The Effect of Digestate and Wood Ash Mixtures on the Productivity and Yield Quality of Maize

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Abstract. **Maize (Zea mays L.) is one of the world's most productive and prevailing crops. It is widely grown as human food and animal feed, as biofuel, and as a raw material for industry. Digestate and wood ash are the byproducts of cogeneration plants. Digestate is rich in nutrients, can provide plants with many nutrients required by the plant during its growing season, as well as improves the soil structure. The aim of the study was to determine the effect of the rates of digestate and wood ash mixture fertilizer on maize productivity and crop quality. In 2020, 2021 and 2022, in field trials with maize, the variety 'Hulk', FAO250, was used; the soil – sod-calcareous, medium-heavy sandy loam. Different variants of the mixture of cattle manure digestate and wood ash were used as a fertilizer on corn plantations. The ratios of digestate and wood ash was 1:0, 1:1, 2:1, and 3:1; fertilizer rates were 15 and 30 t ha^{-1}. In the trial, different types of fertilizers demonstrated different effects on the yield and quality of maize. The use of the new fertilizers produced on average 36.93–38.33 t ha^{-1} of high-quality maize green mass in three years without using mineral fertilizers.**

Keywords: digestate, fertilizer, mixtures maize, wood ash.

I. INTRODUCTION

Agricultural production must be carried out in accordance with environmental protection requirements. It is important to maintain the safe use of fertilizers, especially nitrogen fertilizers, in the agricultural environment. About 180 million tons of anaerobic digestion digestate is produced in the European Union annually, most of which is used as organic fertilizer [1]. Anaerobic digestion residues are products from various sources of organic raw materials, which include sewage treatment, plant sludge, agri-food industry waste (a part of household solid waste, including fruit and vegetable by-products, canteen waste, kitchen waste), green waste (agricultural and horticultural waste), animal waste (pig, cattle, etc., manure), and food waste (animal fat, used cooking oil, degreasing waste from restaurant tanks) [2].

The nutrients present in the digestate are in a form that is easily utilised by plants. Also, digestate is a plant fertilizer competitive to mineral fertilizers. The organic substances present in digestate have a positive effect on the physical and chemical properties of soil and on the soil fertility in general [3].

Digestate performs several functions and plays a beneficial role in both improving the soil properties and promoting the plant growth. First of all, digestate contains nutrients necessary for plant growth and serves as a fertilizer that improves plant productivity. Secondly, digestate significantly affects the overall soil fertility and other important soil parameters. Digestate plays an important role in improving soil efficiency by ensuring the cycle of nutrients in the soil, carbon transformation, and maintenance of soil structure [4]. Field application of digestate could have less short-term results due to the slow mineralization or microbial activity [5].

In order to use digestate as an organic fertilizer, it is usually divided into a solid (dry) and a liquid fraction. They differ in dry matter content and chemical composition, which in turn can affect biomass production differently [6].

In agricultural practice, digestate is often used as a fertilizer for crops grown for biomass production, especially for the production of biogas, as digestate is rich in nutrients. Maize is one of the most important biomass crops in Europe [7]. However, practice shows that maize cultivation is very sensitive to nitrogen losses (through leaching and gaseous emissions) and soil erosion [8].

In Germany, researches were carried out on the use of digestate's solid and liquid fractions in maize fertilization. Different digestate application variants were compared with the mineral fertilizer application variant. In all variants, the applied ratio and amount of fertilizer was calculated so that the annual fertilizer rate makes N 150 kg ha^{-1}. The researches showed that the use of mineral fertilizer gave the highest maize dry matter yields, but the use of solid digestate fraction in fertilizer produced the

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lowest dry matter yields. The use of mineral fertilizer proved to be most efficient when maize was grown in unfavourable years, i.e., when spring was cold or summer was dry [9].

