates. Analysis of variance was performed on the data to compare the effect of the different treatments. Where a significant *F*-test was observed, mean separation among treatments was obtained by Duncan Multiple Range Test (DMRT) at a significance level of 5%.

RESULTS AND DISCUSSION

Nutrient Content

Nitrogen, phosphorus and potassium content of the coated and uncoated fertilizers ranged from 11.91 – 14.04%, 5.28 – 7.06%, and 10.69 – 13.42% respectively (Table 1). In general, the nutrient content of the coated fertilizers (C1 to C6) did not change much compared to the uncoated one (C0). However, some starches and CMC seemed to have a little addition to P and K contents. The N content tended to be lower because of the dilution effect and volatilization that possibly happened during the coating process. That means the addition of starch and CMC as the coating might affect the analysis of nutrients in the coated fertilizer.

Nutrient Release of NPK SRF

Nutrient release in this experiment was observed from the amount of nutrient leached from percolation test every week. The more nutrients leached in the percolate means the more nutrients released from fertilizer. Control (K) was used to show the leached nutrients from the soil without the addition of fertilizer.

Nitrogen from the fertilizer was analyzed in the form of ammonium-N (NH_4^+-N) and nitrate-N (NO_3^--N) in the percolate. The release pattern shows that ammonium-N kept increasing until reaching the peak then gradually decreased (Figure 1a). It can also be seen that SRF C2 and C6 had faster release than other coated SRFs, because both had the highest peak in the second week of observation. Other treatments had the highest releases in the third week. In general, the release rate of ammonium-N from NPK SRF C1 to C6 still faster than the standard (C7). The decrease in leaching of NH_4^+-N could be due to loss of NH_3 by volatilization or transformation of NH_4^+-N to NO_3^--N by nitrification (Paramasivam & Alva, 1997).

There were significant differences in the amount of cumulative ammonium-N leached among the treatments (Figure 1b). Among the SRFs made, C3 exhibited the lowest amount of cumulative ammonium-N leached, but it still could not meet the standard of C7. The order from the highest ammonium-N leached is as follow: C2 > C6 > C4 > C5 > C1 > C3 > C0 > C7. Nitrogen, phosphorus and potassium content of the coated and uncoated fertilizers ranged from 11.91 – 14.04%, 5.28 – 7.06%, and 10.69 – 13.42% respectively (Table 1). In general, the nutrient content of the coated fertilizers (C1 to C6) did not change much compared to the uncoated one (C0).

Table 1. The result of analysis of fertilizer nutrient content (mean ± SD)

Fertilizer	N	P	K
		%	
C0	14.04 ± 0.69	5.83 ± 0.38	12.65 ± 0.48
C1	13.01 ± 1.09	6.50 ± 0.01	12.92 ± 0.02
C2	12.56 ± 1.11	5.28 ± 0.09	13.42 ± 0.02
C3	14.00 ± 0.22	7.06 ± 0.37	10.69 ± 0.46
C4	13.18 ± 0.90	6.76 ± 0.22	12.27 ± 0.02
C5	13.42 ± 0.46	6.53 ± 0.08	11.64 ± 0.00
C6	12.58 ± 1.52	6.95 ± 0.10	12.22 ± 0.82
C7	11.91 ± 0.42	5.50 ± 0.00	12.32 ± 0.00

However, some starches and CMC seemed to have a little addition to P and K contents. The N content tended to be lower because of the dilution effect and volatilization that possibly happened during the coating process. That means the addition of starch and CMC as the coating might affect the analysis of nutrients in the coated fertilizer.

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Release pattern of nitrate-N shows the contrary from ammonium-N pattern except for C7 (Figure 1c). This pattern shows that when ammonium-N was decreasing, the amount of nitrate-N was increasing. It also proves that there was a transformation of NH_4^+-N to NO_3^--N by nitrification on the fourth week. The C7 is an exception because Osmocote® is a nitrate-based fertilizer, while the base fertilizer used to make NPK SRF in this experiment is a urea-based fertilizer. The difference between the fertilizer's raw materials explains the low release amount of nitrate-N from the NPK SRFs and the uncoated NPK fertilizer in the first three weeks.

