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The Effectiveness of Co-Digestion of Sewage Sludge and Phytogenic Waste

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Abstract: The authors explore the effect of the composition of mixtures of sewage sludge and phytogenic waste, their preliminary inoculation with a methanogenic community and the length of the process on biogas release in anaerobic co-digestion in thermophilic conditions. The study determines the effect of co-digestion products on the soil microbial community, as well as biometric parameters of the oat plants (*Avena sativa L.*). The authors demonstrate the principal possibility of co-digestion of the wastes. In terms of biogas release, the most preferable is the mixture of sewage sludge and maize silage. This mixture's co-digestion products possess fertilizing qualities.

Key words: Anaerobic co-digestion · Organic waste · Biogas · Non-traditional fertilizers

INTRODUCTION

The buildup of household and industrial waste is a topical ecological issue [1, 2]. Much of the waste that forms is organic [3]. Development of ways of waste treatment is among the promising dimensions allowing us to achieve both the ecological and economic effect. One of the ways of organic waste utilization is anaerobic co-digestion [4]. This type of processing has a number of advantages: formation of less secondary waste compared with aerobic utilization; effective processing of moist (60% and more) waste; elimination of pathogenic organisms, especially using multistage reactors or using the intermediary stage (pasteurization); the possibility of using fermentation products as fertilizers; formation of ecologically clean fuel – biogas [5, 6, 7, 8].

The characteristics of waste have a substantial effect on both the co-digestion process and biogas release. These characteristics include: the content and composition of the organic substance, the size of the particles, moisture, pH, the presence of toxic and decomposition-resistant substances, etc. [2, 9, 10].

Negative factors can be overcome through the co-digestion of waste that possesses various characteristics [10]. The increase in biogas release through the co-digestion of household sewage sludge and agricultural production waste has been demonstrated by a number of authors [11, 12, 13]. Having said that, most major publications are dedicated to the digestion of sewage sludge, while in the Russian Federation sludge is formed in cleansing mixed (industrial and household) sewage waters, which leads to the buildup of toxicants in them [14]. The effectiveness of co-digestion of such sludge and its mixtures with phytogenic waste has been explored insufficiently.

The purpose of this work is to provide an analysis of the efficacy of co-digestion of the anaerobic processing of sewage sludge and phytogenic waste.

MATERIALS AND METHODS

The object of the study is sewage sludge (SS), mixtures of SS and maize silage that has lost its consumptive qualities and sunflower husks (Table 1). The samples were co-digested adding a 10% (mass-wise) inoculate (a fermentative mass after a previous co-digestion). One of the variants of the experiment envisaged the co-digestion of SS with no inoculates.

Anaerobic co-digestion was performed in hermetically sealed vessels under 55.5°C. Every 12 hours, the vessels were stirred for 30 seconds. Fermentation was performed for 14 and 21 full days. Prior to incubation, the pH of the mixtures was adjusted to 7.5 with milk of lime. The moisture content of the initial mixtures was 92-96%.

In assessing the fertilizing qualities of fermentation products, they were introduced into urban soil (in a dose of 30 t/ha), which was first moistened to 60% of overall moisture-holding capacity and incubated under room

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Table 1: The composition of mixtures for anaerobic co-digestion

Name of variant	Composition of fermentative mixture
SS	Sewage sludge
SS+I	Sewage sludge with inoculate
SS+SH+I	Sewage sludge with sunflower husk that has lost its consumptive qualities, in a ratio of 7:3 mass-wise and inoculate
SS+Si+I	Sewage sludge with maize silage that has lost its consumptive qualities, in a ratio of 7:3 mass-wise and inoculate

temperature (22°C) for 30 full days. Subsequent to incubation, microbial biomass and respiratory activity were determined in the soil. Then the soils were seeded with oat seeds and in 14 full days biometric indicators for seedlings were assessed.

The respiratory activity of the soils was determined in accordance with ISO 14240-1 [15].

Microorganism biomass was assessed based on the determination of substrate-induced respiration in accordance with ISO 14240-2 [16].

