

The Effect of an Innovative Fertilizer of Digestate and Wood Ash Mixtures on Winter Garlic Productivity

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Abstract. Garlic (*Allium sativum* L.) is a widespread crop in vegetable production. The popularity of garlic is due to its bactericidal and antioxidant properties. Digestate and wood ash are the by-products of cogeneration plants. The digestate is rich in nutrients, can provide a large part of the nutrients needed by the plant during the growing season, as well as improves the soil structure. Wood ash contains small amounts of phosphorus and potassium and is strongly alkaline (pH 8–12) due to the oxides in its composition, mostly calcium carbonate. The purpose of the study was to determine the effect of fertilizer rates of the digestate and wood ash mixtures on winter garlic productivity and harvest quality. Field trials with the winter garlic variety 'Lubaša' were established in sod clay, loamy soil. In the garlic plantation, different variants of fertilizer mixtures were used – they contained pig or cattle manure or plant residue digestate, and wood ash. The ratio of digestate and wood ash in the mixtures was 3:1; fertilizer rates for winter garlic were 15 and 30 t ha⁻¹. In the study, the different types of fertilizers showed different effects on the yield and quality of winter garlic.

Keywords: digestate, fertilizer, winter garlic, wood ash, yield quality, yield.

I. INTRODUCTION

Garlic (*Allium sativum* L.) is a widespread crop and one of the oldest cultivated vegetables. Its medicinal effects have been proven for thousands of years. The edible part of the garlic plant is the garlic cloves. Garlic contains antibiotics, enzymes, amino acids, and trace elements. It is eaten directly or added to food for flavor. It is also used in the preparation of smoked meat products and in some medicines. Today, garlic is valued for its essential oil content. The popularity of garlic is due to its bactericidal and antioxidant properties.

Digestate, or fermentation residue, is produced as a by-product in biogas production plants under anaerobic conditions and is considered one of the most valuable types

of organic fertilizers. It contains valuable macro- and microelements and is a valuable fertilizer [1], [2], [3]. The digestate is rich in nutrients, can provide a large part of the nutrients needed by the plant during the growing season, as well as improves the soil structure. Approximately 35–81% of the total nitrogen content in the digestate is ammonia (NH₄), which is available to plants. Various products are used as a raw material for biogas production, such as manure, food waste, the waste of plant production, forest, and wood processing, as well as peat, sewage sludge, and various types of grass and corn silage. The most suitable material for biogas production is manure. In anaerobic conditions, in thermophilic mode, and during processing, manure remains safe for the environment and immediately usable.

Digestate contains dissolved minerals and unbroken organic matter, which are bacterial cells and substances with a high lignin content. Digestate as a fertilizing material is divided into two groups depending on its dry matter content: liquid fraction, with dry matter content below 15%, and solid or separated fraction, with dry matter content above 15%. The separated digestate can be used as a compost together with various organic waste products. The solid fraction is rich in phosphorus and organic nitrogen, but the liquid fraction contains much more nitrogen in a form available to plants [4], [5], [6].

Wood ash, the by-product of biomass combustion, can return important nutrients to the soil and prevent soil acidification. Soil pH can be adjusted using various soil liming materials (e.g., dolomite flour, lime) or wood ash. The burning of biomass for heat production has considerably increased recently, which remarkably increases the production of wood ash as a by-product. Wood ash consists of sand residues, inorganic compounds from harvested biomass, and a very small fraction of unburned organic material [7]. The element concentrations

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of the ashes, as well as their other chemical constituents, vary considerably depending on the incinerated material and the incineration technique [8], [9], [10]. Thus, wood ash contains all inorganic plant macro- and micronutrients from biomass, except for N [8]. Various oxides are formed during combustion, and subsequent aeration may lead to the formation of carbonates in wood ash, making the ash highly alkaline with a pH of 8 to 12 [10].

