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Impact of Single and Cumulative Applications of Biogas Liquid Digestate on Soil and Plant

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ABSTRACT

The surge in biogas energy production has resulted in an accumulation of Liquid Digestate (LD), a byproduct with possible agricultural utility. To discern its benefits and shortcomings, a field trial was conducted to evaluate the effects of different doses of LD on maize yield, soil salinity, leaf and grain Nitrogen (N) content. The study included both single-year and consecutive two-year applications of LD at doses of 10, 30, 50, and 70 t ha^{-1}. Based on maize N requirements, any N deficit was supplemented with chemical fertilizers. For the one-year experiment, the highest grain yield was obtained from the chemical fertilization treatment and 70 t ha^{-1} dose of LD. In the two consecutive years, 70 t.ha^{-1} dose gave the highest grain yield. LD provided N to the soil as effectively as chemical fertilization and stabilized the soil pH within approximately 1 month. However, high doses of digestate resulted in increased soil salinity and decreased N Use Efficiency (NUE). Consecutive two-year application increased Electrical Conductivity (EC) and pH stabilization in the soil to a greater extent than single-year applications. However, there was no difference in the N content of the plant between single-year and two consecutive applications. In summary, LD provides significant agricultural benefits such as pH stabilization and increased inorganic N levels. However, our findings indicate that overuse can lead to soil salinity and N losses, underscoring the importance of balanced application to maximize its benefits while minimizing potential drawbacks.

Keywords: Maize, Nitrogen fertilizer, Soil electrical conductivity, Soil pH.

INTRODUCTION

Modern agricultural practices aim to continually increase productivity to meet the food needs of the growing global population. However, the excessive use of chemical fertilizers not only disrupts the natural structure of the soil but also leads to environmental issues (Geisseler and Scow, 2014; Marschner *et al*., 2003; Zhong *et al*., 2010). Among these problems are the adverse effects on soil microorganisms and contamination of water reservoirs (Rohila *et al*., 2017). Soil conservation and enhancement are at the core of sustainable agriculture. At this juncture, the consideration of natural resources and recyclable wastes as alternatives to chemicals gains significance. In this context, introducing the Liquid Digestate (LD) resulting from biogas energy production to agricultural use carries the potential to reduce environmental pollution while enhancing soil productivity.

Biomass-based fuels are increasingly crucial in meeting energy needs (Canisares *et al*., 2017; Rawoof *et al*., 2021). In particular, biogas stands out as a bioenergy source with a low ecological footprint

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(Deviren *et al*., 2017; SAPEA, 2012). The globally rising number of biogas facilities results in an increase in the amount of digestate waste produced (Karimi *et al*., 2022). Sustainable biogas production necessitates the reuse of by-products to maintain economic balance (Holm-Nielsen *et al*., 2009). Considering climate change, this can be seen as an opportunity to return digestate to the soil, thereby reducing greenhouse gas emissions and enhancing carbon sequestration in the soil (Karimi *et al*., 2022). When properly utilized, this material can serve as a soil enhancer and fertilizer, strengthening the concept of circular agriculture (Shi *et al*., 2018; Jurgutis *et al*., 2021; Sürmen and Kara, 2022).

During the biogas production process, energy is transferred to methane molecules from organic waste through anaerobic digestion (Angelidaki and Ellegaard, 2003), while nitrogen (N) and other nutrients are retained in the digestate (Massé *et al*., 2007). The solid fraction of the waste material released after biogas production represents Carbon (C) sequestration, while the liquid fraction signifies richness as a plant nutrient source (Robles-Aguilar *et al*., 2019; Barduca *et al*., 2021). Although the solid digestate has the potential to increase the carbon content of the soil (Möller, 2015), it carries a risk of significant NH_3-N (ammonia) loss during storage due to its high pH value (Brito *et al*., 2008). When LD is managed correctly, it can serve as a fertilizer and soil amendment (Chookietwattana *et al*., 2016). The presence of N, Phosphorus (P), and potassium (K) elements in LD and the improvement of soil physical properties due to its organic compounds suggest its agricultural importance (Insam *et al*., 2009). However, since not all organic material can be utilized by microorganisms within the biogas process, digestate can come with potential risks to the soil and environment (Bationo *et al*., 2007). Residual organic compounds in the digestate may include phytotoxic substances, heavy metals, or excess nutrients that can accumulate in the soil (Singh *et al*., 2010). For effective use of digestate, outcomes should be determined based on dosage, cumulative effects, and soil type (Karim *et al*., 2022), and environmental impacts should be researched (Urra *et al*. 2019). Especially concerns arise due to its high ammonium (NH_4^+) and salinity content, which might lead to adverse effects on soil and plants (Fransman and Nihlgard, 1995). In some regions, these concerns have restricted the agricultural use of LD (Piccoli *et al*., 2022). Determining the positive and negative effects of this material on soil and plant development is important for assessing its agricultural impact (Diacono ve Montemurro, 2011). However, many studies are based solely on one cultivation season or are short-term experiments under controlled conditions (Głowacka *et al*., 2020). Furthermore, while the high ammonia nitrogen content in LD seems advantageous in terms of making nitrogen available in a form plants can use, it suggests potential issues like ammonia nitrogen evaporating into the atmosphere and losses in the form of nitrates (Fransman and Nihlgard, 1995; Gürbüz and Oz, 2016).

This study aimed to examine the effect of LD on some soil properties and the yield of maize plants under field conditions. The study evaluated the cumulative effects of LD over two years. Furthermore, effective management and usage of LD in terms of sustainable agriculture were determined as the primary objectives.

MATERIALS AND METHODS

Trial Area and Material

The trial was conducted in 2022 at the Kırklareli Atatürk Soil, Water, and Agricultural Meteorology Research Institute's field, located at a latitude of 41° 42' 11" N and longitude of 27° 12' 29" E. The region's annual average temperature is 13.3 °C, and the total average rainfall is 48.7 mm (TSMS, 2022). There was no rainfall for 9 days following the application of the liquid digestate, but on the 10th day, a precipitation of 5.7 mm was recorded. Rainfall data was monitored with the institute's meteorological station. The soil in the top 0-30 cm layer has a pH of 8.01, a loamy texture, and an organic matter content of 1.39% (Table 1). The soil was analyzed at three depths (0-30, 30-60, and 60-90 cm) to capture the vertical distribution of key soil properties. Soil samples were taken from the 0-30 cm depth. The soil sampling was carried out on 10 May, 20 June, 2 Aug. and 21 Oct. in ??, using a soil auger. These dates represent the 1st, 2nd, 3rd, and 4th sampling periods, respectively. These periods were chosen to monitor soil properties at regular intervals from the time of LD application to harvest. For each treatment plot, five soil samples were randomly collected and combined to form a composite sample for this depth. For the study, the DKC6630 grain corn seed from Monsanto, which is commonly used in the region, was selected as the plant material. This variety belongs to the FAO 600 maturity group and is known for its drought tolerance, and resistance to common diseases. It is cultivated as a main crop in the region due to its adaptability to local conditions. Water for irrigation was sourced from a deep well located within the institute's premises. The used water had values of 7.30±0.03 pH, 1.10±0.05 dS m^{-1} EC, 0.14±0.001 NH_4^+-N, and 0.68±0.02 NO_3^--N.

