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ANALYSIS OF POULTRY MANURE UTILISATION METHODS TO PRODUCE ORGANIC FERTILISER

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Abstract. This article provides an overview of the poultry manure utilisation issues. It gives a comparative analysis of the methods of composting and vermiculation, production of organic-mineral fertilisers, granulation and thermal drying of the output raw product. Integrated combination of granulation and thermal drying is considered to be the most efficient in the poultry manure processing technology.

Key words: ammonia, poultry manure, palygorskite, clinoptilolite, adsorption.

1. Introduction

Application of intensive production processes in poultry farming results in huge accumulation of poultry droppings. According to [1], the amount of generated manure is determined either by a calculation method using an average annual litter output per middle-aged bird or by weighing. An average per-chicken output is 0.27–0.32 kg/day. As defined by the industry-specific regulations for farming design [2–3], farming wastes include manure, liquid manure, waste water, ventilated hazardous gases as well as pathogenic organisms and helminth larvae and eggs. Statistical observation data show that animal excrements, urea and manure in over 13.5 mln ton of agricultural wastes generated in recent years make 37 % (or 4.938 mln ton), phytogenic wastes make 57 % or 7.742 mln ton, and animal wastes combined with mixed waste make 6 % or 0.9 mln ton.

Primary environmental hazards which may be caused by unutilised solid wastes are associated with manure storage and accumulation with the violation of the applicable national sanitary regulations; only a small part of it is processed and utilised. Besides the “traditional” pollutants generated in the process of poultry farming, nowadays it is also necessary to consider requirements for greenhouse gases (methane, carbon dioxide and nitrogen oxide). For instance, its level can rise under the influence of litter materials – 1 m^2 of a 20 cm straw layer releases 8 mg/h of CO_2 [4]. Also, great attention is paid specifically to the nitrogen compound as an indicator in the evaluation of the negative impact on the ecosystem. Recommendations on determining the best available options to reduce ammonia emissions from farming sources are given in [5].

2. Theoretical part

The chemical composition of droppings, which content and properties depend on bird species, a keeping method, a feeding type and accumulation conditions, defines their processability. It is found in [6] that the moisture content of laying-chicken droppings is 68–78 %, pH varies within 6.8–7.4, and density is 1.04–1.15 g/cm^3. Poultry manure has different physical, mechanical and chemical properties, which depend on poultry keeping methods (litter or non-litter), bird species (hen, broiler chicken, duck, goose, turkey) and age (30 or 400 days rearing). The chemical composition of manure based on a poultry breeding process is given in Table A.1, Appendix A, and the dosage calculation for organic mixture for soil application is provided in Appendix B [7].

Solid manure composes of organic matter by 80 % (4.1 % – crude fat, 14.3 % – crude fibre, 46.9 % – nitrogen-free extractive substances, 9.3 % – aminoacids, 7.3 % – admixtures), the rest are: 4.6 % – total nitrogen, 2 % – total phosphorus, 1.7 % – potassium oxide, 8.6 % – calcium, 0.03 % – copper, 0.03 % – iron, 0.02 % – zinc, 0.7 % – magnesium, 0.3 % – magnum [8]. According to the data provided in [9], the average nitrogen content in poultry manure (total N) is 1.5 %, average ammonium-N in poultry manure (in total N) is 7 %, and N protein (in total N) is 40 %. The nitrogen-containing organic compounds are decomposed under the action of urobacteria with the generation of ammonia. Phosphorus in poultry manure is not fixed in soil in form of iron, aluminium or calcium phosphate, and therefore is better assimilated by plants as compared to phosphorus of mineral fertilisers. An assimilable form of nitrogen contained is up to 50 %, phosphorus – up to 20 %, and calcium – up to 70 %.

The initial stage of manure production is accumulation of droppings in a dung yard. During storage of pure poultry manure, its losses can be as follows: by organic matter – up to 30–60 %, by nitrogen – up to 36 %, by phosphorus – 12 %, by potassium – 10 % [6, 10, 11].