Except for C7, the total amount of nitrate-N did not significantly different among all starch-coated and CMC-coated SRFs (Figure 1d). The soil itself also had a higher content of nitrate-N than ammonium-N. The order from the highest nitrate-N leached is as follow: C7 > C2 > C3 > C0 > C1 > C6 > C4 > C5.

The releases of total N (ammonium-N + nitrate-N) display a different pattern (Figure 1e). It can be seen that each coating material used influenced the release rate of N. In this case, mostly was coming from ammonium-N. During the incubation, ammonium-N from C0 to C6 had the greatest release increment in the first three weeks due to the decomposition of urea from fertilizer, the same as reported in Dong & Wang (2007). The highest release of nitrate-N in the first 3 weeks was found in C7 only.

The amount of cumulative N leached still increased gradually during four weeks (Figure 1f). The percentage of N losses by leaching in this experiment reached 27.10% of C0, 28.41% of C7, 28.67% of C5, 28.73% of C3, 29.87% of C1, 30.51% of C4, 32.76% of C6 and 35.66% of C2. The SRF C3 and C5 exhibited the amounts of cumulative N leached which were almost the same as the standard (C7). However, it is also noticed that the uncoated fertilizer (C0) exhibited a lower amount of cumulative N leached than the coated fertilizers.

Figure 2 shows the release pattern of P and cumulative P leached from the percolation experiment. Phosphorus was leached at the lowest rate. The leaching losses varied from 0.43 to 1.93 mg of P leached per week. The percentage of P losses by leaching from the lowest were 0.91% of C1, 0.96% of C6, 0.99% of C7, 1.02% of C4, 1.03% of C3, 1.06% of C5, 1.16% of C6, and 1.17% of C0. Those amounts are very low compared to the N losses. Broschat & Moore (2007) also reported that phosphorus from controlled-release fertilizers was released slower than NH_4^+-N or NO_3^-N. According to Mengel & Kirkby (2001), in most mineral soils mobility