Liquid Digestate

LD was obtained from a private biogas plant facility situated in the Babaeski district of Kırklareli. This establishment processes roughly 1,050 tons of animal and agricultural organic waste daily, including cattle manure (60%), plant waste (primarily maize and sunflower residues; 20%), sheep manure (10%), and industrial waste (10%), to generate biogas energy. At the facility, the resultant solid-liquid mixture (slurry) is separated using a centrifuge, and the liquid fraction is hygienized at 70°C for 1 hour to neutralize pathogens. Specific characteristics of the liquid digestate are outlined in Table 2.

Experimental Set up and Practices

The study was conducted in two separate experimental areas: The first area (A) was chosen for a One Year LD Application (OYA), while the second area (B) was selected for consecutive Two-Year Applications (TYA) (Figure 1). LD was applied to plots at different doses (10, 30, 50, and 70 t ha^{-1}) 20 days before planting, and, in cases of nitrogen deficiency, the specified doses were supplemented with chemical fertilizer. Each treatment had three replicates. Based on the study by Yakan and Saglam (1997), which recommended 210 kg N ha^{-1} to obtain the highest N rate per grain

Table 1. Physical and chemical characteristics of the experimental site soil at different depths (0-30, 30-60, and 60-90 cm).[a]

	0-30	30-60	60-90
pH	8.01 ± 0.1	8.04 ± 0.1	8.07 ± 0.15
EC (dS m^{-1})	0.18 ± 0.02	0.19 ± 0.02	0.19 ± 0.01
$CaCO_3$ (%)	11.02 ± 0.3	10.78 ± 0.25	9.45 ± 0.25
Orcanic matter (%)	1.39 ± 0.08	1.24 ± 0.07	1.07 ± 0.06
NH_4^+-N (mg kg^{-1})	9.22 ± 2	9.10 ± 1,8	4.17 ± 2,3
NO_3^--N (mg kg^{-1})	3.41 ± 0,7	8.02 ± 1,4	14.95 ± 3,6
P_2O_5 (kg da^{-1})	9.71 ± 0.3	10.14 ± 0.3	11.86 ± 0.4
K_2O (kg da^{-1})	44.55 ± 2	33.12 ± 1.5	25.89 ± 1.2
Texture (%)	47 sand, 30,65 silt, 22,35 clay		

[a] Data are presented as mean±standard error. EC: Electrical Conductivity, NO_3^--N: Nitrate.

Table 2. Chemical charactiristic of liquid digestate.[a]

pH	8.90 ± 0.2	Organic Carbon (%)	0,67 ± 0.03
Dry matter (%)	2.41 ± 0.13	K (mg L^{-1})	2.387,00 ± 20
EC (dS m^{-1})	23.61 ± 0.4	P (mg L^{-1})	284,20 ± 2.8
Total N (%)	0.47 ± 0.02	Cl (mg L^{1})	6.980,00 ± 69
NH_4^+-N (%)	0.37 ± 0.01	Na (mg L^{-1})	845,00 ± 8.4

[a] Data are presented as mean±standard error.

in maize under regional conditions, this amount was adopted for our experiment. The remaining nitrogen requirement after LD treatments (e.g., 10 tons of liquid digestate provides 47 kg N) was supplemented with urea fertilizer as shown in Table 3. Since the soil already contained adequate levels of Phosphorus (P), potassium (K), and trace elements necessary for maize plants, no additional fertilization containing these elements was carried out. Drip irrigation was applied based on the plant's water needs. During the growth period of the plant, soil samples were taken five times in total, and inorganic nitrogen, organic matter, pH, and salinity analyses were conducted. Harvesting was done upon determining the R6 maturity phase, grains were separated from their cobs, moisture percentages were calculated, and samples were taken for protein analyses. The raw yields of all plots were recorded by weighing the grains. Agricultural practices carried out during the study are presented in Table 4.

Analysis Methods

Soil samples' pH and EC values were determined using a 1:2.5 soil-pure water mixture (Soil Survey Lab. Staff, 1975). Organic matter content was detected with the modified Walkley-Black method (Jackson, 1979) while lime (% $CaCO_3$) contents were measured using the Scheibler calcimeter method (Loeppert and Suarez, 1996). Micro-elements were determined in samples digested with a 1:3 HNO_3 solution using Inductively Coupled Plasma Optical Emission Spectrometry (ICP-OES) (Sutherland, 2018). Inorganic nitrogen contains values of NH_4^+-N and NO_3^--N extracted with KCl solution (Bremner, 1965). Available phosphorus was analyzed in the ICP-OES device after being extracted according to the Olsen method. Exchangeable potassium was determined based on potassium values extracted with 1 N ammonium acetate (Soil Survey Lab., 1975). Soil texture was identified using the hydrometer method (Gee and Bauder,1986).

In LD, a glass electrode pH meter was used to determine pH values (Soil Survey Lab. Staff, 1975), and an electrical conductivity measurement device was used for salinity (EC). Total nitrogen amount was detected using the Kjeldahl method (Bao, 2005). The same method was preferred for inorganic nitrogen values (APHA, 2012). Organic carbon was determined after the ashing method. ICP-OES (Kacar and Inal, 2010) was chosen for macro-micro elements and heavy metals, and silver nitrate with chromate indicator was selected for Chlorine (Cl) amount (APHA, 2012).