Based on a chicken keeping method and a process of dung removal from poultry farming premises, the manure storage can be aboveground, deepened (to 1.5–2 m) or semi-deepened. The bottom and walls of the manure storage are made of concrete and lined up with panels and hydroisolation. The storage for liquid manure is arranged at the depth of up to 2.5 m, which is made of reinforced-concrete structures. Dimensions of the manure storage depend on bird species, manure volume and its storage period (usually 2–3 years). Along the storage perimeter drainage ditches for filtrate must be arranged. A designated room used for processing of droppings gives an advantage over open grounds. This allows for automatizing special equipment and arranging inlet/exhaust ventilation in order to reduce ecological and sanitary-hygienic hazard for the environment and staff of a farm.

Poultry droppings utilization methods are studied by scientists and technologists for a long time [12]. They involve development of efficient ways of manure storage in a dung yard, composting in heaps and worm composting, thermal drying at different temperatures (65 to 1000 °C) to receive powderette, anaerobic and biologic fermentation using aerobic meso- and thermophylic bacteria to produce biogas, and pyrolysis for production of heat and energy. Also, studies are carried out in the area of formation of balanced compositions of organic and mineral fertiliser, which would combine favourable properties of both organic and mineral fertilisers as a result of change of the phosphorus and nitrogen content. The engineering solutions above are considerably power-consuming, and require improvement, thorough compliance with the process conducting conditions, and sometimes big investments.

Composting Method. Usually, studies on composting with the use of natural sorbents (straw, turf, sawdust) are a primary way to ensure long-term preservation of nutrients in poultry manure. Composting is carried out either on concrete plots or in specially formed heaps. Taking into consideration the specifics of operation of a poultry farm: bird species (laying hens or broilers) and a keeping method (litter or non-litter), organic fertilisers can be produced by following methods [13]:

1. Passive composting – manure is mixed or piled layer-by-layer with one of the components (total weight %): turf (25–30 %), straw (15–20 %), sawdust (30–50 %). Organic mixture is stockpiled up to 2.5 m on field plots. Organic fertiliser is formed within 3–6 months, and pure humus is formed after 6 months. However, intact manure has poor physical and mechanical properties. It is non-flowing, sticky and difficult to transport, pack and distribute uniformly for nourishment. The product becomes the most valuable after its thermal drying.

2. Intensive composting takes 6-7 days as a result of vital activity of mesophylic and thermophylic bacteria and added ferments. This fertiliser is usually sold to consumers.

To study of the composing process [14], vital activity of microorganisms [15] and the moisture content in compost [16]. Heaps are formed 1–2.5 m high, up to 3–3.5 m wide and 50 m long. There are two methods of composting: layer-by-layer and focal. The heap surface is regularly moistened (with 40 l/t several times). The amount of water required for balancing the moisture - content must be 150–250 l/t of raw product in order to ensure the appropriate moisture content of the processing product at the level of 55–65 % [17]. The composting process creates a complex system between manure, microorganisms, moisture and soil oxygen. Microorganisms (bacteria, actinomycetes, fungi and yeasts) consume organic waste in process of their vital activity, producing heat, water, methane, carbon dioxide and humus, including humic acids. Therefore, usually it is necessary to pre-apply adsorbing materials like straw or turf (up to 50 cm) as bedding and a top layer.

Temperature is an indicator of the composting process phases passed. Thermal processes in heaps occur under mesophylic (40–45 °C) or thermophylic (55–65 °C) conditions, which are not enough to completely eliminate pathogenic organisms. During the first phase that is formation of a composting heap, microorganisms create conditions for their existence. Throughout the second phase (1–2 weeks), the population of mesophylic microorganisms rapidly grows, resulting in temperature rise inside of a heap up to 40–45 °C. With the temperature increase to 55–65 °C, the thermophylic population of microorganisms actively develops. It is found that in process of composting the population of microorganisms exceeds the equivalent values in 10 to 20 and sometimes even in 50 times [6]. At temperature above 60 °C most pathogenic organisms die and at beyond 70 °C vital activity of thermophylic microorganisms stops. Therefore, the temperature is then reduced to 45 °C again. This is an attenuation phase [15]. The main phase of maturing can last several months.

The balance ratio between carbon and nitrogen must be C:N = 1:(25-30). When the nitrogen concentration is lower, microbial metabolism decreases as well. Excessive nitrogen results in formation of ammonia and other gases released to the ambient air, which cause foul smell. With the increase of pH >7, nitrogen loss in form of ammonium rises. At the end of the composting process pH = 8.0–9.0. The optimal moisture content in order to preserve nitrogen in biomass is within 50–70 %. High biomass temperature also facilitates ammonium emission to the atmosphere [6].

