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Slow Release Fertiliser Production from Poultry Manure

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Fertilisers are essential nutrient supplements, which can enhance the productivity and growth rate of plants. Application of slow release fertiliser (SRF) on plants is advantageous such that it provides uniform growth. Poultry manure mixed with rice husk from a chicken farm house was dried and milled to produce dry powder that is ready to be used as a SRF matrix. The powder was mixed with a binder (starch) and nitrogen source (urea) and then compacted using screw extruder and pan granulator. The two procedures of the fertiliser production were employed and evaluated. Based on the nutrient release profile, it was observed that pelletised SRF using extruder has longer capability in retaining the nutrient content than granule SRF. Even though the granule SRF has lower nutrient retention capability, the granule process requires less energy and processing time than the extrusion process. In order to determine the optimum choice for the SRF production method, all processing aspects should be considered including the quality of SRF matrix, and processing time, cost, and energy.

1. Introduction

Chicken farm industry (poultry), nowadays grows rapidly to satisfy the growing global demand of the society for healthy and nutritious foods. In Indonesia, huge poultry farm with a capacity of more than 100,000 chickens for commercial purpose is commonly established close to residential areas, creating many pollution hazards to the surrounding. The most apparent problem is usually the bad odour released from the chicken farm due to the production of poultry manure as a side product of the farm. The manure released bad odour due to its chemical properties, which is high in ammonia content. A commercial chicken farm with this huge capacity normally produces up to 200 t of chicken manure for every 4-month period. The bad odour problem becomes severe during the harvesting stage due to the cleaning, collecting and transporting activities of the poultry manure out of the farm site. The smell also attracts flies, resulting in the rapid breeding of flies and in turn, creating sudden explosion of flies' population. Flies as a disease vector will spread out into surrounding houses creating unhealthy and inconvenience situation to the nearby society. This situation is worsened during rainy season.

The collected chicken manure is mostly transported to the dumping site for traditional composting process, or direct application to the agriculture site as natural fertiliser such as potatoes and tobacco farms. This conventional practice has also created similar problems of bad odour and flies bloom. It is necessary to develop a proper handling system of the chicken manure from the chicken farm for application on agricultural farm to mitigate the environmental hazards. Chicken manure is packed with nutrients due to the heavy nutritional contents from food supplements consumed by the chickens to promote rapid growth. It contains macro and micro nutrients that are very suitable for fertiliser production. It has the potential to be utilised as fertiliser if it can be shaped into pellets and the odour can be reduced. This mitigation efforts can provide several positive impacts at the same time including utilising waste from chicken manure, solving pollution problems and also supporting organic farming practices. This also will be one of the solutions to ensure the

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increase in the acceptance rate of the nearby society for continuous establishment of the commercial poultry industries.

Many efforts have been made to increase the efficiency of nitrogen fertiliser especially urea by increasing the size, coating the fertiliser with other compounds and containing the fertiliser into solid matrices to produce slow release fertiliser (SRF) (Liang and Liu, 2006). SRF is a fertiliser that is designed to release nutrients in a controlled manner in accordance to the nutritional needs of plants, thereby, increasing the fertiliser adsorption efficiency, which in turn, resulting in the reduction in fertilising cost and increasing the plants productivity (Azeem et al., 2014). The method for making matrix-based urea SRF is easier to produce and lower in production cost (Al-Zahrani, 1999).

There are several types of matrices that can be utilised to slow down the releasing rate of nutrients into soils, and the most common type is natural zeolite (Hoeung et al., 2011). Zeolite is preferred due to its cation exchange capacity, which is beneficial for soil remediation and nutrient storage. Since zeolite matrix does not have binding ability, the addition of binding agent such as starch is required to modify its binding properties (Zhang et al., 2016). The other possible matrix with binding ability is the clay group such as bentonite (Xiaoyu et al., 2013) and montmorillonite (Rashidzadeh and Olad, 2014). By using clay as the SRF matrix, any additional binding agent is no longer necessary and also it has cation exchange capacity as well even mostly lower than zeolites. The other potential matrices are agricultural wastes such as straw ash, and rice husk ash (Yu et al., 2011). It is expected that poultry wastes can be used as the one of the potential raw materials to produce SRF matrix in the future.