Unlike landfilling ash, recycling ash as a soil conditioner will return important nutrients to the soil and prevent acidification [9]. Wood ash has a relatively low content of heavy metals and is more alkaline. High concentrations of Ag, Cd, Cr, Pb, Zn, and Cu in ash can appear when wood waste treated with industrial preservatives is burned. Wood ash is safer to use for fertilization if soot and slag fractions are broken down during combustion, as heavy metals (except zinc) accumulate in soot [9]. Ash is mainly used as a source of potassium, calcium, and phosphorus, which is especially lacking in acidic organic soils; the average potassium content in ash is 50–60 g kg⁻¹. In agriculture, in practice, digestate and wood ash are most often used separately to improve soil fertility; however, the use of both of these products separately can cause certain ecological problems. In order to at least partially prevent the pollution of the surrounding environment, an idea arose to mix digestate and ash together in certain proportions and use the obtained mixtures for crop fertilization.

The purpose of the study was to determine the effect of fertilizer rates of the digestate and wood ash mixtures on winter garlic productivity and harvest quality.

II. MATERIALS AND METHODS

Field trials with the winter garlic variety 'Lubaša' were established during the two vegetation seasons of 2020/2021 and 2021/2022 in sod gley, sandy loam soil (56°66' N, 23°75' E).

Agrochemical indicators of the soil: pHKCl 6.7, organic matter content – 3.8%, phosphorus (P₂O₅) content – 199 mg kg⁻¹, and potassium (K₂O) content – 97 mg kg⁻¹ soil. In the garlic plantations, different variants of fertilizer mixtures with the digestates of pig manure (from LLC "Latvi Dan Agro"), cattle manure (from JSC "Ziedi JP"), and plant residue (from the farm "Līgo"), as well as wood ash (from LLC "Gren Jelgava") were used. Using these components, mixtures of relevant variants were prepared in the Biogas Scientific Laboratory of Latvia University of Life Sciences and Technologies. The ratio of digestate and wood ash in the mixtures was 3:1, and fertilizer rates for winter garlic were 15 and 30 t ha⁻¹. To compare the types of fertilizers, the traditional mineral fertilizer NovoTec classic (NPK12-8-16), 500 kg ha⁻¹, was also used. Fertilizer options are shown in Table 1. The fertilizer norms of unfertilized winter garlic plantings and of all three types of digestates were used as control variants. The pre-plant – black fallow; the planting rate of winter garlic

cloves was 1.6 t ha⁻¹. Fertilizer was incorporated into the soil and garlic was planted by hand. For recording the harvest, the plot area in replicates was 2 m². The placement of the variants in the trial was randomized, in three replications.

During the vegetation period, the development dynamics of winter garlic was registered, the harvest was recorded, and the quality of garlic bulbs was evaluated: the content of dry matter, crude protein, sulfur, phosphorus, potassium, and reducing sugars in dry garlic bulbs. To determine the quality of the harvest, two average garlic bulbs were selected from each replicate and put together for all variants, forming an average united sample.

Qualitative indicators were determined in the Biotechnology Scientific Laboratory (BSL) of the Latvia University of Life Sciences and Technologies. The samples were prepared for chemical analyses according to the LVS EN ISO 6498:2012 method. The dry matter content was determined using gravimetric analysis (ISO 6496:1999), the amount of crude protein was determined by the Kjeldahl method (LVS EN ISO 5983-2:2009), the phosphorus content was determined by gravimetric analysis of quinoline phosphomolybdate (ISO 6491:1998), the potassium content was determined by flame emission spectrometry (LVS EN ISO 6869:2002), and sulfur (S) was determined by using CS-500 analyzer method.

Data processing was carried out using the two-way analysis of variance (ANOVA) "Microsoft Excel" computer program.