Other trials in Germany investigated the effect of the application of mineral fertilizers and digestate on the yield of maize at different nitrogen rates (from N0 to N180). Certainly, the lowest average maize dry matter yield (13.4 t ha^{-1}) was obtained in the N0 variant. In the digestate fertilization variant, significantly higher corn dry matter yields (19.3 t ha^{-1}) were obtained when the nitrogen rate of 96 kg ha^{-1} was used. Significantly higher nitrogen rates (150 kg ha-1) had to be applied to obtain the same amount (19.1 t ha^{-1}) of maize dry matter yield using mineral fertilizers [10].

According to Gatenby [11], the analysed crude protein contained nutrients supporting ruminant production, i.e., 8–11%, which is recommended for the growing of ruminants. Accordingly, this amount of protein is sufficient to meet the protein needs of growing ruminants, generating significant levels of ammonia in the rumen to guarantee an effective digestion process [12]. The analysed crude protein content in maize exceeded its critical limit (7%), below which the forage intake by ruminants and rumen microbial activity would be antagonistically influenced [13].

II. Materials and methods

Field trials (2021–2022) with maize were established in sod-calcareous, medium-heavy sandy loam soil: pH KCl 6.6-6.8; phosphorus (P_2O_5) content – 50–54 mg kg-1; potassium (K_2O) content – 182–206 mg kg-1. Maize trials were carried out using fertilizer mixtures consisting of cattle manure digestate (from JSC "Ziedi JP") and of wood ash (from LLC "Gren Jelgava") at different digestate: wood ash ratios – 1:0, 1:1, 2:1, and 3:1. The rates of the innovative mixed fertilizer with cattle manure digestate for maize were 15 and 30 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 in dry matter, %			
	D+P 1:0	*D+P 1:1*	*D+P 2:1*	*D+P 3:1*
Nitrogen in a natural sample (N)	0.29	0.27	0.30	0.51
Ammonium nitrogen (N/NH4), g kg^{-1}	1.20	0.43	0.40	0.76
Phosphorus (P)	0.74	0.90	0.89	0.83
Potassium (K)	1.70	2.90	2.92	2.73
Calcium (Ca)	2.41	13.44	13.55	10.48
pH	9.27	12.19	11.84	11.22

D – cattle manure digestate; P – wood ash

For field trials, maize variety 'Hulk', FAO 250, was sown in 2020 and 2021, and the variety 'Vitaly', FAO 220, was sown in 2022; sowing rate – 80 000 germinating seeds per ha; sowing depth – 5 cm; row width – 70 cm; sowing date – May 10 and 5, respectively; precrop – winter wheat; direct seeding technology. Study areas for each variant and replication were arranged before fertilizer application. Research experimental plots was 100×12 m or 0.12 ha in each replication. All research variants were set up in triplicate. For weed control, the herbicides Maister Power and Estets were applied; rate – 1.0 L ha^{-1} and 0.4 L ha^{-1}, respectively. Herbicides were sprayed only once per season, when maize had four leaves.

Qualitative indicators were determined at the Biotechnology Scientific Laboratory (BSL) of the Latvia University of Life Sciences and Technologies (LBTU): the content of dry matter (DM), fat and ash were determined by gravimetric analysis, the crude protein (CP) content of DM yield was determined by modified Kjeldahl; mineral elements P, K and Ca were analysed by atomic adsorption spectrometry.

Data processing was performed using a three-way analysis of variance (ANOVA) "Microsoft Excel" computer program.

III. Results and discussion

Maize (*Zea mays* L.) is one of the most important crops for both human food and livestock feed. The primary goal of its cultivation is to maximize the productivity and yield while maintaining crop quality.