This study aims to design a proper onsite processing technology of the poultry manure to produce organic fertiliser. The poultry waste is expected to become valuable side product that can increase the industry's revenue while mitigating the pollution problems. The processing system should be reliable to process all the produced manure from commercial poultry farm into fertiliser. The SRF product is produced using the leaching method, which proved that the fertilisers have a slow release features and is able to store and slowly release the nutrient contents into the soils. A simulation modelling was also developed to study the matrix ability in storing the contained nutrient.

2. Materials and methods

Materials

Chapter 2 Poultry manure was collected from a broiler chicken teaching farm in Agro-technology Innovation Center (PIAT) at Universitas Gadjah Mada, Indonesia. The physical appearance of the manure is covered by rice husk, which was added on the closed-house floor to reduce the odour problem. A typical manure to rice husk ratio was 0.5 on a dry basis. The manure is then sun dried, milled and sieved to produce poultry manure powder. The powder was smell free and ready to be used for SRF preparation.

2.2 Slow release fertiliser preparation

The first SRF preparation was using screw extruder. Before pelleting, the powder was mixed with urea powder (urea : manure = 1 : 2) and starch paste in a mixer. Starch paste was prepared by heating starch solution. The mixture dough then extruded to produce noodle-like long shape mass. Then the extruded paste was sun dried and cut at about 1 cm length of pellets. The pellet then oven dried to complete the drying step and stored in an air tight container. For comparison, poultry manure pellet without urea addition was also prepared in the same procedure as above.

The second method of SRF production was using pan granulator. The poultry powder was mixed with urea powder in the same ratio of the SRF pellet, the powder mixture was placed inside the pan and rotated. During rotation, a starch solution was spayed to produce a ball shape granule with the diameter range of 0.5 to 1.0 cm. The SRF granule then oven dried and stored in a sealed container.

2.3 Nutrient release measurement

The release measurement was conducted by a simple dissolution method. 0.5 g of pellets or granule was submerged into a capped bottle consisting of 100 mL aquadest. The 10 bottles were prepared for each SRF sample. Then each day one bottle from each SRF type was filtered and the total nitrogen content inside the filtrate measured. The total nitrogen analysis of the solution used spectrophotometric method by HANNA Benchtop Multiparameter Photometer for Water Analysis HI83200.

2.4 Release simulation

The release of nutrient from the fertiliser matrix was modelled by applying component (nitrogen) mass balance inside the pellets as indicated in Eq(1). It is assumed that the shape of pellet remains the same anytime and the radial diffusion is neglected. The concentration of nutrition in the solid (C_A) is the function of the radius (r) and the immersion time (t). It is also assumed that initial concentration of nutrient (C_{A0}) is equal throughout the pellet with radius R and height z. The release mechanism is by diffusion of nutrient from the inside of the matrix into the surface of pellets with the effective diffusion coefficient equal to D_{eff}. A higher D_{eff} value indicates faster release of the nutrient from the matrix. Several other assumptions were made to simplify the mass balance equation which are the release in axial direction is neglected, the pellet porosity (ε) and density (ρ) remain unchanged during the leaching test.