III. RESULTS AND DISCUSSION

In the study, the type of fertilizer differently affected the yield of winter garlic. Depending on the type of fertilizer, the yield varied between 8.92 and 9.15 t ha⁻¹. The use of different types of digestates, including mixtures with wood ash, ensured a significant ($p < 0.05$) increase in the yield of winter garlic bulbs – on average by 0.71–0.94 t ha⁻¹ compared to the control variant. The use of the mixture of plant residue digestate and wood ash as well as the use of horse manure compost (Table 1) ensured higher garlic yields. The highest yield - 9.35 ha⁻¹ in this study was provided by the application of horse compost. The high efficiency of horse compost in garlic plantations is also confirmed by other studies [11].

Fertilizer rates of all digestates and their mixtures with wood ash did not significantly affect the yield of garlic. However, when using pig manure digestate and its mixtures, it is recommended to use higher fertilizer rates – 30 t ha⁻¹. The use of digestate and wood ash mixtures in neutral soils can sometimes have a negative impact on the yield due to the reason that the soil may become alkaline. When using all digestates and their mixtures with wood ash for the fertilization of garlic, depending on the type and rate of fertilizer, the pH of the soil layer

increased by an average of 0.5–0.8 units. The application of these mixtures provided a significantly better effect in acidic and moderately acidic soils.

The health benefits of garlic are related to its chemical composition. The chemical composition of garlic is significantly influenced by the variety, growing conditions, and the agrotechnology applied.

In terms of taste and dietary properties, garlic is one of the most valuable vegetable crops. Garlic has a higher nutritional value compared to other onion species, it contains a large amount of carbohydrates, proteins, vitamins, especially C, B1, B2, B6, PP, antibiotics garlicin and allistatin, some enzymes and amino acids [12]. Winter garlic needs soils with available forms of nutrients, they respond positively to the use of easily soluble fertilizers. The correct use of fertilizers increases the commercial quality of products, early ripening, promotes the accumulation of dry matter, vitamins, sugars and nutrients [13].

Fertilization regime and soil properties can significantly affect quality indicators, such as mineral composition, dry matter, protein content and its composition. The mineral analysis of garlic is presented in Table 2. The results indicated high values in crude protein, sulfur, phosphorus, potassium and reducing sugars.

The dry matter content of winter garlic bulbs was in the range of 35.4–39.1 %. The high content of the dry matter is associated with a large amount of inulin (20–27%), which, under the action of gastric acids, turns into a valuable sugar for the human body – fructose. Dry matter is also an important indicator of the quality – the higher it is, the less susceptible garlic is to mechanical damage and the better it is stored during winter period.

TABLE 1 INFLUENCE OF DIGESTATE AND WOOD ASH MIXTURES ON THE YIELD OF WINTER GARLIC VARIETY 'LUBAŠA' (ON AVERAGE 2021-2022)

Type of fertilizer (F _A)	Fertilizer rate, t ha ⁻¹ (F _B)	Digestate and wood ash ratio in the mixture (F _C)	Average winter garlic yield, t ha ⁻¹		
			(F _C)	(F _B)	(F _A)
			LSD 0.05 =0.30	LSD 0.05 =0.30	LSD 0.05 =0.36
Control			8.21	-	-
Horse manure compost, 30 t ha ⁻¹			9.35	-	-
Mineral fertiliser NovoTec classic (NPK12-8-16), 500 kg ha ⁻¹			8.58	-	-
Cattle manure digestate	15	1:0	9.10	9.20	9.08
		3:1	9.29		
	30	1:0	9.31	8.96	
		3:1	8.62		
	15	1:0	8.98	8.82	8.92

Type of fertilizer (F _A)	Fertilizer rate, t ha ⁻¹ (F _B)	Digestate and wood ash ratio in the mixture (F _C)	Average winter garlic yield, t ha ⁻¹		
			(F _C)	(F _B)	(F _A)
			LSD 0.05 =0.30	LSD 0.05 =0.30	LSD 0.05 =0.36
Control			8.21	-	-
Horse manure compost, 30 t ha ⁻¹			9.35	-	-
Mineral fertiliser NovoTec classic (NPK12-8-16), 500 kg ha ⁻¹			8.58	-	-
Pig manure digestate	30	3:1	8.66	9.02	9.15
		1:0	9.18		
		3:1	8.87		
Plant residue digestate	15	1:0	9.35	9.23	9.15
		3:1	9.11		
	30	1:0	9.00	9.07	
		3:1	9.13		

Fertilizer mixture norms did not significantly affect the changes in crude protein content in garlic – it fluctuated between 6.1% and 7.8% in the total dry matter of the studied variants (Table 2).