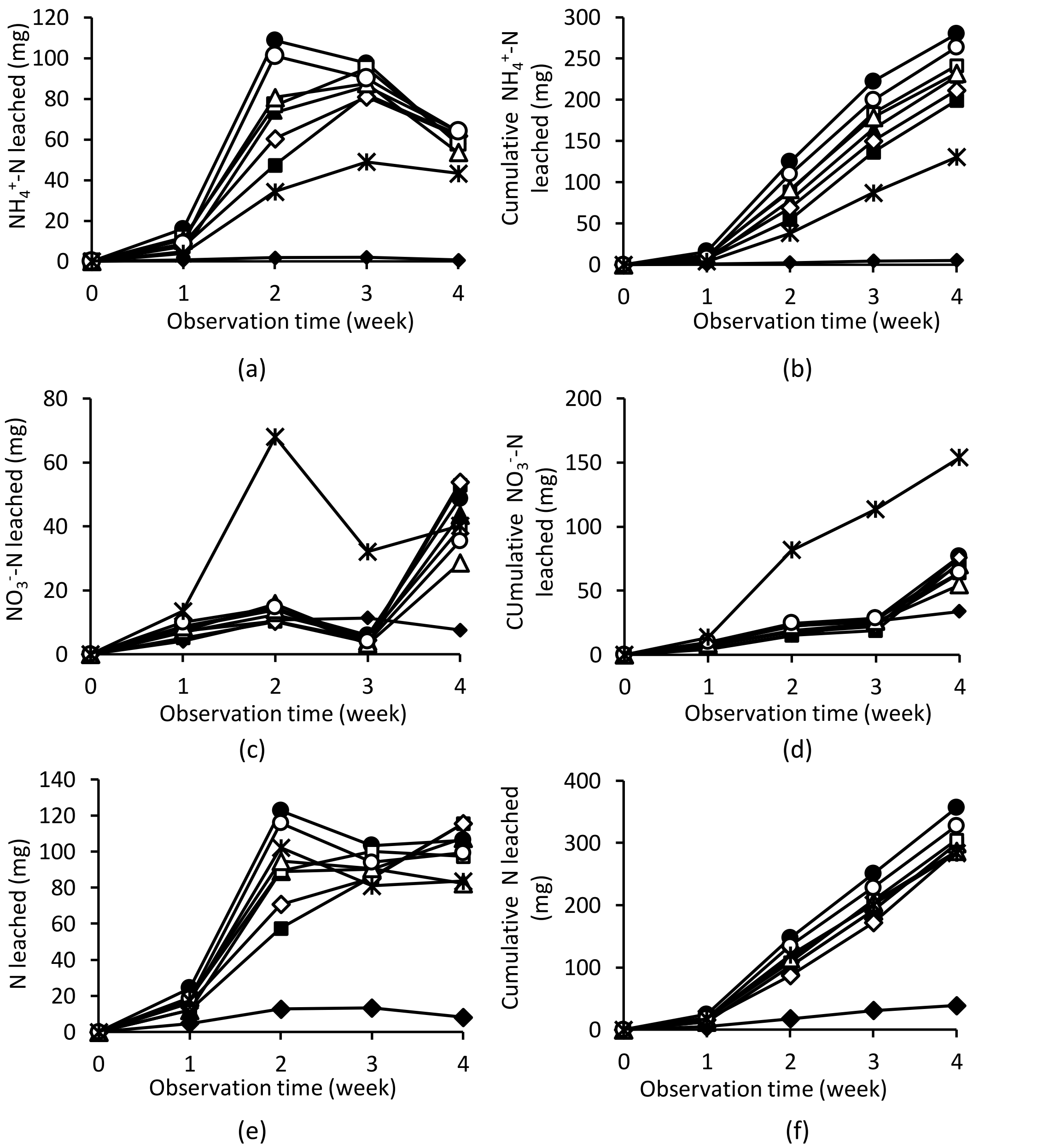
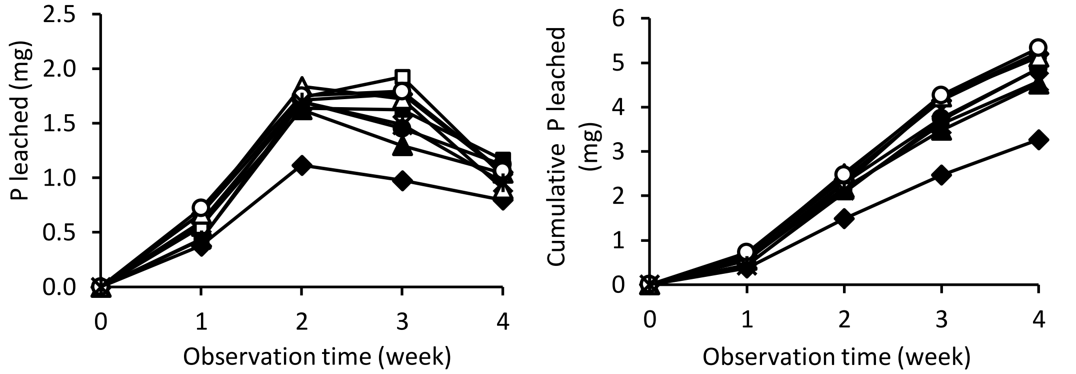
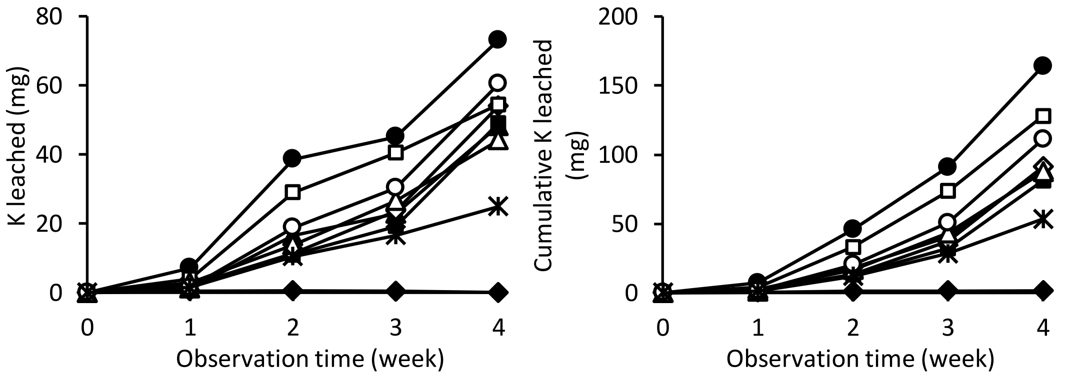