$$\frac{\partial^2 C_A}{\partial r^2} + \frac{1}{r}\frac{\partial C_A}{\partial r} = \frac{\varepsilon}{D_{eff}}\frac{\partial C_A}{\partial t} \quad (1)$$

$$\pi R^2 z C_{A0} = \int_0^R 2\pi r z C_A dr + VC_{A_f} \quad (2)$$

The equations were solved using MATLAB programming (MATLAB 7.10.0, 2010) using the boundary condition of maximum concentration in the inner axis of the pellets and zero at the surface. The equilibrium nutrient concentration between the solid surface with the concentration in the interface of solid and liquid is represented using a simple Henry's law. The solid liquid mass transfer is represented using film theory method. The aim of the modelling is to determine the effective diffusivity of each pellet type in Eq(1), that being correlated with the experiment data using Sum of Squared Error (SSE) method. In this experiment, the only data that can be measured is nitrogen concentration in the liquid (C_{Af}). Based on Eq(2), the total nitrogen mass balance is needed to correlate between C_A and C_{Af}. The D_{eff} of each SRF with different preparation method can be a sign of how fast the matrices release the content.

3. Results and discussion

By drying and milling the poultry manure, the odour problem was solved. The two SRF production schemes are shown in Figure 1.

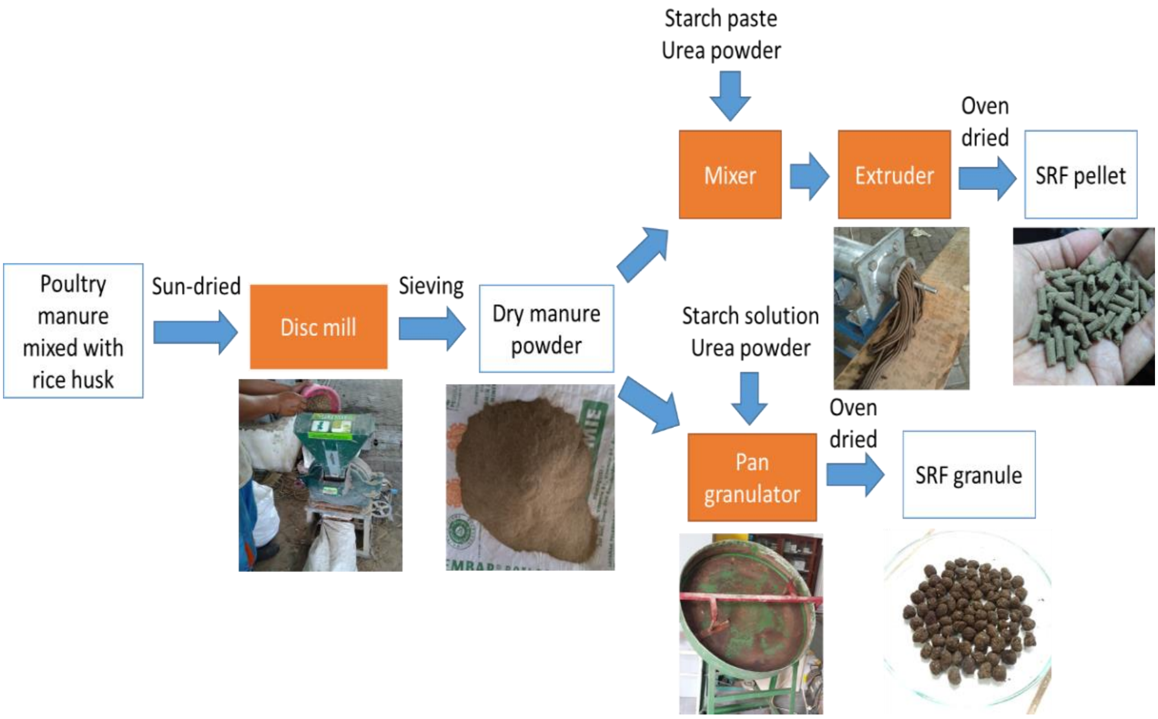


Figure 1: The SRF preparation schemes from poultry manure powder using screw extruder pelleting and pan granulating

The powder can be stored in bags for a long period of time. During dry season, the demand of compost from poultry manure declines. It is often that the manure cannot be sold and just piled up close to the farm houses which create the odour problems. The manure powdering method alone can solve many problems in poultry industry.