The soil samples treated with fermentation products were biotested using *Avena sativa L.* oat seeds in accordance with ISO 11269-1 [17].

The measurement of all the parameters was performed no less frequently than in triplicate. All the graphs provide the mean value and the mean-square deviation value. The significance of differences between means was assessed using the Student criterion ($p<0.05$).

Main Part: One of the parameters reflecting the effectiveness of co-digesting the substrate is the amount of biogas released [9, 10]. In the first stage of the study, the effect of the following factors on the gas-generation process was assessed: 1) the introduction of an inoculate; 2) the composition of the mixtures subjected to fermentation. The effect of the first factor was assessed on the initial SS. In both cases, biogas release actively takes place within 15-16 full days and then the process dies down. The maximum activity of the gas-generation process in co-digesting manure, the organic fraction of solid household waste and phytogenic waste in the first 2-3 weeks has been pointed out by a number of authors [18, 19, 20]. The introduction of an inoculate stimulates the process – the cumulative volume of biogas released in the SS+I variant is 1.5 times higher than that in the SS variant. Further experiments were conducted with fermentation mixture inoculation.

In the next stage, the effect of the composition of fermentation mixtures on the effectiveness of biogas release was assessed. The maximum gas-generation period varies depending on the variants of the mixtures. Thus, for instance, in the SS+SH+I variant, the greatest amount of gas (51%) is released in the first full day. Further, the gas-generation process becomes less intensive: there is a daily release of 2-8% of the cumulative volume of gas. On the 17th full day, the process ceases completely. In co-digesting the mixture composed of SS and silage, the gas-generation process is more even: in the first full day, 12% is released and in the following 15 full days, the gas volume fluctuates insignificantly (4 to 11% of the cumulative gas volume). Starting from the 17th full day, no gas release was observed.

Based on the cumulative volume of gas released, we get the following row of the mixture variants: SS+Si+I> SS+I> SS> SS+SH+I – 2361, 1299, 878 and 813ml/kg of raw mass respectively. The addition of silage leads to a 1.8-times increase in biogas release compared with the SS variant. The ability of maize silage towards co-digestion has been mentioned earlier [21]. In co-digesting the mixture composed of SS and sunflower husks, the study recorded a lower (by 7%) amount of gas released compared with SS. This may be associated with the low accessibility of organic compounds (fiber, lignin) that form part of husk [22]. This assumption is substantiated by data compiled by Demirer and Chen [9], who have demonstrated that, as a result of the presence of lignin and fiber in the substrate composition, there is a more than 2-times decrease in the effectiveness of methane fermentation assessed based on the intensity of gas generation.

It should be noted that in all of the variants the main amount of gas (over 90%) is released in 14 full days of fermentation. Note that gas generation is the most intensive in the SS+Si+I variant (2153 ml) and the least – in the SS+SH+I variants (796 ml).

Since fermentation products contain organic substances, it makes sense to use them as non-traditional fertilizers. With this in mind, the following stage determined their fertilizing qualities. To achieve this, fermentation products were introduced into urban soil in the amount of 30 t/ha and after 30 full days the effect on the soil microbial community and plants was determined.

To assess the effect of fermentation products on the condition of the indigenous microflora of soils, two indicators were selected: biomass and respiratory activity. The level of microbial biomass was one of the most sensitive indicators for the quality of the environment [23, 24, 25, 26]. Laboratory and field studies also widely

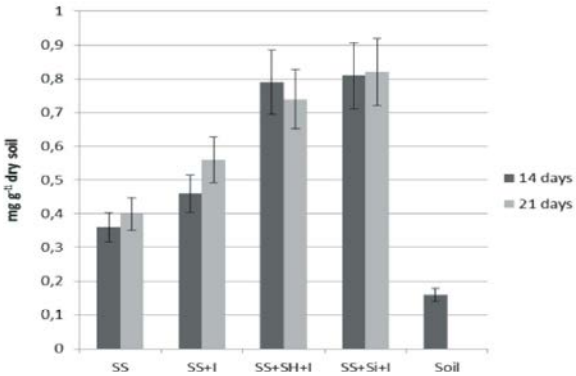

Fig. 1: Microbial biomass in soil samples treated with biogas production waste after 30 days following incubation (soil – untreated soil; 14 and 21 full days – the length of the co-digestion process)