Figure 1. (a) Release pattern of NH_4^+-N, (b) cumulative NH_4^+-N leached, (c) release pattern of NO_3^--N, (d) cumulative NO_3^--N leached, (e) release pattern of N, and (f) cumulative N leached during percolation experiment. K, C0, C1, C2, C3, C4, C5, C6, C7.



(a) (b)

Figure 2. (a) Release pattern of P, and (b) cumulative P leached during percolation experiment.
◆ K, ■ C0, ▲ C1, ● C2, ◇ C3, ■ C4, △ C5, ○ C6 , ✱ C7.



(a) (b)

Figure 3. (a) Release pattern of K, and (b) cumulative K leached during percolation experiment.
◆ K, ■ C0, ▲ C1, ● C2, ◇ C3, ■ C4, △ C5, ○ C6 , ✱ C7.

of phosphate is low so that fertilizer P is scarcely leached into the deeper soil layer. Thus, in producing slow-release compound fertilizer, the function of coating in reducing nutrient losses can be focused on N.

Figure 3a shows that the release pattern of K gradually increased by the observation time and had not reached the peak yet. As shown in the N release pattern before, C2, C6, and C4 also exhibited significantly faster release rate of K. Figure 3b displays that there were significant differences in the amount of cumulative K leached for those treatments. However, cumulative K leached of C0, C1, C3 and C5 did not differ much. The leaching percentage from the lowest amount are 5.17% of C7, 8.96% of C1, 9.01% of C0, 10.07% of C5, 11.43% of C6, 11.94% of C3, 13.74% of C4, and 15.34% of C2.

It was observed that the nutrients from a fertilizer with starch and CMC coating were released faster than the uncoated fertilizer, especially for nitrogen and potassium. This indicates that those coating materials can stimulate soil microbes' activity in degrading the coating and causing its disintegration, thereby enhances the nutrient solubility. As a biodegradable coating, the degradation of starch and CMC coating in the soil depends largely on biological processes. Mizuta, Taguchi, & Sato (2015) proved that soil respiration of the soil increased when amended with starch and cellulose, which means there was an increase in the microbial activity.

The similar finding was observed by Jarosiewicz & Tomaszewska (2003) that the release rate of components from the fertilizer coated with a biodegradable coating such as cellulose acetate was higher compared to the non-biodegradable coating.

Microorganisms (bacteria and fungi) present in the soil could influence the degradation of the coating by using it as their food source. Starch and cellulose are enzymatically degraded by amylase and cellulase. Some bacteria and fungi from genera of *Bacillus, Pseudomonas* and *Aspergillus* isolated from soil were known to produce amylase and cellulase (Bergmann, Abe, & Hizukuri, 1988; Mishra & Behera, 2008). The differences in the release rate of nutrients can be also associated with the structure of the coating and the nature of the coating material. In this case, each starch may have different nature and structure or molecular complexity which affects its decomposability by soil microorganisms. Moreover, starches used in this study were all native starches which their molecular structure was not chemically modified. Therefore soil microorganisms are easier to utilize those starches.

Evaluation of Plant Growth with NPK SRF

Vegetative growth consists mainly of the growth and formation of new leaves, stems, and roots. From Figure 4, it can be seen that fertilizers with slower N released in the percolation experiment also resulted in lower plant height of corn and vice versa. It also demonstrates that C3 was a slow-release fertilizer as well as C7 because the plant grew slower than the treatment with uncoated fertilizer (C0). During the vegetative stage, the N nutrition of the plant to a large extent controls the growth rate of the plant (Mengel & Kirkby, 2001). The use of slow-release fertilizer in this experiment seemed did not match with the N requirement by corn plant in the vegetative stage.