For maize grain, yield calculation based on moisture was carried out taking weights at 15.5% moisture value as the basis. Nitrogen ratio in leaves and grain was analyzed with the Kjeldahl method (APHA, 2012). Nitrogen use and uptake efficiencies were calculated using the following formulas (Moll *et al*., 1982):

Nitrogen uptake amount in grain: % N in grain×YF (t ha^{-1})

Nitrogen use efficiency: [(YF-YC) / N application amount (t ha^{-1})] * 100

In these formulas, Yield with Fertilizer (YF) represents the treatment to which fertilizer was applied, and Yield with Control (YC) represents the control treatment without fertilizer.

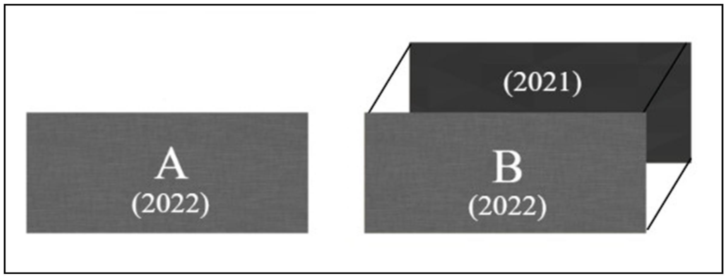


Figure 1. Experiment site layout.

Table 3. Experimental topics, application amounts, and periods.

Treatments	Applications	Mineral fertilization periods	
		Sowing period	Hoeing period
G_0	Control	-	-
G_M	(456 kg ha^{-1} urea)	228 kg ha^{-1} urea	228 kg ha^{-1} urea
G_1	10 ton LD+330.4 kg ha^{-1} urea	102.1 kg ha^{-1} urea	228.2 kg ha^{-1} urea
G_3	30 ton LD+78.2 kg ha^{-1} urea	-	78.2 kg ha^{-1} urea
G_5	50 ton LD	-	-
G_7	70 ton LD	-	-

Table 4. Agricultural practices.

Date	Practices	Date	Practices
23.04.2022	Liquid Digestate (LD) application	05.06.2022	Weedicide application
02.05.2022	Soil tillage	11.06.2022	Hoeing
02.05.2022	Weeding	07.07.2022	Second fertilization
11.05.2022	Fertilization	14.07.2022	Weeding
11.05.2022	Sowing	19.10.2022	Harvesting

Statistical Analysis

Statistical analysis of the obtained data was conducted in the SPSS software (IBM Corp., 2017). The experimental design used was the Randomized Complete Block Design, and variance analysis was applied to these data. Potential differences between the resulting mean values were evaluated with the help of the Duncan's multiple range test.

RESULTS

Soil EC and pH

Due to its high salinity content (25.86 dS m^{-1}), LD increased soil salinity levels (Figure 2). In OYA, no significant difference in salinity was observed after the 3rd period, while in the TYA, differences were determined in every period. However, starting from the 3rd period, an increase in salinity was also observed in the GM (mineral fertilizer application), so the effect of LD could not be clearly determined for the periods after this. It was assumed that the rainfall over time had reduced the salt content in the soil.

After high-dose LD applications (G5 and G7), an increase in salinity was observed in the 3rd and 4th periods (Figure 9). However, this increase was not sufficient to change the classification of the soil EC values.

Following the LD application, a decrease in soil pH was observed in the 1st period (Figure 3), and this decrease was more pronounced in TYA. In the 2nd period, the

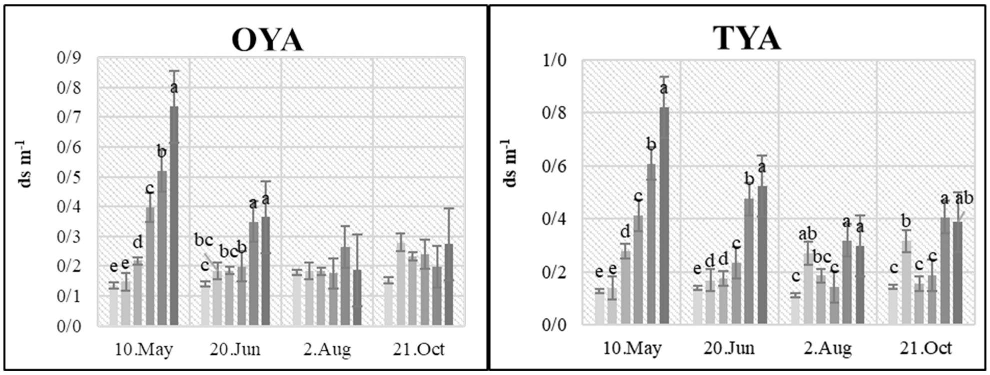
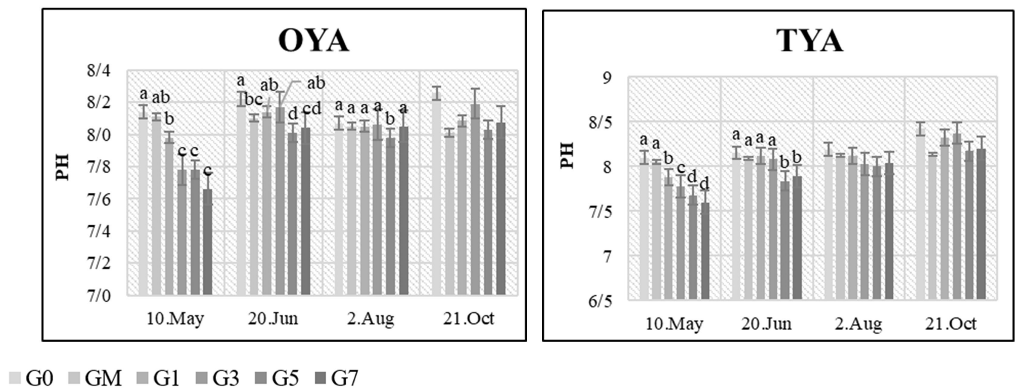


Figure 2. Electrical Conductivity results of the soils sampled on different dates in two types of experiments (OYA: One Year Application, TYA: Two consecutive Year Application).



Agricultural Applications: 23 Apr: LD application.; 11 May: Fertilization, Sowing; 7 Jul: Fertilization; 13 Oct: Harvest

Figure 3. pH results of the soils sampled on different dates in two types of experiments (OYA: One Year Application, TYA: Two consecutive Year Application). Different letters in each histogram indicate significant differences at P< 0.05 (Duncan's Multiple Range Test) among means.

acidifying effect of the high dose of LD continued in TYA, while the acidic effect of chemical fertilizer application was determined in OYA. In the subsequent periods, no significant difference in pH was observed in either method.

