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The Effects of Digestate and Wood Ash Mixtures on the Productivity and Yield Quality of Winter Wheat

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***Abstract*—Field trials were conducted at the Study and Research Farm "Peterlauki" (56°53' N, 23°71' E) of the Latvia University of Life Sciences and Technologies. Soil characteristics: sod-stagnogley soil; granulometric composition – heavy dusty sand clay. Soil agrochemical parameters: pH KCl 6.7; organic matter content – 26 g kg^{-1}; phosphorus content – 60 mg kg^{-1} P_2O_5; and potassium content – 144 mg kg^{-1} K_2O. Winter wheat sowings were established using different variants of a fertilizer mix with cattle (from JSC "Ziedi JP") manure digestate (D) and wood ash (P) (from LLC "Gren Jelgava") in different ratios. The norms of the innovative mixed fertilizer for cattle manure digestate and wood ash were 5, 10, and 20 t ha^{-1}. Unfertilized winter wheat plots were used as control. Variants in the two-factor trial were randomized in triplicate. In the experiment, the influence of the researched factors on winter wheat grain yield, the content of starch and protein in grains, grain volumetric weight (kg hL^{-1}), and the mass of 1000 grains were determined. The aim of the study was to determine the impact of biogas fermentation by-product (digestate) and cogeneration plant and boiler house residues (wood ash) on the yield and quality of winter wheat. Depending on the study variant, the winter wheat yield varied from 4.26 to 9.03 t ha^{-1}. It was established that the average winter wheat grain yield in the control variant was 5.29 t ha^{-1}, which is significantly ($p<0.05$) lower (5.94 t ha^{-1}) than in the variants using fertilizers of digestate and wood ash mixtures. Using digestate and wood ash mixtures, sufficiently high and high-quality winter wheat yields can be obtained without the use of mineral fertilizers. The mixtures of digestate and wood ash are an innovative fertilizer way for improving the soil fertility, which is also suitable for winter wheat.**

***Keywords*—Digestate, mixtures, winter wheat, wood ash.**

I. Introduction

The anaerobic digestion of biomass for biogas production is considered as one of the most efficient ways of renewable energy production.

As a result of anaerobic fermentation processes, digestate can have higher nitrogen and other nutrient content compared to unfermented manure [1], [2], which in turn can affect fertilizer efficiency and yield. Some short-term studies have found lower nitrogen use efficiency for organic fertilizers (slurry, digestate) compared to mineral fertilizers [3], which is probably related to the risk of nitrogen losses due to leaching and ammonium emissions [4], [5]. However, long-term studies have observed a positive effect of organic fertilizer on crop yield, which depends not only on the amount of nitrogen applied to plants, but also on other aspects of organic fertilizer use related to changes in soil fertility [6]. The different results of studies on the effect of digestate on wheat yield are explained by the interaction of many factors, including dose and substrate type [7], [8]. The effect of digestate on crop yield depends on many factors, such as soil properties, climatic conditions during the growing season, chemical composition of the digestate, and application methods [9], [10]. Studies in England compared the effects of digestate and mineral fertilizers on winter wheat yield: the nitrogen rate for both types of fertilizer was N250 kg ha^{-1}. No significant differences in biomass and grain yield were found between the use variants of digestate (respectively 19.2 t ha^{-1} and 11.3 t ha^{-1}) and mineral fertilizers (respectively 19.6 t ha^{-1} and 11.6 t ha^{-1}). Also, when analyzing the protein content in grains, no significant differences were found between the use variants of digestate and mineral fertilizers (11.52% and 11.06%, respectively) [11]. In other studies, when digestate fertilizer was used, a higher protein content was found in wheat grains compared to the mineral fertilizer variant, but no significant differences in starch content were found [12]. Due to the significant increase in the cost of mineral fertilizers and their more difficult availability, it is necessary to find alternatives to the use of mineral fertilizers and improve soil fertility as soon as possible. The

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aim of the study was to determine the impact of biogas fermentation by-product (digestate) and cogeneration plant and boiler house residues (wood ash) on the yield and quality of winter wheat.