Compared to the uncoated fertilizer (C0) and control (K), SRF C3 showed a significantly different effect on vegetative growth of corn (Table 2). But the statistical analysis showed that it did not significantly different with the SRF standard (C7), which also showed a slow plant growth. That means sago starch, which is used as the coating on C3, has the same slow-release performance as polymer coating on C7. Other starch-coated fertilizers gave better effect to the plant growth due to their faster release of nutrients, especially in N.

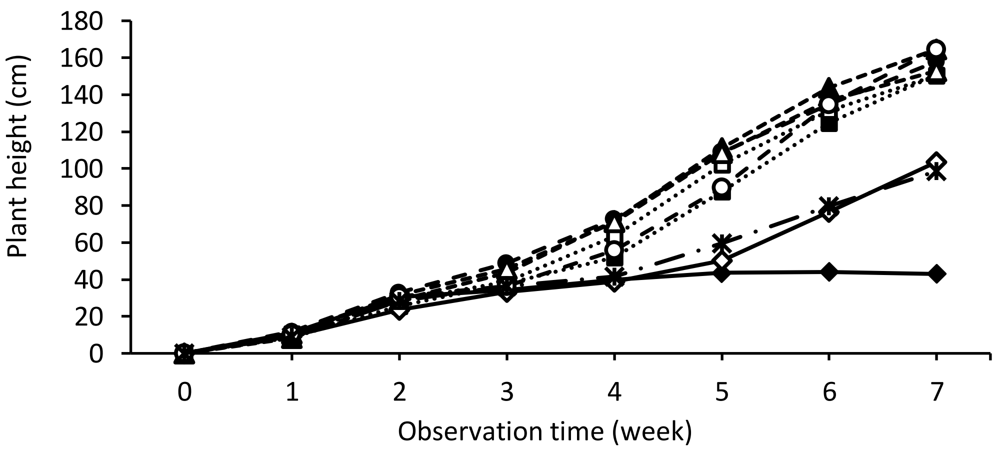


Figure 4. The effect of NPK SRF on the growth of corn plant. K C0 C1 C2 C3 C4 C5 C6 C7.

Table 2. The effect of NPK SRF on the vegetative growth and dry weight of corn plant on 7 weeks after planting

Treatment	Plant height (cm)[a]	Leaf number (blade)[a]	Leaf width(cm)[a]	Stem diameter (cm)[a]	Biomass above ground (g)[a]	Root biomass (g)[a]
K	42.97d	2.3c	1.40d	0.24d	0.35b	0.20d
C0	150.80ab	9.0a	5.17a	0.88ab	12.04a	1.88abc
C1	164.60a	7.7ab	5.77a	1.09a	16.65a	2.38ab
C2	157.93a	8.3ab	5.37a	0.83ab	13.65a	2.25abc
C3	103.63bc	7.3ab	3.57bc	0.68bc	4.48b	0.86bcd
C4	150.43ab	9.0a	4.93ab	0.89ab	13.86a	2.96a
C5	152.93ab	8.3ab	5.87a	0.98a	16.73a	3.05a
C6	164.67a	9.3a	5.27a	1.00a	12.41a	1.94abc
C7	98.63c	6.0b	2.73cd	0.51c	3.49b	0.64cd

Remarks: [a] Values with the same letters at the same column are not significantly different at a significance level of 5% (DMRT)

Increasing level of the dry mass of green parts of plants (biomass above ground) indicates their good productivity. A significant increase of dry matter of plants of C0, C1, C2, C4, C5, and C6 has been observed (Table 2), indicates that those fertilizers are suitable for corn. On the other hand, C3 and C7 which has slow-release characteristic are not suitable for corn.