On average, 36.93–38.33 t ha^{-1} of maize green mass were obtained using the new fertilizer in three trial years (Table 2). The increase in the rate of fertilizer had a negative effect on maize yield. Significantly ($p<0.05$) higher maize yields in 2022 were obtained using lower (15 t ha^{-1}) fertilizer rates. Also, in 2020 and 2021, it was observed that maize yield tended to increase at lower fertilizer rates; however, the yield difference was not significant, but the yield difference was not significant (Table 2). The decrease in maize yields at a doubled fertilizer rate can be partially explained by the high pH (>11) of the new fertilizer (Table 1), which could have increased the soil acidity and affected the plant growth.

The trial demonstrated that the effects of the different digestate-to-ash ratios in fertilizer mixture on maize yield had no significant differences in 2020 and 2021.Only in 2022, significantly higher maize yields were obtained in fertilizer variants with prevailing amounts of digestate (digestate: ash – 1:0; 2:1, and 3:1), compared to the variant with equal amounts of digestate and ash (1:1).

Increasing the fertilizer rate from 15 t ha^{-1} to 30 t ha^{-1} significantly ($p<0.05$) reduced the average three-year yield of maize. No significant effect of the digestate-to-ash ratio on the average maize yield was found in the three trial years.

When applying lower rates of fertilizer (15 t ha^{-1}), a tendency was observed to obtain higher maize yields in variants with greater amounts of digestate (digestate:ash – 1:0, 2:1, and 3:1), compared to the variant with equal amounts of digestate and ash (1:1) in the fertilizer.

The applied rate of fertilizer, as well as the ratio of digestate to ash in the fertilizer did not have a significantly different effect on the quality indicators of maize dry matter in 2020. High-quality maize yield was obtained in all research variants. The rate of fertilizer used in 2021, as well as the ratio of digestate and ash in fertilizer did not have significantly different effects on the quality indicators of maize forage. Similar results were obtained also in 2022. The rate of applied fertilizer, as well as the digestate-to-ash ratio in the fertilizer had an insignificant effect on maize dry matter quality indicators maize. The applied fertilizer rate did not have a significant effect on the quality indicators of maize forage in 2022. The ratio of digestate and ash in fertilizer had a significant ($p<0.05$) effect only on digestibility. The application of both fertilizer rates (15 and 30 t ha^{-1}) gave higher digestibility indicators.

TABLE 2 THE EFFECT OF DIDDERENT DIGESTATE AND WOOD ASH MIXTURES ON MAIZE MASS YIELD, T HA^{-1}

Fertilizer rate, t ha^{-1} (F_A)	Digestate and wood ash ratio in the mixture, (F_B)	Trial year			On average in three trial years
		2020	*2021*	*2022*	
15	1 : 0	36.08	39.38	40.52	38.66
	1 : 1	34.98	38.87	39.51	37.79
	2 : 1	34.74	37.11	40.77	37.54
	3 : 1	36.39	41.01	40.63	39.35
	On average	**35.55**	**39.09**	**40.36**	**38.33**
30	1 : 0	33.74	38.24	40.06	37.35
	1 : 1	33.84	37.71	38.58	36.71
	2 : 1	34.53	37.01	40.02	37.18
	3 : 1	33.86	36.19	39.33	36.46
	On average	**33.99**	**37.29**	**39.50**	**36.93**
$LSD_{0.05}$ A		1.63	2.17	**0.60**	**1.13**
$LSD_{0.05}$ B		2.31	3.07	**0.84**	1.59
$LSD_{0.05}$ AB		3.27	4.34	1.19	2.25

Although dry matter yield level is very important for the production of forage, the yield quality is more important. Due to the cool climatic conditions in Latvia, the main maize yield quality indicator in this country is dry matter content at harvest. The dry matter content in maize reached on average 31.2–33.4% in two trial years, which is very good for obtaining high-quality silage, and it varied slightly depending on fertilizer rate and the digestate-to-wood ash ratio in the fertilizer mixture (Table 3).

Maize yield and total crude protein content are closely related to maize growing conditions. As it is seen in Table 3, crude protein content varied between 8.67% and 10.48% of maize dry matter. The crude protein content in maize yield increased with the increase in fertilizer rates. This is also confirmed by other research results of scientists.