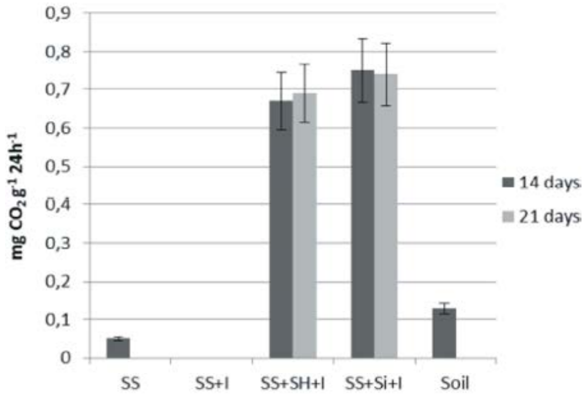

Fig. 2: The respiratory activity of soil samples treated with biogas production waste after 30 days following incubation (the notation is the same as in Figure 1)

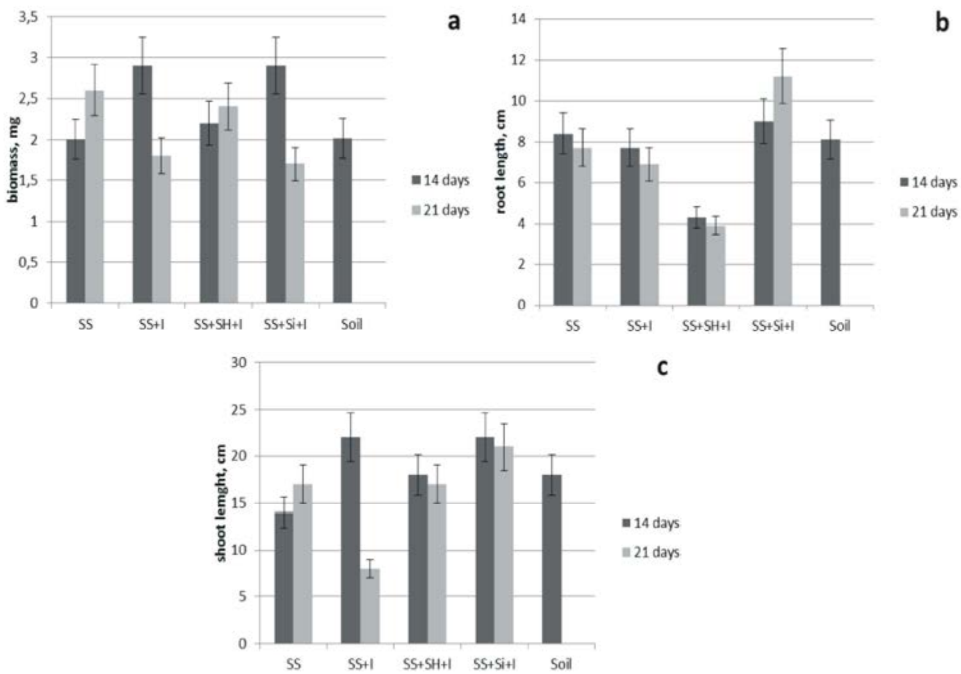

Fig. 3: The effect of soils treated with fermentation products selected on the 14th and 21st full days on *Avena sativa* L. biomass (a) and mophrometric indicators (b – length of root; c – length of above-ground shoot)

Table 2: A point-by-point assessment of the effect of fermentation products on soil

Name of variant of mixture	Length of fermentation process												
	14 full days						21 full days						
	Microorganism biomass	Respiratory activity	Plant biomass	Length of root	Height of shoot	Sum of points	Microorganism biomass	Respiratory activity	Plant biomass	Length of root	Height of shoot	Sum of points	Final score
SS	1	-1	0	1	-1	0	1	-1	1	0	0	1	1
SS+I	1	-1	1	0	1	2	1	-1	-1	0	-1	-2	0
SS+SH+I	1	1	0	-1	0	1	1	1	1	-1	0	2	3
SS+Si+I	1	1	1	1	1	5	1	1	-1	1	1	3	8

employ the intensity of mineralization of the organic substance of soil as an indicator sensitive to toxic action [20]. Besides, the indicator for basal respiration is often used for assessing soil fertility and reflects the accessibility of the organic substance to soil microorganisms, since all the carbon lost by soil with respiration must pass through the microbial pool [27].

The level of microbial biomass in soils treated with fermentation products selected after 14 and 21 full days of fermentation is provided in Figure 1. As it is seen from the data obtained, in all of the cases the introduction of fermentation products triggers a 2.3-5.1-times increase in the level of microbial biomass in soil compared with untreated soil. The highest effect is observed in introducing the fermentation products of mixtures composed of SS and sunflower husks and SS and silage. The times for fermentative mixture incubation have no effect on the level of microbial biomass in soil.

The assessment of the respiratory activity of soil revealed that the effect of fermentation products depends on the composition of the mixtures (Figure 2). Thus, for instance, the introduction of SS and SS+I inhibits soil respiration, whereas mixtures composed of SS and sunflower husks or SS and silage lead to a 5.2-5.8-times increase in it. Just like with microbial biomass, the length of incubating fermentative mixtures has no effect on the level of respiratory activity.

Since fermentation products are considered as non-traditional fertilizers, in the following stage the study determined their effect on biomass and morphometric indicators for *Avena sativa* L.

The introduction of 14-full-day fermentation products has no inhibitory effect on plant biomass; in several cases (SS+I and SS+Si+I), a stimulating effect is observed. At the same time, these products have an inhibiting effect on the length of the root (SS+SH+I) and the height of the above-ground shoots of oats (SS and SS+SH+I). The biogas production waste selected on the 21st full day of fermentation had a negative effect on the level of plant biomass in the SS+I and SS+Si+I variants, the length of the root and the height of the above-ground shoot in the SS+SH+I and SS+I variants respectively (Figure 3).

CONCLUSION

On the whole, it should be noted that introducing biogas production waste into soil has led to a variedly directed effect on plants. More specifically, in introducing the SS+I (14 full days) variant, *Avena sativa* L. biomass turned out to be 1.4 times higher than in the control variant, while in the case of the SS+I (21 full days) variant it was 1.1 times lower. This variant of the mixture, irrespective of fermentation times, has no effect on the length of the root of oat plants; note that it leads to a 1.2-times increase in the length of the shoot in fermentation for 14 full days and a 2.3-times decrease in it in fermentation for 21 full days.

To consider the whole aggregate of actions fermentation products have on soil, we assessed them point by point: if the fermentation product caused a stimulating effect in relation to the parameter, a “1” was scored, an inhibitory effect – “-1” and no effect – “0”. Then the points were summed. The results provided in Table 2 demonstrate that the length of the fermentation process had no substantial effect on the products’ fertilizing qualities in the case of the SS and SS+SH+I variants. Compared with these variants, the SS+I variant co-digestion products had varied effects on soil: the 14-full-day products stimulated the microbiological parameters and plants, while the 21-full-day ones had a negative effect on the above indicators. The highest score was with the mixture composed of SS and silage.

This mixture variant has the best effect on soil both in fermentation for 14 full days and that for 21. It should be noted that this variant has proved the most preferable in terms of biogas release as well.

Inferences: Thus, the work has demonstrated the principal possibility of the anaerobic processing of waste coming from various types of production, the co-digestion of mixtures from it being the most effective method. Based on the determination of biogas release and the quality of fermentation products, the study has determined the optimum length of the fermentation process – 14 full days. The reduction of the process time to 14 full days will ensure a decrease in energy costs and help boost the efficiency of equipment use.

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