An interesting finding is SRF C5, which exhibited the low amount of N leached or released, actually performed a good effect on the plant growth and biomass. Based on the dry weight of root biomass, it can be seen that C5 stimulated the root growth. With good root formation, the plant can absorb nutrients optimally. Glutinous rice starch used as the coating material for C5 may have a better effect than other starches in stimulating microbial activity in the rhizosphere. Some rhizosphere microbes were known as plant growth-promoting rhizobacteria (PGPR), therefore a good rhizosphere condition will give a good impact in plant-microbe interaction which can enhance the plant growth (Ahkami, Allen White, Handakumbura, & Jansson, 2017).

There is a possibility that kinds of starch or cellulose used to have a different effect due to the complexities of those starches to be utilized by soil microbes. It seems that cassava starch, corn starch, wheat starch, glutinous rice starch, and CMC were easier to be utilized by soil microorganisms than sago starch. That makes sago starch as a potential starch to be used further as a slow-release fertilizer coating material because it degrades slowly. But due to its slow-release performance, this fertilizer is not suitable for annual crops such as corn. This slow-release fertilizer is more suitable for perennial crops. On the other hand, glutinous rice starch has a good potential to be used as a slow-release fertilizer coating for annual crops.

CONCLUSION

The release rate of slow-release fertilizer was influenced by the kind of starch used as its coating material. This study shows that sago starch has high potential as a base coating material for slow-release fertilizer according to the slow nutrient release rate and its slow effect on plant growth which has proved it. Glutinous rice starch also has a potential to be used as a slow-release coating material for but annual crop fertilizer. The use of starch or cellulose (CMC) as biodegradable coating material has a possibility to stimulate the microbial activity in rhizosphere because of the biodegradation process by soil microorganisms. Therefore further improvement is needed to make the coating more durable in the soil.

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REFERENCES

Ahkami, A. H., Allen White, R., Handakumbura, P. P., & Jansson, C. (2017). Rhizosphere engineering: Enhancing sustainable plant ecosystem productivity. *Rhizosphere*, *3*(2), 233–243. http://doi.org/10.1016/J.RHISPH.2017.04.012

Bai, C., Zhang, S., Huang, L., Wang, H., Wang, W., & Ye, Q. (2015). Starch-based hydrogel loading with carbendazim for controlled-release and water absorption. *Carbohydrate Polymers*, *125*, 376–383. http://doi.org/10.1016/J.CARBPOL.2015.03.004

Bergmann, F. W., Abe, J., & Hizukuri, S. (1988). Selection of microorganisms which produce raw-starch degrading enzymes. *Applied Microbiology and Biotechnology*, *27*(5–6), 443–446. http://doi.org/10.1007/BF00451610

Broschat, T. K., & Moore, K. K. (2007). Release Rates of Ammonium-Nitrogen, Nitrate-Nitrogen, Phosphorus, Potassium, Magnesium, Iron, and Manganese from Seven Controlled-Release Fertilizers. *Communications in Soil Science and Plant Analysis*, *38*(7–8), 843–850. http://doi.org/10.1080/00103620701260946

Chen, L., Xie, Z., Zhuang, X., Chen, X., & Jing, X. (2008). Controlled release of urea encapsulated by starch-g-poly(l-lactide). *Carbohydrate Polymers*, *72*(2), 342–348. http://doi.org/10.1016/J.CARBPOL.2007.09.003

Dong, Y., & Wang, Z. (2007). Release Characteristics of Different N Forms in an Uncoated Slow/Controlled Release Compound Fertilizer. *Agricultural Sciences in China*, *6*(3), 330–337. http://doi.org/10.1016/S1671-2927(07)60053-4

Han, X., Chen, S., & Hu, X. (2009). Controlled-release fertilizer encapsulated by starch/polyvinyl alcohol coating. *Desalination*, *240*(1–3), 21–26. http://doi.org/10.1016/J.DESAL.2008.01.047

Jarosiewicz, A., & Tomaszewska, M. (2003). Controlled-Release NPK Fertilizer Encapsulated by Polymeric Membranes. *J. Agric. Food Chem.*, *51*(2), 413–417. http://doi.org/10.1021/JF020800O

