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Research article

Manure from biochar, bentonite and zeolite feed supplemented poultry: Moisture retention and granulation properties

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ABSTRACT

Feeding treatments were imposed in two feeding trials involving Cobb broiler and Bond Brown layer birds. Three feed additives (biochar, bentonite and zeolite) were supplied at four rates (0, 1, 2 and 4% w/w) in feed, as previously considered in the context of animal production, was considered in the context of Excreta chemical and water retention properties and granulation characteristics of decomposed excreta (manure) were characterised. At field capacity (− 0.01 MPa), manure produced from control and 4% bentonite diets contained significantly ($p = 0.001$) more water (at 1.93 and 2.44% v/v water, respectively) than zeolite and biochar treatments. Manure mesoporosity was significantly ($p = 0.015$) higher in 2 and 4% bentonite treatments than other feed additives. Fresh excreta from layer birds on the control diet contained 6% w/dw N and 35% C, which was decreased to 2.6% N and 28% C after decomposition, with C:N ratio changing from 5.9 to 12.1. Ammonia loss was higher from biochar and zeolite manures than control or bentonite, associated with higher pH in the biochar and zeolite manures. More N was unaccounted from bentonite manure than other treatments, presumably lost as N_2O or N_2, a result linked to its higher moisture content and its enhanced rate of denitrification. The highest proportion of granules in the size class desired for fertilizer spreading was achieved using decomposed manure from the 1 and 2% w/w biochar treatments of the broiler trial, and 1 and 2% zeolite and 4% biochar treatments of the layer trial. Thus the feed amendments improved poultry manure in specific ways.

1. Introduction

The value of biochar as a soil amendment has been documented in terms of its water retention, cation exchange capacity and impact on soil microbial populations, with the added attraction of acting as a long-term C store (e.g. Lehmann, 2009). However, use of biochar in broad scale agriculture is extremely low, due to the cost of biochar and difficulties in handling a dirty, powdery material. A potential ‘game changer’ is the use of biochar in animal feed (e.g. Joseph et al., 2015; Prasai et al., 2016), and in composting (Li et al., 2016), with positive impacts reported in terms of animal production and rate of composting. In this scenario, biochar is delivered in a nutrient rich waste stream (animal excreta) which can be processed for delivery as a fertilizer. With repeated fertilizer applications, biochar will accumulate in the soil.

Poultry manure (also termed excreta) is composed of uric acid and faeces. In non-caged production, manure is mixed with floor materials (sawdust etc.), producing litter. Both manure and litter may be used in composts. Poultry manures represent an excellent base for preparation of organic fertilizer, given their point source of production and relatively high content of plant essential elements (Harmel et al., 2009). Indeed, use of poultry manure both as a fertilizer and soil ameliorant solves a disposal problem for large scale poultry production (Friend et al., 2006; McGrath et al., 2010). In Australia, total litter output from broiler production in 2013/14 was estimated to be over one million tonnes per annum (Wiedemann, 2015). With an average content of 2.5% Nitrogen (N), this litter contains 38,750 tonne N. Similarly, the Australian egg layer flock of 17.82 million birds, producing 0.221 million tonnes of litter per year with an average content of 3% N (AECL, 2015), will contain 6634 tonnes of N. Therefore, the waste of the Australian chicken industry contains about 45,384 tonne N, equivalent to 6% of total national use of N fertilizer in Australia (800,000 tonne N, FIFA, 2012).

Many studies have reported improvement in soil properties following poultry manure addition, either direct or as compost, with a decrease in soil bulk density and increase in mesoporosity, and thus plant available water (Jones et al., 2011). The addition of

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organic material also increases the aggregate stability of soils, which results in an increased infiltration capacity and improved hydraulic conductivity (Mazurak et al., 1975; Warren and Fonteno, 1993).

Fresh poultry manure generally contains 60–78% moisture, and thus has high transport cost. High moisture also supports microbial activity with N loss as NH_3 and N_2O. The relatively low N content (compared to inorganic fertilizers), N instability and transport costs together limit the value of raw or composted manures (Adeli et al., 2009; Mahimairaja et al., 1994). Large scale use of poultry manures therefore requires use of a dried product that can be handled as current mineral fertilisers are, including use of fertilizer spreaders. This requires the material to be dried and pelletised or granulated. For example, urea pellets can withstand force of approximatley 240 Newton before crumbling (Reiter and Daniel, 2013).

Extruded pellets are created with pressure agglomeration. In contrast, granulated material is not as dense, and the formed pellets are round rather than cylindrical. A round granule can be more efficient than a cylinder in terms of spreading uniformity by a fertilizer applicator. The granulation process consists of a series of phases including drying, grinding, binder addition to the ground manure, and granulation. This granulation process requires a higher equipment investment than production of an extruded pellet, although maintenance costs may be reduced (FEECO, 2015).