According to the 1st period results, the difference in soil EC due to the method is statistically significant. In the 2nd period, both the method difference and the interaction between the method and the LD dose are statistically significant (Table 5).

Table 5. Statistical analysis of EC and pH results based on method.[a]

	EC (1st Period)		EC (2nd Period)		EC (3rd Period)		PH (1st Period)		PH (2nd Period)		PH (3rd Period)	
	F	*P*	*F*	*P*	*F*	*P*	*F*	*P*	*F*	*P*	*F*	*P*
Method	15,718	**	58,152	**	2,933	*	6,469	*	91,558	**	0,511	ns
Method×Treatments	1,012	ns	15,026	**	2,494	ns	0,474	ns	7,763	**	1,096	ns

[a] F: Indicate the statistical significance from ANOVA; P: ns: Not significant, *: < 0.05, **: < 0.01.

TYA led to an increase in soil EC results in both the 1st and 2nd periods. In the same periods, compared to OYA, an increase in soil EC results was observed with all applications, except for the G1 treatment (Figure 4). The changes in soil pH results are consistent with those observed in EC. In the 1st period, only the method difference was statistically significant, whereas in the 2nd period, the interaction between the method and the LD dose also became important. It was determined that the TYA accelerated the decrease in soil pH values caused by LD (Figure 5). However, from the 3rd period onwards, the effect of LD on these parameters decreased.

In the 2nd period, a significant interaction was observed between the method and the LD dose. This reveals the impact of both the application method and the LD dose on the soil's pH and EC values. This pronounced effect was detected in measurements taken two months after the application of LD.

Soil Inorganic Nitrogen Content

LD application on April 23 resulted in monitoring soil inorganic nitrogen (NH_4^+-N, NO_3^--N) levels at specific dates (May 10, June 20, August 2, and October 21). When investigating the effect of LD on soil ammonium nitrogen (NH_4^+-N) levels, it was identified that, as the dosage of LD increased, so did this value (Figure 9). In the plots where LD was applied, the amount of inorganic nitrogen provided by the mineral fertilizer was observed to be added to the soil (Figure 6). This finding suggests that LD applications are effective in adding the necessary inorganic nitrogen to the soil for maize plants. When the inorganic nitrogen levels of the soils were analyzed periodically, no significant difference was detected between the application methods. After mineral fertilizer application and LD applications, the added soil inorganic nitrogen levels showed similar values. Grain Yield and Nitrogen Parameters in the Plant

When comparing the OYA (One-Year Application) and TYA (Two-Year Application) methods, it was observed that the highest yield in OYA was obtained from the G7 and GM applications, while in TYA, the highest yield was obtained only from the G7 application. During the tassel emergence stage, the highest N value in the leaves was identified in the G7 application with the OYA. However, in TYA, this value was recorded highest for GM. On the other hand, the lowest nitrogen values were determined for G0 (control) in both methods. Nitrogen ratios of the harvested grains were found to be highest in GM and G7 for OYA, and in GM, G5, and G7 for TYA (Table 6).

Between the methods, although the effect of LD on yield and nitrogen ratios in the plant has not shown a statistically significant change (Table 7), higher yields have been achieved with the TYA in G3, G5, and G7 treatments (Figure 7). Additionally, in the TYA, a dose of 50 t ha^{-1} of LD had a higher yield compared to mineral fertilization, which is different from the OYA. Within the method framework, there is no linear increase in the amount of nitrogen in the plant with the LD dose.

Nitrogen uptake and nitrogen use efficiencies followed similar trends for both methods. An increase in LD dosage increased yield and thus grain nitrogen uptake, and a higher value was determined at a dosage of 70 t.ha^{-1} compared to the mineral fertilization.

G5 and G7 applications had the lowest Nitrogen Use Efficiency (NUE) compared to other treatments (Figure 8). This is because the amount of N applied in these treatments was higher than in the other treatments. In terms of NUE results, GM, G1, and G3 treatments could be compared as they were given the same amount of nitrogen to the soil. GM had the highest nitrogen use efficiency. However, despite the difference in LD dosages between G1 and G3 applications, obtaining similar NUE values indicates that an increase in dosage after 1 t ha^{-1} LD did not create a significant change in NUE. In G1 and G3 applications, which

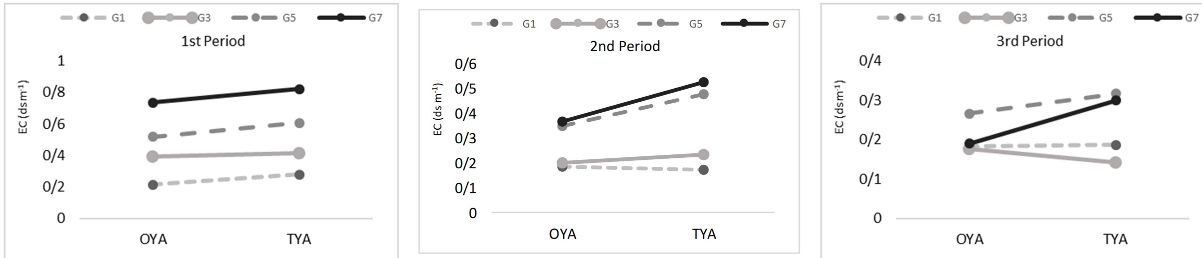


Figure 4. Effect of the method on EC results.

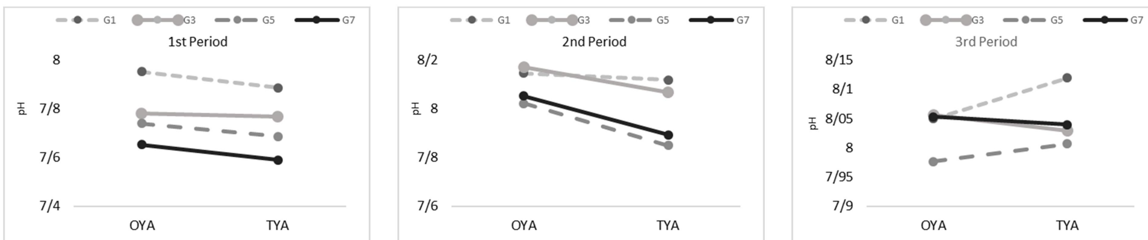


Figure 5. Effect of the method on pH results.