Reduction of the period of stay of manure in heaps is subject to multiple research studies. The method of production of prolonged-action straw and manure compost [18] involves admixing a filler, in particular, straw of 64 % moisture content with poultry manure of 76 % moisture content at the ratio of 1:2, followed by composting for 30 days. In [19] poultry manure of 90 % moisture content is mixed with a filler (straw, sawdust) in a fast-rotating aerating mixer at the weight ratio of 1:3, with composting during 21 days. The composting period is reduced on account of intensive enrichment of a mixture with air oxygen. The disadvantage is the lower nitrogen content due to ammonium emission, which pollutes the atmosphere, as well as presence of pathogenic organisms.

The advantages of composting are simple and inexpensive process, the ability to constantly monitor the process phases and production of high-quality biological humus. The disadvantage is high loss of nitrogen during gas emission – up to 30–60 %. In addition, according to the data of the field project [20], the temperature of manure mass inside of a heap does not rise above 36–38 °C because of the influence of various weather conditions and insufficient aeration, resulting in incomplete decontamination from pathogenic microorganisms, as well as uneven rotting.

In order to speed up and improve the process of biohumus production, in recent decades studies are conducted on the utilisation of vermiculture, e.g. [21–23]. The method of poultry manure processing by vermiculation [24] involves adding straw, sawdust, turf and sand to manure at a certain ratio before fermentation, and populating worms in the finished substrate after fermentation. Despite of the benefits of use of earthworms, vermicomposting has some disadvantages as well, including: long durability of the process (4–6 months) at the temperature of +16–24 °C, uncontrolled microbiological processes and separation of worms from biohumus [25].

Currently, the process of application of organic fertiliser in form of composts is low-profitable because of high costs for transportation. Organic fertilisers unlike mineral ones are still applied either by throwing out at fields with following ploughing (for humus) or by spraying from mobile tanks (for liquid fertilisers) [26].

Method of Production of Organic-Mineral Fertiliser. Studies are also carried out in the area of formation of balanced compositions of an organic and mineral fertiliser, which would combine favourable properties of both organic and mineral fertilisers as a result of change of the phosphorus and nitrogen content.

Organic-mineral fertilisers (OMF) are various types of fertilisers cored with nitrogen, phosphorus or potassium nutrients or their combination, and coated by organic matter. They differ as by physical and chemical properties as by components they are composed of. OMF production processes differ by the content of organic matter (poultry droppings, cattle manure, sapropel, lignin) and by admixtures, which change the manure properties [27]. The way of production of an organic-mineral fertiliser by mixing poultry droppings with zeolite and/or activated carbon, bentonite, phosphoric flour, superphosphate and phosphogypsum is described in [28].

In [29] it is suggested to add brown coal (3 %), montmorillonite (10 %), clinoptilolite (45 %), chemical composition corrector (5 %) and pH corrector (7 %) to litter (30 wt %) from a poultry house. The disadvantage of this method is increased excessive moisture in product (30-40 %) and high content (58 %) of natural sorbents making the fertiliser more expensive. The patent [30] suggests adding gypsum at 5 wt % and mineral fertilisers (e.g. 10 wt % of ammonium nitrogen, 5 wt % of double superphosphate, and 7 wt % of potassium sulphate) to poultry manure in the amount of 73 wt % and with the moisture content of 78 %. The obtained mass is grained to homogeneous 30–450 µm pulp. Drying and granulation are performed by dispersing organic-mineral pulp into a pseudoliquid layer at 55–90 °C.

OMF of UkrTechnoFos, LLC, is composed of the following components: fresh and dry sludge from waste treatment facilities, turf, phosphogypsum, tuff, ammonium nitrate and NPK mineral components. Research is carried out to produce organic-mineral bioactive fertilisers (OMBF) based on droppings initially decomposed anaerobically in a bioreactor. After that, the mass is mixed with mineral ingredients and granulated. Biogas, dung and saturated ammonia water are used for their intended purpose [31–32]. [33] provides the results of studies of the following commercially produced fertilisers:

1) Ecobiom-F Organic-Mineral Bioactive Fertilisers (OMBF), produced based on native non-litter poultry manure added with sawdust, turf, mineral components, sorbents and ion-exchangers, and specific biota in process of composting. The fertilisers are composed of: total forms of nitrogen – 3 %, phosphorus – 3 %, potassium – 3 % and organic matter – 60 %.