Mengel, K., & Kirkby, E. A. (2001). *Principles of Plant Nutrition* (5th ed.). Dordrecht: Springer Netherlands. http://doi.org/10.1007/978-94-010-1009-2

Mishra, S., & Behera, N. (2008). Amylase activity of a starch degrading bacteria isolated from soil receiving kitchen wastes. *African Journal of Biotechnology*, *7*(18), 3326–3331. http://doi.org/10.5897/AJB08.582

Mizuta, K., Taguchi, S., & Sato, S. (2015). Soil aggregate formation and stability induced by starch and cellulose. *Soil Biology and Biochemistry*, *87*, 90–96. http://doi.org/10.1016/J.SOILBIO.2015.04.011

Mulder, W. J., Gosselink, R. J. A., Vingerhoeds, M. H., Harmsen, P. F. H., & Eastham, D. (2011). Lignin based controlled release coatings. *Industrial Crops and Products*, *34*(1), 915–920. http://doi.org/10.1016/J.INDCROP.2011.02.011

Mulvaney, R. L. (1996). Nitrogen—Inorganic Forms. In D. L. Sparks, A. L. Page, P. A. Helmke, & R. H. Loeppert (Eds.), *Methods of Soil Analysis Part 3—Chemical Methods* (pp. 1123–1184). Madison: the Soil Science Society of America, Inc., American Society of Agronomy, Inc. http://doi.org/10.2136/sssabookser5.3.c38

Paramasivam, S., & Alva, A. K. (1997). Leaching of nitrogen forms from controlled-release nitrogen fertilizers. *Communications in Soil Science and Plant Analysis*, *28*(17–18), 1663–1674. http://doi.org/10.1080/00103629709369906

Rashidzadeh, A., & Olad, A. (2014). Slow-released NPK fertilizer encapsulated by

NaAlg-g-poly(AA-co-AAm)/MMT superabsorbent nanocomposite. *Carbohydrate Polymers*, *114*, 269–278. http://doi.org/10.1016/J.CARBPOL.2014.08.010

Riyajan, S.-A., Sasithornsonti, Y., & Phinyocheep, P. (2012). Green natural rubber-g-modified starch for controlling urea release. *Carbohydrate Polymers*, *89*(1), 251–258. http://doi.org/10.1016/J.CARBPOL.2012.03.004

Shaviv, A., & Mikkelsen, R. L. (1993). Controlled-release fertilizers to increase efficiency of nutrient use and minimize environmental degradation - A review. *Fertilizer Research*, *35*(1), 1–12. http://doi.org/10.1007/BF00750215

Suherman & Anggoro, D. D. (2011). Producing slow release urea by coating with starch/acrylic acid in fluid bed spraying. *Int. J. Eng. Technol*, *11*(6), 62–66. Retrieved from http://citeseerx.ist.psu.edu/viewdoc/summary?doi=10.1.1.419.4865%5Cnhttp://scholar.google.com/scholar?hl=en&btnG=Search&q=intitle:Producing+Slow+Release+Urea+by+Coating+with+Starch+/+Acrylic+Acid+in+Fluid+Bed+Spraying#0

Tongdeesoontorn, W., Mauer, L. J., Wongruong, S., Sriburi, P., & Rachtanapun, P. (2011). Effect of carboxymethyl cellulose concentration on physical properties of biodegradable cassava starch-based films. *Chemistry Central Journal*, *5*(6), 1–8. http://doi.org/10.1186/1752-153X-5-6

Trenkel, M. E. (2010). *Slow- and controlled-release and stabilized fertilizers : an option for enhancing nutrient use efficiency in agriculture* (2nd ed.). Paris: IFA, International fertilizer industry Association. Retrieved from https://books.google.co.id/books/about/Slow_and_Controlled_release_and_Stabiliz.html?id=rrQmtwAACAAJ&redir_esc=y

Wu, L., & Liu, M. (2008). Preparation and properties of chitosan-coated NPK compound fertilizer with controlled-release and water-retention. *Carbohydrate Polymers*, *72*(2), 240–247. http://doi.org/10.1016/J.CARBPOL.2007.08.020