Ash content represents the total mineral content in forage or diet. The normal ash content in maize silage makes approximately 5.0% of dry matter. However, in our study, there were maize silage samples containing up to 10.0% of ash. It is important to understand what is a normal ash content in feed and what is an abnormal ash content. If the ash content in feed is too high, there is a high probability that the feed is contaminated with soil, which is not desirable.

Minerals in feed can be divided into two general categories – endogenous and exogenous. Endogenous minerals can be defined as minerals the plants usually contain, for example, calcium, phosphorus, potassium, magnesium, etc. Many endogenous minerals are of nutritional value for lactating dairy cows; therefore, it is recommended that it is high, especially the content of calcium, in order to reduce supplementation costs.

Exogenous minerals can be defined as minerals not found directly in plants. Exogenous minerals (such as silica) are primarily associated with soil, and forages and rations should contain as little soil contamination as possible [14].

It was found that the ratio of digestate and ash in the fertilizer did not have a significant effect on maize quality indicators in 2020. The applied fertilizer rate had a significant ($p<0.05$) effect only on the calcium content in maize dry matter yield. A higher calcium content in dry matter was obtained by applying a 30 t ha^{-1} fertilizer rate. The application of the innovative fertilizer in maize crops ensured the production of high-quality green mass and silage (Table 3).

TABLE 3 THE EFFECT OF DIFFERENT DIGESTATE AND WOOD ASH MIXTURES ON MAIZE GREEN MASS QUALITY (ON AVERAGE IN 2020 AND 2021)

Fertilizer rate, t ha^{-1} (F_A)	The digestate and wood ash ratio in the fertilizer mixture (F_B)	Dry matter content, %	Content in DM, %				
			Crude protein (CP)	Crude fibre (CF)	*Ash*	*Ca*	*P*
15	1 : 0	31.24	9.90	16.30	3.39	0.18	0.26
	1 : 1	32.91	8.73	15.20	3.50	0.23	0.28
	2 : 1	29.42	8.80	24.55	4.65	0.26	0.26
	3 : 1	31.19	8.67	16.48	3.45	0.23	0.25
	On average	**31.19**	**9.03**	**18.13**	**3.75**	**0.23**	**0.26**
30	1 : 0	33.98	9.92	16.69	4.57	0.26	0.28
	1 : 1	33.78	10.48	19.95	4.29	0.46	0.25
	2 : 1	33.61	9.70	17.45	3.89	0.33	0.24
	3 : 1	32.19	10.31	18.14	4.13	0.33	0.26
	On average	**33.39**	**10.10**	**18.06**	**4.22**	**0.35**	**0.26**
$LSD_{0.05}$ A		2.51	1.27	2.96	1.35	**0.12**	0.04
$LSD_{0.05}$ B		3.55	1.80	4.18	1.91	0.17	0.05

Ca – calcium; P – phosphorus

Calcium and phosphorus are particularly important for animal health. Calcium and phosphorus should be analyzed together because the dietary levels of Ca and P should be balanced to increase their availability and utilization [15]. Some studies suggest that the Ca:P ratio in animal feed should range from 1:1 to 2:1 [16]; whereas, according to some authors, the optimal Ca:P ratio is 2:1 [17,18]. Diets with a Ca:P ratio higher than 2 can have a detrimental effect on animal health [19]. Grzegorczyk et al. [20] have indicated that an insufficient Ca:P ratio can lower the availability, absorption and utilization of these elements.

IV. Conclusions

The mixtures of digestate and wood ash are an innovative way for improving the soil fertility. The use of innovative fertilizers favoured to the nutritional qualities of maize yield without using mineral fertilizers.

The application of the analyzed innovative fertilizer mixture is recommended because it increases soil fertility, which eventually improves the nutritional qualities of maize plants.

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