2) "Dobri dobryva" OMF, produced based on native poultry manure mixed with sorbents (containing magnesium, zinc, copper and cobalt microelements) and mineral fertilisers (NPK), which are composed of total forms of nitrogen – 2 %, phosphorus – 3 %, potassium – 5 % and organic matter – 30 %.

3) "Vitafield" OMF, produced based on poultry manure added with mineral fertilisers. They are composed of: total forms of nitrogen – 3 %, phosphorus – 2 %, potassium – 5 % and organic matter – 62 %.

The basic requirement for safe utilisation of these fertilisers must be compliance of their dosage by the NPK content with the ecological regulations.

***Granulation Method*.** We believe that one of the most efficient methods of utilization of poultry droppings is granulation followed by drying. The advantages of this process are following:

– a fertiliser is almost sterile from pathogenic organisms and weeds;

– manure dried at relatively low temperatures contains 80–85 % of organic matter, 4–5.5 % of total nitrogen, 2.6–2.8 % of P_2O_5, and 1.3–1.8 % of K_2O;

– after thermal drying the manure weight drops in 3–4 times, resulting in substantial cut of storage and transportation costs;

– today, all agricultural machines are fully equipped for application of fertilisers in a granulated form.

Granulation by an extrusion method is performed under special conditions – in a granulating press with ring or flat dies. A granulating press consists of a press mounted on a frame, and a mixer. The press is intended for producing granules by pressing through the radial openings of a ring die with its pressing rollers.

Formation of granules, provided that manure is in a pseudo-liquefied condition, occurs because of the dispersion of liquid manure with nozzles into a free space of a dryer followed by pressing of the received powder. The heat-exchanging process during granulation in fluidized bed dryers is different from regular drying because of constant supply of fluid and 10–20 µm organic particles to the granule surface. Heat-exchange intensity depends on an air temperature and a heat medium supply rate as well as a particles size and their physical and chemical properties [34].

The disadvantages of granulation in a pseudoliquified state are:

1) inefficient decontamination from pathogenic microorganisms because of short-term keeping (15–20 s) in torch flame – microorganisms remain heat-insulated by the top layer of particles;

2) high residual moisture (within 18–20 %), because pressing granulation is impossible with lower moisture content, and non-plastic forming consistency as a consequence;

3) low packing density of the granulated product, which increases costs for packaging, storage and transportation.

Unlike fresh poultry manure, dried manure (powderette) has low packed density (0,25–0,3 t/m^3) that is high dust-making propensity. In order to avoid this, manure must be granulated. Packed density of granulated manure is 0.6–0.65 t/m^3, which allows to reduce storage area at least twice and enhance environmental safety for employees. Table 1 provides numerical values of manure weight and volume change after drying, granulation and incineration.

Table 1

Weight and volume change values required for manure storage [20, Tab.43, p.183]

Aggregate state of poultry manure	Weight as of initial value, %	Required volume for storage, m^3
Fresh poultry manure (moisture content 70 %)	100	1.5
Dried manure (powderette)	35	4.0
Granulated manure	35	1.5
Ashes (after incineration)	3.5	5.0

Thermal drying of droppings is performed in special plants (dryers) of different types: cylinder (concurrent and countercurrent) dryers, shaft cylinder dryers, fluidized bed dryers, duct and belt dryers, and contact (conductive) dryers. The disadvantage of thermal drying of manure is high cost of a heat carrier. 1 t of droppings to be dried requires 450–500 kg of conditional fuel.

In cylinder dryers manure is dried by scattering from blade to blade when the cylinder rotates. A heat carrier (hot air or furnace gases) is supplied by concurrent or countercurrent flow. In duct dryers drying occurs in process of movement along the runway in a duct with brick walls. Hot air heated by heaters is used as a heat carrier. In belt dryers a heating agent is circulated through a material layer from the bottom upward and from the top downward, and along the transporter by concurrent or countercurrent flow.