All the SRF preparation process was started from manure powder processing. Then, the first SRF method, which is called pellet method is conducted using screw extruder after mixing the manure powder with the binder (starch) and additional nutrients (urea). The second SRF production method is called granule method, which was conducted using pan granulator after the dry mixing step of manure powder and urea (if necessary).

During the pan granulation step, starch solution was sprayed to create the ball shape of granule. The pelleting process requires longer production steps then the granulation process. The amount of energy consumed is also considered higher for the SRF pellets production process since the production scheme requires wet mixing and the starch should be in the form of paste, which requires additional heating of the starch solution. The moisture content inside the extruded mass is higher than the granulated mixture, thus it requires more intensive drying.

The nitrogen content of poultry manure powder was also measured by dissolution and spectrophotometry method. The measured nitrogen content is 7.5 wt% which can be considered as soluble nitrogen content available inside the poultry manure. By the urea addition in SRF processing as stated above, the available nitrogen content inside the pellet/granule increase to 18 wt%. The addition of inorganic nutrient sometime is necessary since the fertiliser requirement of minimum nitrogen content to be sold in the market. By addition of urea the fertiliser can no longer being considered as organic fertiliser and it cannot be used in organic farming sites.

The release profile for each SRF type is illustrated in Figure 2. It is shown that the nitrogen content in the poultry manure pellet only (Figure 2(a)) is released gradually. Both SRFs with urea indicate similar and overlapping release profiles but the SRF pellets produce slower release rates than the granules (Figure 2(b)). The longer fertiliser release time from the pelleted samples could be due to the higher binding content and the larger pressure applied during the production stage, which creates a higher density of the compacted pelleted solid samples.

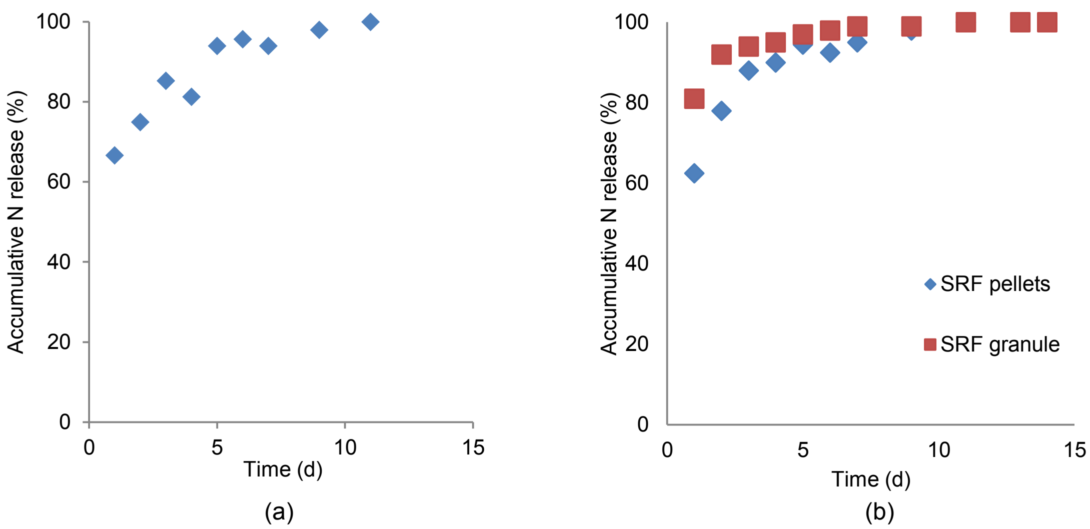
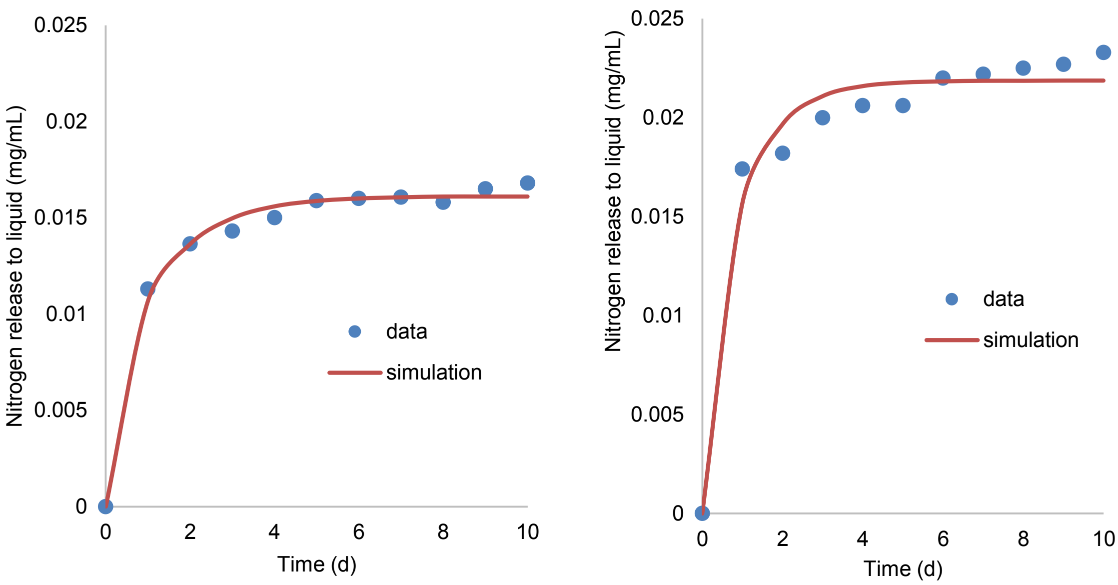