Table 6. Maize grain yield and percentage of total nitrogen in leaves and grains for different treatments in two types of experiments.[a]

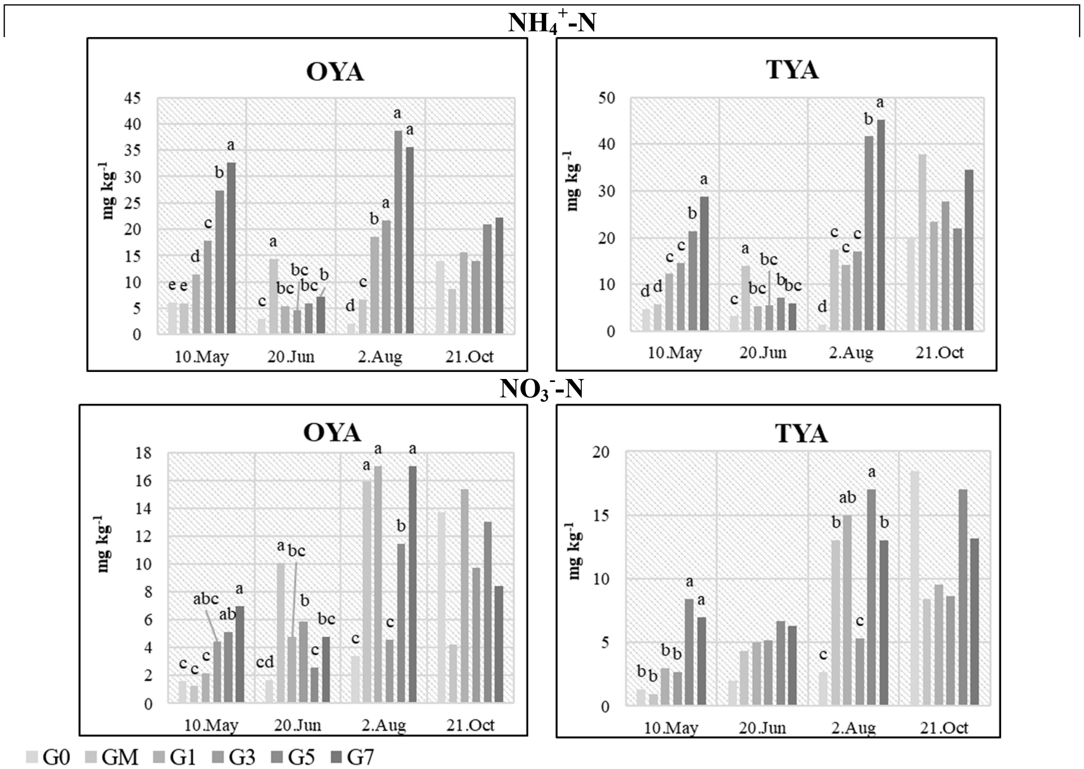
Method	Treatments	Grain yield (t ha^{-1})	N in leaf (%)	N in grain (%)
OYA	G0	13.0 ± 0.5 d	1.86 ± 0.03 d	1.03 ± 0.02 c
	GM	18.2 ± 0.6 a	2.67 ± 0.06 ab	1.17 ± 0.03 a
	G1	16.0 ± 0.4 bc	2.50 ± 0.05 c	1.09 ± 0.02 b
	G3	15.7 ± 0.5 c	2.54 ± 0.04 bc	1.07 ± 0.02 b
	G5	17.4 ± 0.5 ab	2.58 ± 0.05 abc	1.09 ± 0.02 b
	G7	19.1 ± 0.7 a	2.70 ± 0.06 a	1.18 ± 0.03 a
F		18,09**	51,89**	18,34**
TYA	G0	8.9 ± 0.2 c	1.59 ± 0.04 d	0.99 ± 0.02 c
	GM	17.0 ± 0.5 b	2.79 ± 0.06 a	1.18 ± 0.03 a
	G1	16.0 ± 0.4 b	2.51 ± 0.05 c	1.09 ± 0.02 b
	G3	16.4 ± 0.4 b	2.54 ± 0.05 c	1.09 ± 0.02 b
	G5	17.9 ± 0.6 ab	2.67 ± 0.07 b	1.14 ± 0.03 a
	G7	19.4 ± 0.8 a	2.73 ± 0.06 ab	1.17 ± 0.03 a
F		38,64**	182,19**	26,01**

[a] Different letters in each histogram indicate significant differences at P< 0.05 (Duncan's Multiple Range Test) among means. F: Indicate the statistical significance from ANOVA. *: < 0.05, **: < 0.01; OYA: One Year Application, TYA: Two consecutive Year Application.

Table 7. Statistical analysis of yield and nitrogen results based on the method.[a]

	Yield		N in Leaf		N in Grain	
	F	P.	F	P	F	P.
Method	1,023	ns	1,284	ns	2,532	ns
Method×Treatments	0,135	ns	0,463	ns	1,604	ns

[a] F: Indicate the statistical significance from ANOVA. P: ns= Not significant.



Agricultural Applications: 23 Apr: LD application.; 11 May: Fertilization, Sowing; 7 Jul: Fertilization; 13 Oct: Harvest.

Figure 6. Values of inorganic nitrogen in the soil in two types of experiments (OYA: One Year Application, TYA: Two consecutive Year Application). Different letters in each histogram indicate significant differences at P< 0.05 (Duncan's Multiple Range Test among means).

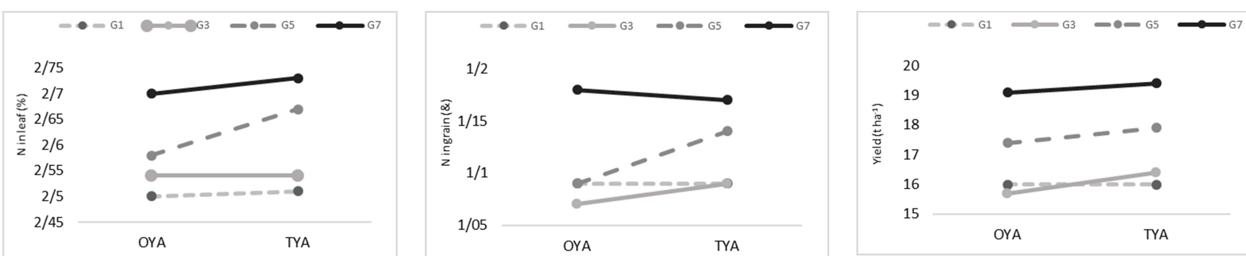


Figure 7. Effect of the method on grain yield and nitrogen values.

