GOOD MANURE MANAGEMENT: CASE STUDY OF DAIRY FARM WITH LOOSE HOUSING SYSTEM

Roman Uvarov, Natalia Vasileva, Ekaterina Vorobyeva
Federal Scientific Agroengineering Centre VIM, Russia
rauvarov@gmail.com, vasileva0203@yandex.ru, ekaterina.vorobyeva@gmail.com

Abstract. One of the most important directions of economic development is improving the environmental safety of production. Farm manure is the factor, which has the greatest effect on the environmental sustainability of the local agroecosystem. The rational manure handling system reduces the negative impact on the environment. Application of sustainable nature management principles allows producing various types of useful products, for example, bedding for farm animals. Thereby, the economic costs of manure processing and the purchase of bedding materials drop, and the production profitability increases. Three manure-processing options, which are used to produce bedding from manure, were considered for a dairy farm with the cow stock of 100 head. Option 1 – solid-liquid manure separation, aerobic fermentation of the solid fraction in a drum bio-fermenter and long-term storing (maturing) of the liquid fraction. Option 2 – mixing the native manure with peat and the subsequent aerobic fermentation in a drum bio-fermenter. Option 3 – mixing the native manure with peat and the subsequent aerobic fermentation in a chamber bio-fermenter. According to the study results, Option 1 had the capital costs of 395 914 EUR, the operational costs of 151 302 EUR, the labour inputs of 0.45 man-hours·t^{-1}, and the payback period of 2.5 years. Options 2 and 3, requiring the addition of peat as a moisture absorber, showed higher capital costs (1 416 571 EUR and 1 030 429 EUR, respectively), operating costs (457 305 EUR and 376 922 EUR, respectively) and labour inputs (0.84 and 0.94 man-hours·t^{-1}, respectively), resulting in negative profitability. The choice of a rational manure-processing technology allows the farmers to reduce costs and to receive an additional profit.

Keywords: manure handling, bedding, solid-state fermentation, economic viability.

Introduction

The changes observed in various sectors of the economy in recent years also apply to agriculture. Intensification of farming, introduction of best available techniques (BAT), and transition to new livestock housing practices result in higher volumes of both main agricultural products – milk, meat, eggs, animal and poultry stock, and the associated waste – animal and poultry manure [1].

Many livestock enterprises do not have their owned agricultural land sufficient for the application of all manure produced. Therefore, they are forced to search for new, more efficient ways of manure processing and use. One such method is to produce manure-based bedding for farm animals. This technology was first tested in the 1970s on the farms located in the arid western regions of the United States of America.

Due to the high bacterial risks, additional processing steps were added to reduce the number of pathogens in the final product by increasing the processing temperature [2]. In the past few years this technology is gradually becoming more widespread in other countries as well [3-5]. This manure processing method allows improving the farm profitability through lower manure spreading costs and lower purchasing costs of bedding materials.

The study was focused on the economic feasibility of bedding production technologies in a functioning livestock enterprise.

Materials and methods

For the study purposes a dairy farm with 100 milking cows was selected for modelling the application of three technologies to produce manure-based bedding. Annually the selected farm produces around 800 t of milk, 18 t of meat in live weight and 16 head of young animals. The farm has 100 ha of agricultural land, located at a distance of 20 km and used for growing spring and winter cereals. The farm has a loose housing system of animals [6]. The annual peat bedding consumption is 40.2 tons. Under the loose housing systems of livestock the dry matter content in the native manure is 8 %. The manure output is 10.9 t·day^{-1} or 3975.5 t·$year^{-1}$.

Three manure processing options were considered:

- Solid-liquid separation of manure with subsequent aerobic fermentation of the solid fraction in a drum bio-fermenter and long-term storing (maturing) of the liquid fraction in the manure storage [7].
- Mixing of fresh manure with peat and subsequent aerobic fermentation in a drum bio-fermenter [8].
- Mixing of fresh manure with peat and subsequent aerobic fermentation in a chamber bio-fermenter [8].

The daily and annual manure output was calculated by the methodology elaborated and tested on 30 livestock and poultry farms [9]. The daily productivity of bio-fermenters depended on their dimension range substantiated by the guaranteed disinfection of the material [10-13].