Figure 2: The release profile of the SRF samples: (a) poultry manure SRF; (b) SRF poultry manure with added urea

SRF pellet release all the nutrient content at the tenth day of the leaching test, while the SRF granule has shorter total release time. The longer retained matrix usually preferred but the other consideration should be assessed as well such as the energy requirements. Extruded system can produce the fertiliser faster than the granule, the size and shape also can be better controlled. Due to wet mixing method of the matrix with the binder and the nutrient, it requires an intensive drying stage after the mixture extrusion. The mechanical integrity of SRF pellet is also better than SRF granule. The compacting mechanism is more intense using extruder creating denser pellet with higher density.

For the release modelling, only SRF pellet can be observed. The model compares the release behaviour of nitrogen inside the pellet between only poultry manure SRF and the urea mixture SRF when it was immersed into the water. The amount of water used during the experiment was sufficiently enough to dilute all the nutrient far from its saturation limit. The diffusivity coefficients and SSE values are listed in Table 1 and the fitting curves are represented in Figure 3.

It can be noted that the release rate of low nutrient content (from pure manure SRF samples) compared to the higher nutrient content (from urea added SRF samples) is not significantly different. The release profile within 10 d of experiment is similar with fast release during the first two days and followed by slow and steady release afterward.
Based on the experimental and simulation data from Figure 3, the cumulative nutrient release for pure manure SRF is 0.017 mg/mL while for urea SRF is 0.023 mg/mL at the tenth day of immersion. It is still plenty of nutrient stored inside the matrix even after 10 d of dilution. It indicates that the poultry matrix is suitable for SRF preparation.