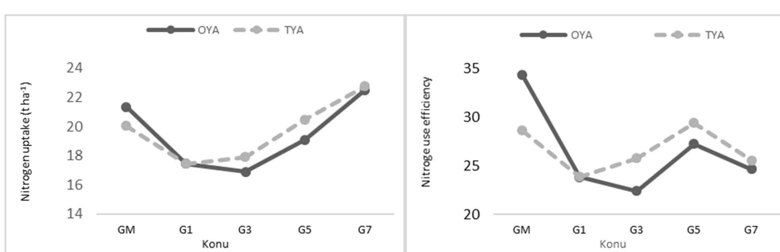


Figure 8. Grain nitrogen uptake and nitrogen use efficiency.

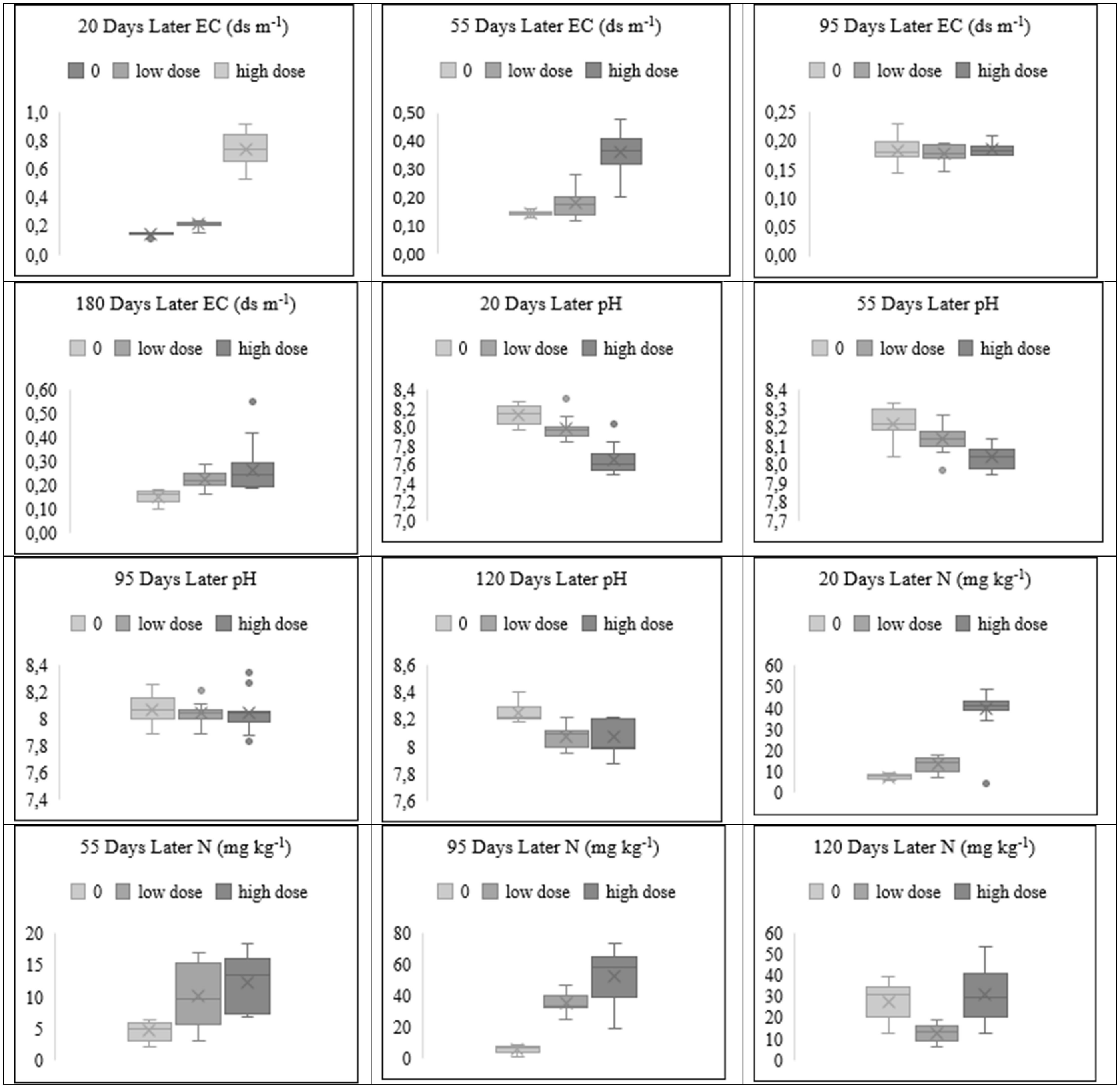


Figure 9. The effect of low and high doses of LD on inorganic Nitrogen (N), pH, and EC parameters in the OYA.

were combinations of LD with chemical fertilizer, NUE showed a similar trend. However, in the TYA, G3 had higher nitrogen uptake and NUE values compared to G1.

DISCUSSION

EC and pH

Throughout the first two periods, an increase in the application of the LD was observed to proportionally elevate the salinity (EC) values in the soil. However, after the 3rd period, this rise was noted to decrease. This suggests that the rainfall during the trial period might have reduced the salt concentration in the soil. Additionally, the high sand content of the research site facilitated the leaching of EC. While Panuccio *et al*. (2021) emphasized that the solid fraction of biogas increased the EC value in the soil, Aimrun *et al*. (2009) pointed out that soil salinity could vary with many factors and determining these dynamics is complex.

A notable decrease in soil pH values was recorded after LD application. Similar reductions were observed in the first period with doses of 35 and 70 t ha^{-1}, whereas in the second period, it was determined that chemical fertilizer applications also caused a slight acidifying effect in the soil. The acidification became more pronounced with the impact of LD but diminished in subsequent periods. While Jia *et al*. (2013) stated that the LD raised soil pH values, Ren *et al*. (2020) observed a slight decrease. Panuccio *et al*. (2021) also pointed out that LD application neutralized the pH value in high pH soil. El-Khatib *et al*. (2018) noted that biogas fermentation residues lowered the soil pH and the main reason for this decrease was organic acids and ammonium ions. Brady and Weil (2008) also mentioned that high NH_4^+-N concentrations in the soil could lead to acidification by releasing H^+ ions through nitrification.