The main quality characteristic of garlic is the specific smell and taste of its cloves. Garlic is a particularly rich source of organosulfur compounds, which are thought to be responsible for its flavor and aroma, as well as its potential health benefits [14]. Many favorable experimental and clinical effects of the consumption of garlic preparations, including garlic extract, garlic oil, dehydrated garlic powder have been reported. These biological responses include reduction of risk factors for cardiovascular diseases and cancer, a stimulation of immune function, enhanced foreign compound detoxification, radioprotection, restoration of physical strength, resistance to various stresses and potential anti-aging effects.

Garlic has a relatively high sugar content among vegetable crops, and the presence of a large amount of sugar is not felt in the taste because of the presence of essential oils in onions. The sugar content in the experimental samples of garlic was in the range of 0.53-0.70%. The trend of accumulation of sugars in garlic bulbs depending on the application of fertilizers was similar to the dry matter content. When fertilizer was applied, the amount of sugars in garlic bulbs significantly increased by 0.13-0.3% compared to the control.

TABLE 2 INFLUENCE OF DIGESTATE AND WOOD ASH MIXTURES ON YIELD QUALITY OF WINTER GARLIC VARIETY 'LUBAŠA' (ON AVERAGE 2021-2022)

Type of fertilizer, (F _A)	Fertilizer rate, t ha ⁻¹ (F _B) and digestate and wood ash ratio in the mixture (F _C)	Average content in a natural product, %				
		crude protein	sulfur	phosphorus	potassium	reducing sugars
Control		8.84	0.98	0.51	1.17	0.40
Horse manure compost - 30 t ha ⁻¹		9.35	0.98	0.54	1.28	0.55
NovoTec classic NPK12-8-16 - 500 kg ha ⁻¹		8.90	0.87	0.51	1.23	0.57
Cattle manure digestate	15; D/P** 1:0	9.11	0.99	0.50	1.21	0.53
	15; D/P 3:1	9.05	0.89	0.50	1.19	0.67
	30; D/P 1:0	9.49	0.90	0.51	1.19	0.56
	30; D/P 3:1	9.09	0.90	0.56	1.30	0.66
	On average	9.19	0.92	0.52	1.22	0.61
	Pig manure digestate	15; D/P 1:0	9.21	0.90	0.51	1.25
15; D/P 3:1		9.01	0.94	0.52	1.35	0.64
30; D/P 1:0		9.56	0.89	0.53	1.22	0.64
30; D/P 3:1		8.93	0.84	0.50	1.39	0.67
On average		9.18	0.89	0.52	1.30	0.65
Plant residue digestate		15; D/P 1:0	9.97	0.98	0.55	1.33
	15; D/P 3:1	9.08	0.98	0.50	1.23	0.65
	30; D/P 1:0	9.49	1.01	0.55	1.23	0.61
	30; D/P 3:1	9.85	1.01	0.57	1.30	0.70
	On average	9.60	1.00	0.54	1.27	0.63
	LSD _{0.05} F _A	0.523	0.071*	0.048	0.086	0.039
LSD _{0.05} F _B	0.427	0.058	0.040	0.071	0.032*	
LSD _{0.05} F _{AB}	0.740	0.100	0.068	0.122	0.055*	

* LSD are not relevant; LSD in bold are significant at p<0.05.