(a) (b)

Figure 3: Release simulation of (a) nutrient from pure poultry manure SRF pellet and (b) poultry manure with urea SRF pellet

Table 1: D_{eff} and SSE values from nutrient release simulation model

Nutrient source (wt% N)	D_{eff}, (× 1,000 cm^2/d)	SSE (× 10^{-6})
Poultry manure (7.5)	3.6914	3.2144
Poultry manure + urea (18)	2.8380	3.2577

Based on the D_{eff} values in Table 1, it shows that the SRF samples from poultry manure only has higher diffusion coefficient than the added urea SRF samples. It can be deduced that the nutrient content inside the manure poultry SRF pellet samples is released at a higher rate than the urea SRF samples. It is an interesting finding that needs to be further explored. The nutrient content inside urea SRF is more than doubled compared with the pure poultry pellet but the release profile is not much different between them (Figure 3). It suggests that there is an interaction between urea and the matrix. Somehow the matrix has a strong bound with urea molecules which prevent a fast nutrient lost. The speed of nutrient release from an SRF should be fitted with the targeted plant. For instance, SRF for yearly crops such as coffee, cocoa and palm oil require very slow release of nutrient, while SRF for fast growing plant such as vegetables, rice and corn need a fast nutrient release.
The SSE values determined are relatively small, which indicate that the simple release model based on mass balance can fit the experimental data properly. The real observation from the experimental works shows that the SRF pellets break within a certain day of immersion after swelling. Even in the mathematical model, the shape of pellet remained the same throughout the experimental process. The results obtained from the simulated model still can properly fit the data, which is indicated by small SSE value and also represented by the curve fitting. It is suggested that for future work, the mathematical model be developed to incorporate the

deformation of the pellet during the immersion experiment for better understanding of the nutrient release behaviour.

4. Conclusions

Based on the study conducted, it can be concluded that poultry manure is suitable to be used for SRF matrix to contain nutrients inside the fertiliser using screw extrusion or pan granulation method. The designed matrix does not only have ability to decrease the nutrient release rate but also add to the nitrogen availability. It was shown that the pellet SRF using extrusion method has longer release of nutrient compared with the granulated SRF.

This study has opened up a new possibility of poultry manure utilisation for SRF production with or without inorganic nutrient addition. The poultry power also has a strong bond with urea that open a possibility of SRF production specific for yearly crops. In the term of choosing a proper production scheme, the nutrient release profile of produced SRF and also other factor such as energy requirements should be properly considered. In terms of release behaviour simulation, a simple mass balance model of nutrient release from SRF matrix to outside solution can be used.

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References

Al-Zahrani S.M., 1999, Controlled-release of fertilisers: modelling and simulation, International Journal of Engineering Science 37, 1299-1307.

Azeem B., Kuzilati K., Zakaria B.M., Abdul B., Trinh H.T., 2014, Review on materials & methods to produce controlled release coated urea fertiliser, Journal of Controlled Release 181, 11-21.

Hoeung P., Bindar Y., Senda S.P., 2011, Development of granular urea-zeolite slow release fertiliser using inclined pan granulator, JTKI 10, 102-111.

Liang R., Liu M., 2006, Preparation and properties of coated nitrogen fertiliser with slow release and water retention, Industrial & Energy Chemistry Research 45, 8610-8616.

MATLAB 7.10.0, 2010, The Mathworks Inc., Massachusetts, USA.

Rashidzadeh A., Olad A., 2014, Slow-released NPK fertiliser encapsulated by NaAlg-g-poly(AA-co-AAm)/MMT superabsorbent nanocomposite, Carbohydrate Polymers 114, 269-278.

Xiaoyu N., Yuejin W., Zhengyan W., Lin W., Guannan Q., Lixiang Y., 2013, A novel slow-release urea fertiliser: Physical and chemical analysis of its structure and study of its release mechanism, Biosystem Engineering 115, 274-282.

Yu L., Ni X., Wu L., Wu Z., Wu Y., Zhang H., Cai D., Qiu G., 2011, Built-in Screen Type Controlled – Release Urea as well as Production Method and Its Application, Chinese Patent, CN 102173962 A.

Zhang Y., Zhao L., Chen Y., 2016, Swelling Properties and Environmental Responsiveness of Superabsorbent Composite Based on Starch-G-Poly Acrylic Acid/Organo-Zeolite, Journal of Macromolecular Science: B 55 (7), 662-679.