Yield and Nitrogen Results

The application of LD positively affects grain yield and increases the yield as the dosage amount increases. The results of various studies have demonstrated the positive effects of LD on different plants. Specifically, Zhao *et al*. (2023) and Yaraşır (2018) noted a significant increase in plant height, branch count, pod count, and yield in the rapeseed plant due to LD. These findings are corroborated by another study conducted by Du *et al*. (2019) in maize. Furthermore, Głowacka *et al*. (2020) reported the potential to obtain a higher biomass by reducing the use of mineral fertilizers with digestate. In their study, where they applied doses of biogas digestate compared with irrigation water in a maize experiment, it was determined that an increase in the applied dose amount also increased the yield.

According to this study, the effect of LD on the soil's inorganic nitrogen amount was similar to that of chemical fertilizer application. Due to the high NH_4^+-N content of the LD, it is anticipated to have a positive impact on grain yield compared to organic fertilizers (Möller and Müller, 2012; Nkoa, 2014; Du, 2019). This positive effect has been identified by Al-Juhaimi *et al*. (2014) on alfalfa and by Ernst *et al*. (2008) as well as Chantigny *et al*. (2008) on other plants. Barłóg *et al*. (2020) suggested that the digestate can replace urea fertilizer as a nitrogen source in the soil.

The nitrogen levels detected in leaves and grains have been found to be consistent with the effect of LD on the inorganic nitrogen values in the soil. Variability in the concentration of NH_4^+-N or NO_3^--N in the soil can be a determinant on the nitrogen uptake of plants (Pan *et al*., 1995; Barber *et al*., 1992). In maize, in particular, the amount of inorganic N in the soil, as well as the form in which the plant takes up nitrogen, can influence the nitrogen rate in the leaves at different growth stages. Significant findings on the dynamics of NH_4^+-N in the soil have been provided by

Köster *et al*. (2011) and Nyberg *et al*. (2004). Notably, it has been indicated that certain substances that limit losses of NH_4^+-N in the form of NH_3^--N may be present depending on the dose of LD.

In this study, no difference was determined between the One-Year Application (OYA) and the consecutive Two-Year Application (TYA) methods in terms of inorganic nitrogen amounts in the soil. However, De França *et al*. (2021) pointed out that the effect of the digestate on the amount of nitrogen in the soil was more effective with the OYA than the TYA.

Compared to chemical fertilization, the NUE decreased with LD applications, but there was no significant difference in terms of NUE between the 10 and 30 $t.ha^{-1}$ applications. This suggests that LD application could lead to nitrogen losses in the soil. Materials with a low C/N ratio can promote a rapid mineralization process in the soil, leading to nitrogen losses (Brady and Weil, 2008). The fermentation process reduces the C/N ratio of organic wastes. In this context, the C/N ratio of 1.42 of the LD applied to the soil in our study may have triggered nitrogen losses.

CONCLUSIONS

This study comprehensively examines the effects of the Liquid Digestate (LD), obtained following biogas energy production, on soil and maize plants. The impacts of various LD doses (10, 30, 50, and 70 t ha^{-1}) have been evaluated in one-year and two-year consecutive applications.

The results show that for maize grain yield and nitrogen parameters, mineral fertilization treatment and 70 t ha^{-1} LD dose were the most efficient in one-year application, while70 $t.ha^{-1}$ application was the most efficient in two-year consecutive application. Especially, the grain yield obtained with a 70 $t.ha^{-1}$ was found to be considerably higher than the control group and other doses. However, it was determined that, with the increase in liquid digestate doses, soil salinity also increased. This became particularly pronounced in two-year applications. It was observed that within the first two months, the digestate application lowered the soil pH value, but this effect did not show significant change in the subsequent months. The effect of LD on the soil's inorganic nitrogen amount was similar to the chemical fertilizer applications. However, it was observed that nitrogen use efficiency was lower in 50 and 70 t ha^{-1} applications compared to the other treatments. In the applications of LD, potential nitrogen losses were determined due to its high ammonium content.

Based on the findings of this study, future experiments should consider application of similar N, P, and K inputs, as well as uniform water application in each period for all treatments, to ensure a comprehensive evaluation of the effects of liquid digestate.

In conclusion, it was noted that the LD has potential value for agricultural applications. However, it was concluded that with an increase in the dose amount of this product, soil salinity might increase and ammonia and nitrate losses should not be overlooked in high-dose applications. This study contributes to the accurate evaluation of the impacts of the LD obtained after biogas energy production in agricultural applications. Taking into consideration the sustainability and environmental effects of the applications will ensure efficient and effective use of liquid digestate.