** D/P- digestate and wood ash ratio in the mixture

In addition to taste properties, they also determine the medicinal properties of garlic. In the study, depending on the fertilizer rate and type applied, the sulfur content in total dry matter was 0.28–0.70%.

Sulfur content in dry matter had a weak non-significant (p>0.05) correlation with dry matter yield (r=0.34), crude protein content in dry matter (r=0.41) (Fig. 1, Fig. 2), and potassium content in dry matter.

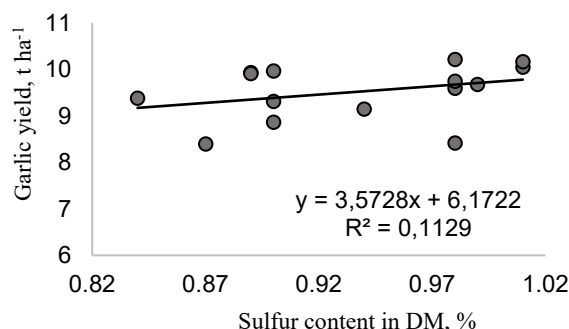


Fig.1. Correlation between garlic yield, and sulfur content in dry matter.

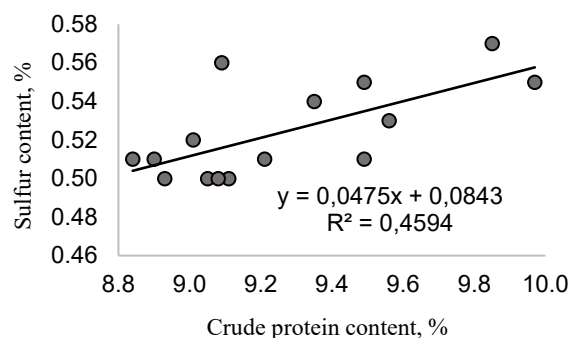


Fig. 2. Correlation between garlic crude protein content and sulfur content in dry matter.

Crude protein content in dry matter showed the only significant (p<0.05) correlations with yield (r=0.63) and potassium content in dry matter (r=0.68) (Fig. 3, Fig.4).

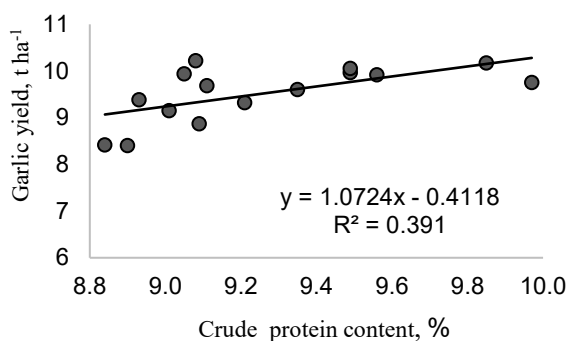


Fig.3. Correlation between garlic yield, crude protein content in dry matter.

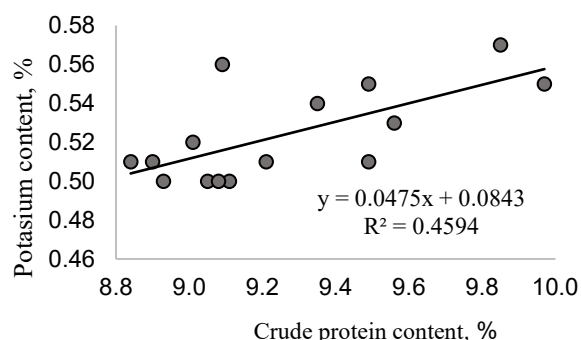


Fig. 4. Correlation between garlic crude protein content and potassium content in dry matter.

IV. CONCLUSIONS

Research results showed that by using digestate and wood ash mixtures, sufficiently high and good quality winter garlic yields can be obtained without using mineral fertilizers.

A higher yield was ensured by the use of plant residue digestate and wood ash mixtures.

In order to determine more precisely which fertilizer mixture and in what amount is the most effective, further research is required.

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