It was assumed in calculations that no other components were to be added to have the aerobic fermentation process running for both the solid fraction of cattle manure and a mixture of cattle manure with peat [14].

The economic efficiency of the considered technologies was estimated by the standard methodology for determining the economic efficiency of technologies and agricultural machinery [15]. The prices of farm facilities, machines and equipment were relevant for December 2019.

Results and discussion

Option 1. Solid-liquid separation of manure, subsequent aerobic fermentation of the solid fraction in a drum bio-fermenter and long-term storing (maturing) of the liquid fraction in the manure storage.

Mechanical separators allow achieving up to 32 % of dry matter content in the solid fraction of manure that is close to the optimal values to run the aerobic fermentation process [16].

The calculation results of the solid fraction after the manure separation are shown in Table 1.

Table 1

Characteristics of separated solid fraction of manure produced on the selected farm

Housing system	Production of solid fraction of manure		Dry matter content, %	Dry matter amount, kg·day^{-1}		Required productivity of a bio-fermenter with due account for the type and size range, t·day^{-1}
	kg·day^{-1}	m^3·day^{-1}		In manure	In solid fraction	
Loose housing	1907	2.9	32	872	610.4	2

So that the processed manure can be used as a bedding material, it must meet the animal safety requirements. According to the experiments [13], manure is reliably disinfected from pathogenic microflora and parasites within 120 hours, or 5 days, after fermentation started in a cyclic (batch) mode and within 96 hours, or 4 days – in the continuous fermentation mode.

In view of this and the dimension range of bio-fermenters, it was found in our previous study that a bio-fermenter with the productivity of 2 t·day^{-1} was needed to process the produced solid fraction of manure. At 0.75 filling degree, the working volume of the bio-fermenter's drum was 15.6 m^3 that was sufficient for its continuous operation [10]. The bedding production rate was 1.43 t·day^{-1}, considering the mass and moisture loss.

The annual amount of bedding produced was 522.2 tons that was 482 tons more than the required amount. The surplus produced can be either sold to other farms or applied to the fields as an organic fertiliser.

Option 2. Mixing of native manure with peat and subsequent aerobic fermentation in a drum bio-fermenter.

For efficient aerobic fermentation the dry matter content in the fermented substrate should not be below 32 %. This can be achieved by adding a moisture absorbing material, peat, in particular, the required amount of which is determined by the formula (1):

$$m_P = \frac{m_M \cdot (W_M - W_S)}{W_S - W_P}, \quad (1)$$

where m_P – required mass of peat, t;
m_M – mass of native manure, t;
W_M – manure moisture content, %;
W_S – substrate moisture content, %;
W_P – peat moisture content, %.

According to our calculations, 20.1 tons of peat with 45 % dry matter content need to be added to 10.9 tons of native manure with 8 % dry matter content produced on the farm daily to meet the above condition. The total mass of the substrate to be fermented will be 31 tons. To process this substrate the required equipment includes three bio-fermenters with the productivity of nine tons of the initial substrate per day with the working volume of 73.85 m^3 and 1 bio-fermenter with the productivity of 6 $t \cdot day^{-1}$ and the working volume of 49.2 m^3.

Considering the mass and moisture loss during the fermentation process, the daily bedding produced will be 23.3 t, the annual – 8 492.6 t. This amount significantly exceeds the farm's bedding requirement and sets the task of selling the surplus, as 8 452.4 tons of processed material per year exceeds the allowable amount of organic fertiliser that can be applied to the own agricultural land.

Option 3. Mixing of native manure with peat and subsequent aerobic fermentation in a chamber bio-fermenter.

The initial data on the amount and humidity of the substrate to be fermented are the same as in Option 2. The annual amount of substrate is 11 323.4 t. In general, the organic waste processing in chamber-type bio-fermenters has lower intensity compared to drum bio-fermenters resulting in smaller moisture loss and a longer fermentation process. With this fact in mind, the annual amount of bedding produced in these installations is 9 058.7 t.

A distinctive feature of aerobic fermentation in chamber bio-fermenters is the cyclical (batch) process. It is impossible to remove a part of the ready product and to replenish partly the bio-fermenter every day. The production of bedding has more stringent sanitary, hygienic and moisture content requirements for the resulting product compared to the organic fertiliser production. Therefore, the duration of one bio-fermentation cycle was taken to be 8 days [17-19].

Depending on the filling degree of the biofermenter and the processed material (substrate) density, the capacity of one chamber bio-fermenter is 55-65 t of the initial substrate [16]. In our calculations, a capacity of 60 t was adopted. Therefore, 6 chamber bio-fermenters are required to process the prepared substrate. The sequence diagram of filling the chamber bio-fermenter is shown in Table 2.

Table 2

Sequence diagram of filling the chamber bio-fermenter

Biofermenter	Fermentation cycle, day											
	1	2	3	4	5	6	7	8	9	10	11	12
1	31	29	ssf	ssf	ssf	ssf	ssf	ssf	ssf	ssf	u	31
2	u	2	31	27	ssf	ssf	ssf	ssf	ssf	ssf	ssf	ssf
3	ssf	ssf	u	4	31	25	ssf	ssf	ssf	ssf	ssf	ssf
4	ssf	ssf	ssf	ssf	u	6	31	23	ssf	ssf	ssf	ssf
5	ssf	ssf	ssf	ssf	ssf	ssf	u	8	31	21	ssf	ssf
6	ssf	ssf	ssf	ssf	ssf	ssf	ssf	ssf	u	10	31	ssf

31 – mass of substrate loaded in the fermenter, t;
ssf – solid-state fermentation;
u – unloading of the ready product.

The calculations of the economic efficiency of the considered manure processing technologies took into account the working volumes and areas of facilities, vehicle performance, production rates and recommended application rates of solid organic fertilisers.

Option 1. Solid-liquid separation of manure, subsequent aerobic fermentation of the solid fraction in a drum bio-fermenter and long term storing (maturing) of the liquid fraction in the manure storage require the following facilities and equipment:

- Manure separation: one building with a volume of 9×6×3 m^3 (11 570 EUR); one accumulation tank with a volume of 9×4×3 m^3 (7 715 EUR); one screw separator of specified productivity (35 000 EUR); one manure pump (5 500 EUR); one mixer (7 700 EUR).
- Bedding production: one concrete pad of 4×10 m^2 in area (1 430 EUR); one drum bio-fermenter with the productivity of 2 $t \cdot day^{-1}$ (50 000 EUR); one receiving hopper (5 000 EUR); one loading device (2 000 EUR).
- Storing facilities for the bedding production components and ready products: two storages for the liquid fraction of a volume of 2000 m^3 each (40 000 EUR); one concrete pad with a shelter of 16×10 m^2 in area (5 715 EUR).
- Transport facilities: one pipeline with a pump (7 850 EUR); one tractor of 2.0 drawbar category (35 715 EUR); one trailer with a 6 t capacity (12 140 EUR); one front-end loader with at least a 1.5 m^3 bucket (42 850 EUR).
- Organic fertiliser application: one tractor of 2.0 drawbar category (35 715 EUR); one machine for solid fertiliser spreading with a 6 t capacity (14 285 EUR); one tractor of 3.0 drawbar category (45,700 EUR); one machine for liquid fertiliser application with an 11 t capacity (30 000 EUR).

Option 2. Processing of manure mixed with peat in a drum bio-fermenter requires the following facilities and equipment:

- Bedding production: one concrete pad of 20×15 m^2 in area (10 715 EUR); one drum bio-fermenter with the productivity of 6 $t \cdot day^{-1}$ (121 400 EUR); three drum bio-fermenters with the productivity of 9 $t \cdot day^{-1}$ each (535 600 EUR); four receiving hoppers (20 000 EUR); four loading devices (8 000 EUR).
- Storing facilities for the bedding production components and ready products: one concrete pad with a shelter to store a three-day supply of peat of 30×12 m^2 in area (12 850 EUR); one concrete pad with a shelter to store the ready bedding of 55×48 m^2 in area (94 280 EUR).
- Transport facilities: three tractors of 2.0 drawbar category (107 145 EUR); three trailers with a 6 t capacity each (36 430 EUR); two front-end loaders with at least 3 m^3 bucket each (120 000 EUR).
- Organic fertiliser application: seven tractors of 2.0 drawbar category (250 000 EUR); seven machines for solid fertiliser spreading with a 6 t capacity each (100 000 EUR).

Option 3. Processing of manure mixed with peat in a chamber bio-fermenter requires the following facilities and equipment:

- Bedding production: one concrete pad of 32×16 m^2 in area (18 280 EUR); six chamber-type bio-fermenters (214 280 EUR); one front-end loader with at least a 3 m^3 bucket (60 000 EUR).
- Storing facilities for the bedding production components and ready products: one concrete pad with a shelter to store a three-day supply of peat of 30×12 m^2 in area (12 860 EUR); one concrete pad with a shelter to store the ready bedding of 60×52 m^2 in area (111 430 EUR).
- Transport facilities: three tractors of 2.0 drawbar category (107 140 EUR); three trailers with a 6 t capacity each (36 430 EUR); two front-end loaders with at least a 3 m^3 bucket each (120 000 EUR).
- Organic fertiliser application: seven tractors of 2.0 drawbar category (250 000 EUR); seven machines for solid fertiliser spreading with a 6 t capacity each (100 000 EUR).

Comparative economic assessment of the considered cattle manure processing options to produce the bedding material is shown in Table 3.

In general, the solid-liquid manure separation significantly reduces the volume of processed waste. The relevant studies in EURpe, Asia and Russia have established that many agricultural producers consider this technology to be a fundamental one under agriculture intensification [11, 20-24]. Manure separation allows the use of more intensive, economically feasible and environmentally friendly technologies for manure utilization thereby increasing production profitability and safety [25]. Our study has confirmed this trend.

Table 3

Comparative economic assessment of the considered cattle manure processing options to produce the bedding material

Indicator	Option 1	Option 2	Option 3
Capital costs, EUR, including	395 914.3	1 416 571.4	1 030 428.6
• Buildings and structures	66 428.6	117 857.1	356 857.1
• Machines and equipment	329 485.7	1 298 714.3	673 571.4
Capital costs on a per unit basis, EUR^{-1}	99.6	356.3	259.2
Operating costs, $EUR \cdot year^{-1}$, including	151 302.2	457 304.7	376 921.6
• Depreciation	34 277.1	132 228.6	74 494.3
• Maintenance and repairs	30 642.2	120 780.4	62 642.1
• Fuel	46 255.7	92 960.0	133 840.0
• Electricity	15 627.1	38 585.7	27 195.1
• Wages	24 500	45 500	51 500
• Peat	-	27 250	27 250
Operating costs on a per unit basis, EUR per unit	38.1	115.0	94.8
Labour inputs, $man\text{-}hours \cdot t^{-1}$	0.45	0.84	0.94
Profit, EUR per unit	159 824.3	-116 714.3	-21 164.3
Pay-back period, year	2.5	-	-

Conclusions

1. Three manure processing options, which are used to produce bedding from manure, were considered for a dairy farm with the cow stock of 100 head: Option 1 – Aerobic fermentation of the solid manure fraction in a drum bio-fermenter; Option 2 – Aerobic fermentation of the manure-absorbing material (peat) mixture in a drum bio-fermenter; Option 3 – Aerobic fermentation of the manure-absorbing material (peat) mixture in a chamber bio-fermenter.
2. The annual production of bedding exceeds the farm's requirement of 40.2 t. The surplus can be either applied to the fields as a high-quality organic fertiliser or sold to other farms, thereby increasing the profitability of production. Following Option 1, 697 t of bedding is produced annually. In Option 2 and Option 3, the annual bedding output is 6,740.6 and 7189.9 t, respectively. This sets a new task for the farm to search for potential consumers of the produced material since such amounts of processed manure cannot be used for fertilisation of the own agricultural land in the regulated agrotechnical time limits.
3. The study proved Option 1 (separation of manure into fractions, aerobic fermentation of the solid fraction in a drum bio-fermenter and long-term storing (maturing) of the liquid fraction in the manure storage) to be the most economically feasible manure utilisation. This option has the lowest capital (395 914 EUR) and operating costs (151 302 EUR), the least labour inputs (0.45 $man\text{-}hours \cdot t^{-1}$) and a short payback period of 2.4 years. Options 2 and 3 require significantly higher costs for implementation and operation that ultimately results in negative profitability.
4. The choice of a rational manure-processing technology allows the farmers to reduce costs and to receive an additional profit.

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