II. Materials and Methods

Field trials were conducted in the sod - stagnogley soil of the LBTU teaching research farm "Peterlauki" with a soil reaction of pHKCl 6.7, phosphorus (P_2O_5) content in the soil of 60 mg kg^{-1}, potassium (K_2O) content in the soil of 144 mg kg^{-1}, and organic matter (OM) content in the soil of 2.6%. A two-factor experiment was set up: 1) mixtures of cattle manure digestate (from JSC "Ziedi JP") (D) and wood ash (from LLC "Gren Jelgava") (P) with different component proportions (D+P 1:0; D+P 1:1; D+P 2:1; D+P 3:1; D+P 3:1 + NPK 8-20-30 200 kg ha^{-1},in autumn; D+P 3:1 + N 64 kg ha^{-1}, in spring; D+P 4:1); 2) different norms of mixtures used for fertilization (5 t ha^{-1}, 10 t ha^{-1}, 20 t ha^{-1}).The nutrient content of the digestate and wood ash mixtures are given in Table 1.

Table 1. Nutrient content of the digestate and wood ash mixtures

Nutrients	Nutrient content			
	D+P 1:0	D+P 1:1	D+P 2:1	D+P 3:1
Nitrogen in a natural sample (N), % of fresh weight	0.29	0.27	0.30	0.51
Ammonium nitrogen (N/NH4), g kg^{-1} in dry matter	1.20	0.43	0.40	0.76
Phosphorus (P), % of dry matter	0.74	0.90	0.89	0.83
Potassium (K), % of dry matter	1.70	2.90	2.92	2.73
Calcium (Ca), % of dry matter	2.41	13.44	13.55	10.48

Note: D – cattle manure digestate; P – wood ash.

Winter wheat fields fertilized only with digestate were used as control variants. Variants in the experiment were arranged randomly, in three replications. The size of each individual plot in the replications was 30 m^2. Winter wheat pre-crop – fallow. All previously prepared mixtures of cattle digestate and wood ash were spread in the plots prepared before sowing. The mixtures were incorporated into the soil with the combined soil tiller "Farmet Kompaktomat K400", which simultaneously crumbles and levels the soil while applying fertilizer. The winter wheat variety 'Zeppelin' was used for sowing; sowing rate – 500 germinating seeds per m^2. Sowing depth – 3–4 cm; row spacing – 12.5 cm. In the spring, when vegetation was restored, 200 kg ha^{-1} ammonium nitrate (N 34.4%) was incorporated into the plots of the trial variant D+P 3:1+N. Harvesting was carried out with a small-sized combine harvester "Sampo". After threshing of the experimental plots, the yield of each plot was weighed and cleaned using the "PFEUFFER SLN3" sample cleaning device. Qualitative indicators were determined at the Biotechnology Scientific Laboratory (BSL) of the Latvia University of Life Sciences and Technologies (LBTU). Using the express analyzer "Infratec NOVA Foss", the moisture content of the samples, the total nitrogen and starch content in the grains (%) and the bulk density (kg hL^{-1}) were determined. Using the obtained result, the obtained yield (t ha^{-1}) was calculated at 14% standard moisture and complete (100%) sample purity. For the samples, the weight of 1000 seeds, in grams, was also determined using the standard method (LVS EN ISO 520). Data processing was performed using two-factor analysis of variance (ANOVA) in the "Microsoft Excel" computer program.

III. Results and Discussion

Depending on the study variant, the winter wheat yield varied from 4.26 to 9.03 t ha^{-1} (Fig.1). Using wood ash and digestate mixtures, it is possible to significantly ($p<0.05$) increase the grain yield of winter wheat. The winter wheat yield was significantly ($p<0.05$) affected by the fertilizer rate used, as well as the ratio of digestate to ash in the fertilizer. Significantly higher wheat yields were obtained when using a higher (20 t ha^{-1}) fertilizer rate, but lower yields were obtained when using lower (5 t ha^{-1}) fertilizer rates.

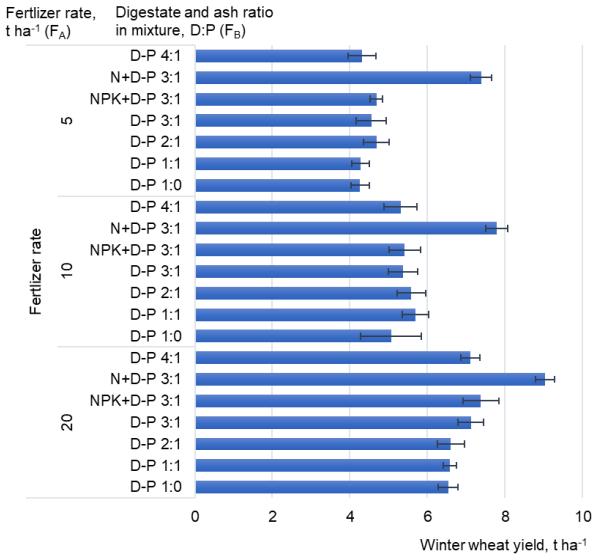

Fig. 1. Effect of digestate and wood ash mixtures on winter wheat grain yield, t ha^{-1}.

The ratio of digestate to ash in fertilizer had a significant ($p<0.05$) effect on winter wheat yield. For all fertilizer rates used (5, 10 and 20 t ha^{-1}), significantly higher wheat yields were obtained in the variant using a digestate-ash mixture in a ratio of 3:1 + N, but the lowest yields were obtained in the variant with a digestate-ash ratio of 1:0, in which ash was not used (Fig.1).

The applied fertilizer rate had a significant ($p<0.05$) effect on the following wheat quality indicators: protein content, gluten content, starch content in dry matter, Zeleny index and 1000-grain weight (Table 2, Table 3).

TABLE 2. EFFECT OF DIGESTATE AND WOOD ASH MIXTURES ON WINTER WHEAT GRAIN QUALITY INDICATORS

Fertilizer rate, t ha^{-1} (F_A)	**Digestate and wood ash ratio in mixtures (F_B)**	**Protein content, %**	**Gluten content, %**	**Starch content, %**
5	D-P 1:0	9.40	16.10	71.40
	D-P 1:1	9.50	16.27	71.37
	D-P 2:1	9.40	16.07	71.47
	D-P 3:1	9.27	15.63	71.43
	D-P 3:1+NPK	9.13	15.73	71.50
	D-P 3:1+N	10.53	18.80	71.03
	D-P 4:1	9.40	15.93	71.63
	On average	9.52	16.36	71.40
10	D-P 1:0	8.50	14.67	71.60
	D-P 1:1	9.07	15.77	71.23
	D-P 2:1	8.40	14.53	71.93
	D-P 3:1	9.17	15.47	71.30
	D-P 3:1+NPK	8.53	14.53	71.50
	D-P 3:1+N	10.77	19.53	70.87
	D-P 4:1	8.17	14.23	70.83
	On average	**8.94**	**15.53**	**71.32**
20	D-P 1:0	9.63	16.73	71.07
	D-P 1:1	10.00	17.40	71.10
	D-P 2:1	9.80	16.97	71.20
	D-P 3:1	10.33	18.10	70.80
	D-P 3:1+NPK	9.87	16.97	70.87
	D-P 3:1+N	11.23	20.70	70.07
	D-P 4:1	10.07	17.50	70.70
	On average	**10.13**	**17.77**	**70.83**
RS0.05 A (normrate)		**0.35**	**0.74**	**0.25**
RS0.05 B (ratio)		**0.54**	**1.13**	**0.39**
RS0.05 AB		0.94	1.97	0.67

Note: D – cattle manure digestate; P – wood ash.

Significantly higher protein and gluten content in dry matter was obtained by using a higher (20 t ha^{-1}) fertilizer rate, while the lowest indicators were found when using the lowest fertilizer rate (5 t ha^{-1}). Also, significantly higher Zeleny index and 1000-grain weight indicators were obtained by using a higher (20 t ha^{-1}) fertilizer rate, while the lowest indicators were found when using a lower (5 t ha^{-1}) fertilizer rate. In turn, higher starch content in dry matter was found when using lower (5 and 10 t ha^{-1}) fertilizer rates, while the lowest indicators were found when using a 20 t ha^{-1} fertilizer rate (Table 2, Table 3).

TABLE 3. EFFECT OF DIGESTATE AND WOOD ASH MIXTURES ON WINTER WHEAT GRAIN QUALITY INDICATORS

Fertilizer rate, t ha^{-1} (F_A)	**Digestate and wood ash ratio in mixtures (F_B)**	**Zeleny index, mL**	**Grain bulk density, kg hL^{-1}**	**1000-grain weight, g**
5	D-P 1:0	26.00	73.75	44.23
	D-P 1:1	26.15	74.39	45.51
	D-P 2:1	26.08	74.05	44.93
	D-P 3:1	25.94	73.84	44.90
	D-P 3:1+NPK	25.74	74.14	44.81
	D-P 3:1+N	32.80	75.34	47.62
	D-P 4:1	26.39	74.44	45.71
	On average	27.01	74.28	45.39
10	D-P 1:0	22.99	73.20	43.73
	D-P 1:1	25.04	73.64	44.38
	D-P 2:1	24.08	73.39	45.34
	D-P 3:1	24.41	73.47	43.85
	D-P 3:1+NPK	23.99	73.05	44.93
	D-P 3:1+N	35.29	75.52	47.62
	D-P 4:1	21.85	72.62	43.28
	On average	**25.38**	**73.56**	**44.73**
20	D-P 1:0	28.75	74.11	45.91
	D-P 1:1	29.50	74.90	46.54
	D-P 2:1	28.04	74.03	45.55
	D-P 3:1	31.16	74.74	46.85
	D-P 3:1+NPK	28.06	73.88	44.70
	D-P 3:1+N	37.35	74.65	46.95
	D-P 4:1	29.94	73.54	45.63
	On average	**30.40**	**74.26**	**46.02**
RS0.05 A (normrate)		**1.69**	0.68	**0.92**
RS0.05 B (ratio)		**2.58**	**1.04**	**1.40**
RS0.05 AB		4.47	1.80	2.43

Note: D – cattle manure digestate; P – wood ash.

The digestate-ash ratio in the fertilizer had a significant ($p<0.05$) effect on the following wheat quality indicators: protein content, gluten content, starch content in dry matter,

Zeleny index, bulk density and 1000-grain weight. Significantly higher protein and gluten content in dry matter was obtained in the variant that used a digestate-ash mixture in the ratio 3:1 + nitrogen. The differences in protein and gluten content between the other digestate-ash ratio variants were not significant. A tendency to form a lower protein and gluten content in dry matter was observed in the variant with a digestate-ash ratio of 3:1 + NPK. The Zeleny index, bulk density and 1000-grain weight were also significantly higher in the variant that used a digestate-ash mixture in the ratio 3:1 + nitrogen. After winter wheat harvest, the mineral residue in the soil depended on meteorological conditions and fertilizer [13], [14].

When analyzing cereal grain yields, it was found that the use of digestate can provide yields equivalent to those obtained with mineral fertilizers. For spring wheat, higher grain yields were obtained with mineral fertilizers, but no significant differences were found between different manure digestate variants [15]. One of the advantages of using fermentation residues is a higher nutrient content than in their respective raw materials. Although a significant amount of nitrogen (N) is emitted in the form of ammonium during anaerobic fermentation, and carbon (C) is released as methane and carbon dioxide, a large part of nutrients, such as N, phosphorus (P) and potassium (K), is retained [16], [17]. The content of minerals and the properties of the digestate largely depend on the properties of the substrate and the type of fermentation [18]. Digestate performs several functions, playing a beneficial role in both improving soil properties and promoting plant growth. First, digestate contains nutrients necessary for plant growth and serves as a fertilizer that improves plant productivity. Second, digestate significantly affects total soil fertility and other important soil parameters. Digestate plays a huge role in improving soil efficiency through nutrient cycling in the soil, carbon transformation, and soil structure maintenance [19]. Field application of digestate may have less short-term results due to slow mineralization rates or microbial activity [8] Nitrogen is an essential element for plant growth and soil microbial activity, and it is the nutrient most taken up by plants and is the most common limiting factor for plant growth [20]. The contribution of digestate to N availability in the soil is an important argument for its use. Digestate is particularly rich in the ammonium nitrogen (NH4-N)-N form, which is readily available to plants [21].

Digestate is a new type of waste that can be used for soil fertilization [22]. Fertilization with digestate brings an effect on crop yields increases but does not improve significantly the level of organic matter in the soil, so in longer-term it is necessary to add organic matter from other sources. [23], [24].

IV. Conclusions

The mixtures of digestate and wood ash are an innovative way for improving the soil fertility.

The results of the study showed that using digestate and wood ash mixtures, sufficiently high and high-quality winter wheat yields can be obtained without the use of mineral fertilizers. Significantly higher ($p<0.05$) winter wheat grain yield was obtained in the variant D+P 3:1 + N and D + P 3:1 + NPK.

It has been observed that to improve the quality of the winter wheat harvest, in addition to this fertilizer, it is recommended to use nitrogen mineral fertilizers. It has been found that among the studied variants, significantly higher protein and gluten content, as well as Zeleny index, were provided by the fertilizer mixture D + P 3:1 + N, regardless of the fertilizer rate.

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