Drying temperatures may vary within 80 °C to 1000 °C, depending on a dryer's type. The primary task is to eliminate pathogenic bacteria, viruses, larvae and helminth eggs. In concurrent dryers manure is decontaminated at the temperature of inlet gases from 800 °C to 1000 °C, outlet gases – from 120 °C to 140 °C, and the exposure for at least 30 min. In countercurrent dryers the raw product is decontaminated at the temperature of inlet gases from 600 °C to 700 °C, in a cylinder – from 220 °C to 240 °C, cylinder outlet gases – from 100 °C to 110 °C and the exposure from 50 to 60 min. In this case, manure temperature does not exceed 90 °C. The product is dried until the moisture content is 10–12 % [35].

According to the data given in [6], poultry manure dried at 600–700 °C loses up to 18–50 % of total nitrogen, up to 4–12 % of non-organic litter and up to 6–18 % of potassium.

[36] provides the results for manure drying kinetics in a wide range of variable heating load (70 to 700°C) and particle size (1 to 6 mm), as well as under various heat-carrying rates (1–3–5 m/s), which may be used in calculations for a specific dryer. Particles 4÷6 mm in size in process of their drying at above T=500 °C started to blaze up without reaching the balanced moisture content.

In [37] thermal treatment of the output raw product is performed in a drying oven by countercurrent flow with a heat carrier by three stages: the first stage at 90-100 °C, the second stage at 270 °C, and the third stage at 650–700 °C. A process with the step-by-step temperature increase prevents from losing much of valuable nitrogen because of the ammonium release.

In [38] it is suggested to reduce moisture in part of poultry manure from 70 % to 15–18 % with following grinding in a rotation chamber. Temperature inside of the chamber rises up to 70–90 °C as a result of friction in process of grinding. The product dehydrated in this way is then returned to the basic mass in order to form granules (which results in moisture reduction from 70 to 65 %). The produced granules are dried up to the moisture content of 35 %. The disadvantages of this method are ammonia emission, remained pathogenic microorganisms and wet litter straw which is difficult to grind.

In Patent [39] thermal treatment of the output raw product is performed with a heat carrier in a cylinder dryer at T=1200 °C at the initial stage with the temperature decrease to 400–600 °C at the final stage, with 10–12 % moisture content in the finished product. The disadvantages of this method are loss of organic matter in manure, high temperature of thermal treatment which may cause microclimate change, and long duration of the process (5 hours).

In the method of drying with hot gases first the material moves by a countercurrent flow horizontally with gradual heating of the mass. After reaching the area of maximum temperatures, it is turned back, running afterwards by a concurrent flow with hot gases. At the same time, it is separated under own weight by fractional composition of the finished ground product [40].

In Patent [41] it is suggested to use part of manure as biofuel for incineration. The received mixture with 20–25 % moisture content is granulated and dried to 12–14 % with heated (by manure incineration) air.

Thus, we can make a conclusion that granulation followed by thermal heating is an efficient solution to preserve all favourable properties of poultry manure. Certainly, this method has as advantages as disadvantages. In general, the disadvantages include high cost of equipment and heat carriers, loss of a certain amount of ammonia and organic matter in manure, and possible variation of microclimate in process of thermal treatment. The meaningful advantages are relative moisture content (12–15 %), absence of foul smell of the product and convenient packaging and soil application [12].

Conclusions

The analysis of the above methods shows that new types of fertilisers are being developed. They are characterised by higher effectiveness as compared to conventional mineral and organic fertilisers. Researchers are in search of the ways to increase durability and reduce nitrogen loss. Poultry manure processing requires preservation of certain material parameters such as the appropriate moisture content, fineness and uniformity of the mass. All this will stipulate selection of the poultry manure production process.

Advantageous and trending is development of the technological process aimed at production of granulated organic fertiliser of prolonged action, which is the source of permanent and uniform nourishment of plants with the ammonium form of nitrogen. The benefits of dry granulated organic fertiliser are convenience for consumer handling and application operations; easy fertiliser dosing directly into a seed hole (precise or local sowing) helps to distribute it evenly, which significantly increases the agrochemical efficiency. Due to granulation, fertilisers preserve better. They are slowly washed out by ground water and do not dust. Granulated fertilisers have higher flowability and density as well as light granulometric content making pneumatic transportation, dosing, packing, automation and mechanisation of the production processes easier.

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