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REFERENCES

1. Aimrun, W., Amin, M. S., Rusnam, M., Ahmad, D. E. S. A., Hanaf, M. M. and Anuar, A. R. 2009. Bulk Soil Electrical Conductivity as an Estimator of Nutrients in the Maize Cultivated Land. *Eur. J. Sci. Res.,* **31**: 37-51.
2. Al-Juhaimi, F. Y., Hamad, S. H., Al-Ahaideb, I. S., Al-Otaibi, M. M. and El-Garawany, M. M. 2014. Effects of Fertilization with Liquid Extracts of Biogas Residues on the Growth and Forage Yield of Alfalfa (*Medicago sativa* L.) under Arid Zone Conditions. *Pak. J. Bot.,* **46(2):** 471-475.
3. Anderson, J. P. E. 1982. Soil Respiration. In: "*Methods of Soil Analysis: Part 2- Chemical and Microbiological Properties*", (Eds.): Page, A. L., Keeney, D. R., Baker, D. E., Miller, R. H., Ellis Jr., R. and Rhoades, J. D. ASA-SSSA, PP. 831-871.
4. Anderson, J. P. E. and Domsch, K. H. 1978. A Physiological Method for the Quantitative Measurement of Microbial Biomass in Soils. *Soil Biol. Biochem.,* **10(3):** 215-221.
5. Anderson, T. H. and Domsch, K. H. 1986. Carbon Assimilation and Microbial Activity in Soil. *Zeitschrift für Pflanzenernährung und Bodenkunde,* **149(4):** 457-468.
6. Angelidaki, I. and Ellegaard, L. 2003. Codigestion of Manure and Organic Wastes in Centralized Biogas Plants. *Appl. Bioch. Biotechnol.,* **109(1-3):** 95-105.
7. APHA. 2012. Standard Methods for the Examination of Water and Wastewater. 22nd Edition, American Public Health Association, American Water Works Association, Water Environment Federation, Washington.
8. Aydın, B., Öztürk, O., Çobanoğlu, F., Çebi, U., Özkan, E. and Özer, S. 2020. Effects of Drip Irrigation Subsidies on Silage Maize Production: A Case Study from Edirne. *Int. J. Agric. Wildl. Sci.,* **6(3):** 496-505.
9. Bationo, A., Kihara, J., Vanlauwe, B., Waswa, B. and Kimetu, J. 2007. Soil Organic Carbon Dynamics, Functions and Management in West African Agro-Ecosystems. *Agric. Syst.,* **94(1):** 13-25.
10. Bao, S. D. 2005. *Soil and Agricultural Chemistry Analysis.* Agricultural Press, Beijing.
11. Barduca, L., Wentzel, S., Schmidt, R., Malagoli, M. and Joergensen, R. G. 2021. Mineralisation of Distinct Biogas Digestate Qualities Directly after Application to Soil. *Biol. Fertil. Soils,* **57(2):** 235-243.
12. Barłóg, P., Hlisnikovský, L. and Kunzová, E. 2020. Effect of Digestate on Soil Organic Carbon and Plant-Available Nutrient Content Compared to Cattle Slurry and Mineral Fertilization. *Agronomy*, **10(3):** 379.
13. Barber, K. L., Maddux, L. D., Kissel, D. E., Pierzynski, G. M. and Bock, B. R. 1992. Maize Responses to Ammonium- and Nitrate-Nitrogen Fertilization. *Soil Sci. Soc. Am. J.,* **56(4):** 1166-1171.
14. Brady, N. C. and Weil, R. R. 2008. The Soils Around Us. In: "*The Nature and Properties of Doils*". 14th Edition, Pearson Prentice Hall, New Jersey and Ohio, PP. 1-31.
15. Bremner, J. T. 1965. Inorganic forms of Nitrogen. In: "*Methods of Soil Analysis: Part 2- Chemical and Microbiological Properties*". Agronomy Monograph No. 9, ASA and SSSA, Madison, PP. 1179-1237.
16. Brito, L. M., Coutinho, J., and Smith, S. R. 2008. Methods to Improve the Composting Process of the Solid Fraction of Dairy Cattle Slurry. *Bioresour. Technol.,* **99(18):** 8955-8960.
17. Canisares, L. P., Do Carmo, J. B., Pitombo, L. M. and Pires, E. C. 2017. Digested Bioenergy Byproduct with Low Concentration of Nutrients Increased Greenhouse Gas Emissions from Soil. *Geoderma*, **307**: 81-90.
18. Chantigny, M. H., Angers, D. A., Bélanger, G., Rochette, P., Eriksen-Hamel, N., Bittman, S., Buckley, K., Massé, D. and Gasser, M. O. 2008. Yield and Nutrient Export of Grain Maize Fertilized with Raw and Treated Liquid Swine Manure. *Agron. J.,* **100(5):** 1303-1309.
19. Chookietwattana, K., Chumpol, J. and Sumphanwanich, P. 2016. Liquid

Fermented Organic Products: A Potential Alternative for Chemical Fertilizer and Soil Amendments. In: "*Liquid Organic Fertilizer*". Springer, PP. 79-100.

20. De França, A. A., von Tucher, S. and Schmidhalter, U. 2021. Effects of Combined Application of Acidified Biogas Slurry and Chemical Fertilizer on Crop Production and N Soil Fertility. *Eur. J. Agron.,* **123:** 126224.
21. Deviren, H., İlkılıç, C. and Aydın, S. 2017. Biyogaz Uretiminde Kullanılabilen Materyaller ve Biyogazın Kullanım Alanları. *Batman Üniversitesi Yaşam Bilimleri Dergisi,* **7(2/2):** 79-89.
22. Diacono, M. and Montemurro, F. 2011. Long-Term Effects of Organic Amendments on Soil Fertility. *Sustain. Agric.,* **2**: 761-786.
23. Du, H., Gao, W., Li, J., Shen, S., Wang, F., Fu, L. and Zhang, K. 2019. Effects of Digested Biogas Slurry Application Mixed with Irrigation Water on Nitrate Leaching during Wheat-Maize Rotation in the North China Plain. *Agric. Water Manag.,* **213**: 882-893.
24. Du, Z., Xiao, Y., Qi, X., Liu, Y., Fan, X. and Li, Z. 2018. Peanut-Shell Biochar and Biogas Slurry Improve Soil Properties in the North China Plain: A Four-Year Field Study. *Sci. Rep.,* **8(1):** 1-9.
25. El-Khatib, A. A., Al-Muhtaseb, A. H., Al-Makhadmeh, L. A. and Abu-Nameh, E. S. 2018. Impact of Liquid Fermented Organic Waste on Soil Characteristics, Plant Growth, and Yield. *J. Plant Nutr.,* **41(4):** 499-508.
26. Ernst, G., Müller, A., Göhler, H. and Emmerling, C. 2008. C and N Turnover of Fermented Residues from Biogas Plants in Soil in the Presence of Three Different Earthworm Species (*Lumbricus terrestris*, *Aporrectodea longa*, *Aporrectodea caliginosa*). *Soil Biol. Biochem.,* **40(6):** 1413-1420.
27. Fransman, B. and Nihlgård, B. 1995. Water Chemistry in Forested Catchments after Topsoil Treatment with Liming Agents in South Sweden. *Water Air Soil Pollut.,* **85(2):** 895-900.
28. Gee, G. W. and Bauder, J. 1986. Particle Size Analysis. In: "*Methods of Soil Analysis: Part 1- Physical and Mineralogical Methods*", (Ed.): Klute, A., Agronomy Monograph No. 9, 2nd Edition, American Society of Agronomy/Soil Science Society of America, Madison, WI, PP. 383-411.
29. Geisseler, D. and Scow, K. M. 2014. Long-Term Effects of Mineral Fertilizers on Soil Microorganisms– A Review. *Soil Biol. Biochem.,* **75:** 54-63.
30. Głowacka, A., Szostak, B. and Klebaniuk, R. 2020. Effect of Biogas Digestate and Mineral Fertilisation on the Soil Properties and Yield and Nutritional Value of Switchgrass Forage. *Agronomy,* **10(4):** 490.
31. Gürbüz, M. A. and Öz, T. A. 2016. Ayçiçeğinin Azotlu Gübreleme Önerilerinde İndeks Olarak Kullanılabilecek Parametrelerin Araştırılması [Investigation of Parameters that can be Used as an Index in Nitrogen Fertilization Recommendations for Sunflower]. *Çukurova Tarım ve Gıda Bilimleri Dergisi,* **31(3):** 147-152.
32. Holm-Nielsen, J. B., