

PRODUCTION OF ORGANIC FERTILISERS AS A WAY TO IMPROVE ECONOMIC EFFICIENCY OF SMALL FARMS

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Abstract. Russian agriculture is traditionally focused on large agro-industrial enterprises. However, currently, much is done to support small and medium-sized agri-businesses. By 2019, the share of peasant and small private farms reached 84% of the total output in certain agricultural sectors. Small businesses find it difficult to compete with large-scale farms due to the higher self-cost of their products. Organic production is a way to improve their market competitiveness. Aerobic solid-state fermentation of livestock waste makes it possible to produce high-quality organic fertilisers, which can be applied in organic farming and marketed as a standalone product. Such waste processing is an affordable tool for small farms to reduce their negative impact on the environment. The feasibility study of the aerobic fermentation technology of solid organic waste in a drum bio-fermenter was conducted for a small private farm in the Chuvash Republic, Volga Federal District of Russia, with the recyclable material being a mixture of animal and poultry manure, chopped grass, sawdust and peat, and fermenter's productivity being $1 \text{ m}^3 \cdot \text{day}^{-1}$. The study resulted in the following economic indicators: the capital costs of 21,110 EUR; the unit capital costs of 83 EUR $\cdot\text{t}^{-1}$; the operating costs of 14,585 EUR $\cdot\text{year}^{-1}$; the unit operating costs of 57 EUR $\cdot\text{t}^{-1} \cdot \text{year}^{-1}$; the labour inputs of 1.14 h $\cdot\text{hour}^{-1} \cdot \text{t}^{-1}$; and the energy inputs to produce the fertiliser of 27.0 kW $\cdot\text{t}^{-1}$. With the ready organic fertiliser's selling price being 144 EUR $\cdot\text{t}^{-1}$, the payback period of this technology will be 1.53 years (or 18.5 months). Introduction of aerobic fermentation will reduce the nutrients loss by 0.69 t N year $^{-1}$ and 0.08 t P year $^{-1}$ against the passive composting.

Keywords: manure processing, organic fertiliser, economic efficiency, solid-state fermentation, bio-fermenter.

Introduction

Russian agriculture is traditionally focused on large agro-industrial enterprises. Following the global trends in agriculture and food systems, large-scale farms produce the bulk of domestic agricultural products [1]. However, the trend towards small businesses in the agro-industrial complex emerged in the early 2000s. Currently, they account for quite a significant output share in some livestock industries. At the same time, a certain grading is observed – the further south the region is located, the greater is the share of gross product produced by small farms (Fig. 1) [2-4].

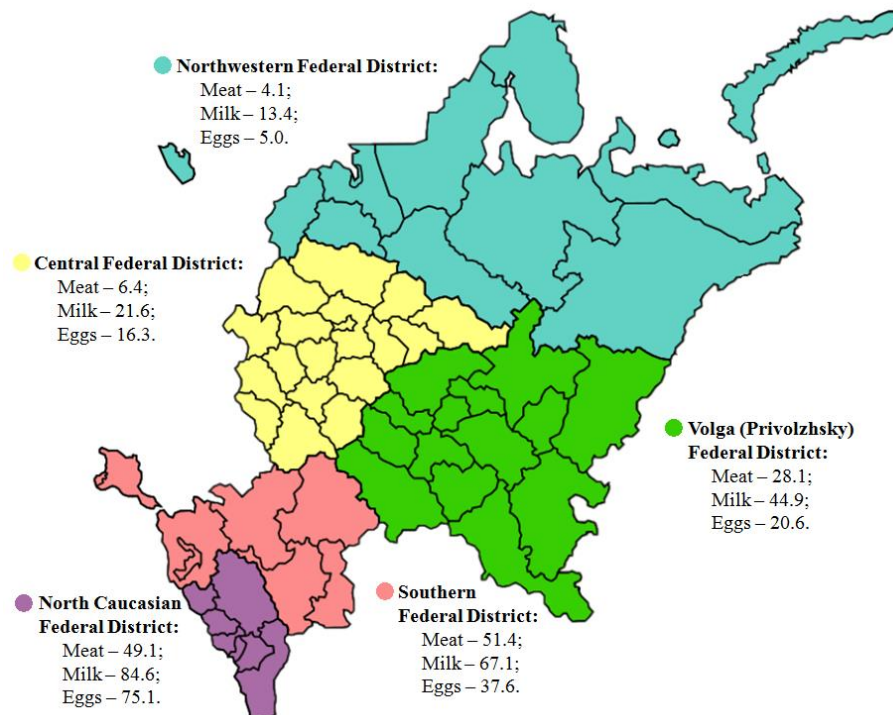


Fig. 1. Share of outputs produced by small farms in the European part of Russia (%)

Small farms do not have sufficient economic potential to compete with large agricultural enterprises. Therefore, they are forced to search for new ways to increase their economic efficiency. The transition to organic farming with a higher marketing value is a way to address this challenge. The application of organic fertilisers in crop rotations is among the major requirements of organic farming [5; 6]. The production of high-quality organic fertilisers from farm waste is also a tool of rational environmental management [7; 8]. It contributes to the mitigation of adverse environmental impact, lower greenhouse gas emissions, nutrients return to the processes of biogenesis and technogenesis, and improvement of soil fertility [9; 10].

Small farms produce relatively small volumes of waste. They can introduce a relevant best available technique (BAT), which would best suit their specific climatic and economic conditions at lower costs compared with large agricultural enterprises. The Northern countries, Russia included, have a long cold period and a short time for produced fertiliser application. Therefore, preference should be given to farm waste processing technologies with minimal dependence on external weather conditions [11; 12]. Aerobic solid-state fermentation in closed-type bio-fermenters is one such technology. Drum-type bio-fermenters provide mixing and additional aeration of the processed material, thereby avoiding material compacting and the stagnant oxygen-free zones in some parts within the bio-fermenter. This guarantees highly stable mesophilic and thermophilic processing modes and uniform compost maturing [13-15].

However, the key factor in decision-making on introducing the specific manure processing technology is its economic efficiency.

This study was focused on identifying the ecological and economic effects of organic fertiliser production on a small farm by aerobic solid-state fermentation.

Materials and methods

The feasibility study of the aerobic fermentation technology of solid organic waste in a drum bio-fermenter was conducted for a small private farm in the Chuvash Republic, Volga Federal District of Russia. The farm has 7 head of cattle, including 6 cows; 700 head of poultry: 450 chickens, 200 turkeys and 50 geese. The farm uses a bedding housing system: peat bedding for cattle and sawdust bedding for poultry. Daily manure output is $1 \text{ m}^3 \cdot \text{day}^{-1}$ or $0.7 \text{ t} \cdot \text{day}^{-1}$ that is $365 \text{ m}^3 \cdot \text{year}^{-1}$ or $255.5 \text{ t} \cdot \text{year}^{-1}$. The type and quality of processed waste are shown in Table 1.

Table 1

Type and quality of processed waste

Waste type	Mass, $\text{t} \cdot \text{day}^{-1}$	N_{tot} , %	P_{tot} , %
Cattle manure	0.35	3.0	1.8
Poultry manure	0.21	3.6	3.4
Chopped grass, sawdust and peat	0.14	1.0	0.6
Total	0.70	-	-

The drum bio-fermenter for waste processing with the productivity of $1 \text{ m}^3 \cdot \text{day}^{-1}$ (Fig. 2) was placed outdoors in a heat-insulated container.

The following electrical equipment was installed in the bio-fermenter: drive of the loading device (2.2 kW); combined motor-reducer of the bio-fermenter drum drive (1.5 kW); drive of the unloading device (2.2 kW); forced-draught fan of the forced ventilation system (1.5 kW).

The bio-fermenter had the following specifications: installed capacity of 7.4 kW, peak capacity of 5.2 kW, daily energy consumption of 18.9 kWh and one operator.

The economic efficiency of the production of solid organic fertilisers by aerobic solid-state fermentation was determined using the calculation methods specified in the Russian regulatory documents – Interstate Standard GOST 34393-2018. “Agricultural machinery. Methods of economic evaluation”, Management Directive for Agro-Industrial Complex 1.10.15.02-17. “Recommended practice for engineering designing of systems for animal and poultry manure removal and pre-application treatment” and “Veterinary and sanitary rules associated with the preparation of animal and poultry manure and wastewater, produced under conditions of infectious and invasive diseases of

animals and poultry, to be used as organic fertilisers” [16-18]. The economic effect was defined as the net profit of the small farm introducing this processing technology.



Fig. 2. Drum-type bio-fermenter

The obtained indicators were compared with the economic efficiency of solid organic fertiliser production by passive composting, which is the basic technology for organic waste utilisation in the Volga Federal District of Russia [19].

The environmental effect was calculated as the difference between the environmental pressure of passive composting and aerobic solid-phase fermentation in drum bio-fermenters in terms of nutrient loss reduction [20].

Results and discussion

The results of calculating the economic efficiency of solid organic fertiliser production by passive composting and aerobic solid-state fermentation are presented in Table 2. The equipment cost, overhead costs and wages are relevant for December 2020. The marketing cost of fertilisers is based on the average market price of such fertilisers in the Volga Federal District of Russia as of March 2021.

Table 2

Economic efficiency of solid organic fertiliser production by passive composting and aerobic solid-state fermentation (ASSF)

Indicator	Unit	Composting	ASSF
Capital costs, including:	EUR	18,890	21,110
unit capital costs	EUR·t ⁻¹	74	83
Operating costs, including:	EUR·year ⁻¹	17,783	14,585
depreciation	EUR·year ⁻¹	822	1,778
maintenance and repairs of equipment	EUR·year ⁻¹	517	1,653
fuel	EUR·year ⁻¹	4,444	-
electricity	EUR·year ⁻¹	-	514
wages	EUR·year ⁻¹	12,000	8,000
packing	EUR·year ⁻¹	-	418
transportation	EUR·year ⁻¹	-	2,222
Unit operating costs (self-cost of produce)	EUR·t ⁻¹ ·year ⁻¹	70	57
Energy intensity of production	kW·t ⁻¹	-	27
Labour inputs	h-hour·t ⁻¹	1.71	1.14
Fertiliser output	t·year ⁻¹	212.1	196.7
Marketing cost of fertilisers	EUR·t ⁻¹	111	144

Table 2 (continued)

Indicator	Unit	Composting	ASSF
Revenue from sales	EUR·year-1	23,563	28,417
Profit on sales	EUR·year-1	5,779	13,832
Payback period	year	3.27	1.53

Our previous studies demonstrated that during the processing of the same type of waste by passive composting and aerobic solid-state fermentation, the nitrogen loss was 24.2% and 6.1% average, respectively, and the phosphorus loss was 5.7% and 0.8% average, respectively [21]. The nutrient content in the source and resulting materials is shown in Table 3.

Table 3

Nutrient content

Material	Nutrient content		Nutrient loss in respect to source mixture	
	N _{tot} , t year ⁻¹	P _{tot} , t year ⁻¹	N _{tot} , t year ⁻¹	P _{tot} , t year ⁻¹
Source mixture	3.84	1.53	-	-
Compost after passive composting	2.91	1.45	0.92	0.09
Compost after aerobic fermentation	3.60	1.52	0.23	0.01

The ecological effect of introducing aerobic fermentation instead of passive composting is expressed in lower nutrients loss – 0.69 t N year⁻¹ and 0.08 t P year⁻¹.

Waste recycling by aerobic solid-state fermentation improves the profitability of production owing to lower operating costs. The higher nutritional value of the resulting fertilisers owing to smaller nutrient loss is also a contributor in this respect.

The orientation of small farms towards entering the organic food sector is one of the global trends. Most farmers process the farm waste by composting [8; 22-24]. Some farmers, however, start applying more intensive and environmentally friendly utilisation technologies including aerobic solid-state fermentation [25; 26]. Relatively high capital costs for small farms are counterbalanced by lower operating costs, the possibility of waste processing in cold period and guaranteed disinfection of the material [12; 27; 28]. The resulting fertilisers have higher commercial quality, good particle size distribution and can be sold through trade networks [14; 27].

The authors of [29] in two case studies in South Italy found the operating costs for the disposal of one ton of cattle manure to range from 9.9 to 31.5 EUR·t⁻¹·year⁻¹ depending on the animal housing system and the bedding material not including the employees' wages. The values from our study (23 EUR·t⁻¹·year⁻¹ for passive composting and 26 EUR·t⁻¹·year⁻¹ for aerobic solid-state fermentation) are near these findings. The wages of agricultural workers in Russia and Italy differ significantly. Therefore, the comparison of unit operating costs is not quite correct. In Italy, this indicator can reach 250 EUR·t⁻¹, while in Russia it is 70 EUR·t⁻¹ for passive composting and 57 EUR·t⁻¹ for aerobic solid-state fermentation. It would be more adequate for the Russian conditions to compare the obtained values with similar indicators during the upgrade of the waste management system on a large-scale farm: unit capital costs from 99.6 to 356.3 EUR·t⁻¹; unit operating costs from 38.1 to 115.0 EUR·t⁻¹·year⁻¹ [30].

Conclusions

1. The production of organic fertilisers, which can be used in organic farming and sold through trade networks, is a way to increase the profitability of agricultural enterprises. Introduction of an efficient and consistent with the principles of rational environmental management waste handling practice on small farms, for example, the aerobic solid-state fermentation, requires relatively small capital (74-83 EUR·t-1) and operational (57-70 EUR·t-1) investments.
2. In the study, the economic efficiency was calculated for a small farm with the waste output of 0.7 t day-1 or 255.5 t year-1. Two waste processing technologies were considered – passive composting and aerobic solid-state fermentation, and the payback period of 3.27 years and 1.53 years, respectively, was determined.

3. The nutrient loss in aerobic solid-state fermentation was found to be 4 to 7 times smaller than that in passive composting. The ecological effect of introducing aerobic fermentation instead of passive composting was expressed in lower nutrient loss – 0.69 t N year⁻¹ and 0.08 t P year⁻¹. Owing to the higher nutrient content, the resulting organic fertiliser contributes to more effective soil fertility improvement.

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