There are currently no granulated chicken manure products that meet the standards required for field fertilizer applicators, i.e. are able to withstand normal handling in the fertilizer application process (Walker et al., 1997). A granulated organic fertilizer should use finely ground materials to improve the solubility/rate of breakdown, be composed of a homogenous mixture of materials, contain less than 18% moisture and be of a consistent granule size, i.e. 1–4 mm diameter (typically to pass through a No. 6 screen, 3.36 mm, but be retained on a No. 18 screen, 1.0 mm), without presence of fines which create dust and cause caking of spreading equipment (FEECO, 2015). In addition, the product should have a particle strength (breaking/crushing strength 1.5–3.5 kgf or approx. 15–35 Newton) to survive transport, handling and application, with attrition of less than 2% during handling and application. A critical factor in achieving granulation of non-sticky materials (to an appropriate crush strength) is the addition of a binder, such as bentonite, starches, latexes, molasses, calcium or sodium sulphate (FEECO, 2015), silicates and lignosulfonates (GreenAgrochem, 2015; Veverka and Hinkle, 2001).

There is potential to include inert materials in poultry diet that impact litter, composting and granulation properties. Such materials concentrate approximately four fold in the excreta, given a feed digestibility of 75%. The quality of poultry manure compost was improved with the addition of zeolite (Latifah et al., 2015) and biochar (Agyarko-Mintah et al., 2016), with improved N retention reported in both cases. Jindo et al. (2012) showed a higher diversity of fungi in poultry manure composted with biochar than in the unamended control. Khan et al. (2016) reported that co-composting of biochar and chicken manure increased the cation exchange properties (CEC) of the biochar (Khan et al., 2016). Bentonite clay can be used as a feed additive in treatment of scours (Miazzo et al., 2005), providing protection to the gut wall and decreasing free water availability in manure. In 'deep litter' poultry production, an absorbent floor material (e.g. wood shavings) is used to remove free water, with the material dried *in situ,* so materials with a high mesoporosity (water held between field capacity and −1.5 MPa) are desirable. Besides impacting granulation properties, changes to manure water content may also impact on the processes of N volatilisation and ammonification.

Prasai et al. (2016, 2017) reported on the impacts of amending feed with biochar, bentonite and zeolite, each at 1, 2 and 4% w/w, on gut microbiota and on animal production of broiler and layer birds. Excreta from those trials was used in the current activity with the aims of developing a granulated fertilizer that delivers recalcitrant C (biochar) into the soil, comparing biochar to other feed amendments (zeolite and bentonite) in the contexts of manure moisture retention, N loss and granulation properties. In the current study, the effects of the amended diets is considered in context of (i) excreta water retention, (ii) N loss in manure decomposition and (iii) granulation properties.

2. Material and methods

2.1. Excreta sources

Hereafter we use the term excreta for urine plus faeces collected from caged birds and manure for the stored/composted/decomposed excreta.

All procedures involving animals were approved by the Animal Ethics Committee of the Central Queensland University (CQU) (Approval number A 12/06–283). Broiler and egg laying birds were reared in small scale pens and cages in open air exchange sheds (as described in Prasai et al., 2017a,b) on 10 diets, i.e. rations amended with biochar, bentonite and zeolite, each at 1, 2 and 4% w/w for granulation. Detail on the feeding trials, including the properties of the biochar, bentonite and zeolites, are presented in Prasai et al. (2016, 2017a,b).

In the broiler trial, excreta was collected from each pen at weekly intervals into a 20 L plastic bin (one per experimental unit, 10 treatments x 2 replicates, i.e. 20 bins) over the period of the feeding trial (46 days) and retained for a further 35 day period of decomposition (81 days in total). The decomposed manure was then air dried in shed for 15 days. Replicate trial materials were combined (giving 10 samples, one per feed treatment) and moisture content determined ahead of granulation trials.

In the egg chicken trial, excreta was collected daily from trays below each cage, weighed and stored into 60 L plastic bins (one per experimental unit, 10 treatments x 4 replicates, i.e. 40 bins) without turning once per fortnight. This was continued for 35 days past the end of the feeding trial (239 days), giving a total incubation period of 274 days. Granulation trials were undertaken using air dried material (5 kg per treatment) from each of the broiler and egg layer trials.

2.2. Physical characterisation of excreta

During week 37 of feed amendment in the egg layer trial, excreta was collected daily from each experimental unit (40 pens) over a 6-day period. Excreta was mixed thoroughly using a spatula before collection of a 50 g sub-sample. Bulk density was measured following the method of Haynes and Goh (1978) and particle density was determined using the pycnometer method, with total porosity calculated as the difference between bulk density and the particle density (Jones et al., 2010).

Pore size distribution was assessed using a pressure plate apparatus. Sample containers (rings 30 mm diameter × 10 mm length, volume 7.07 cm^3) were filled with excreta samples and placed on the surface of ceramic plates inside the pressure plate apparatus (Soil moisture Equipment Corp, USA). Samples were saturated to ensure the moisture content was above field capacity. Pressures of −10, −200, −400, −800, −1100 and −1500 kPa were sequentially applied, each for 24 h. After 24 h, the pressure plate apparatus was opened and samples weighed immediately. At the end of the run, samples were dried at 70 °C for 48 h and reweighed to estimate water content. Mesoporosity was determined as the water remaining between −10 and −1500 kPa, microporosity as the

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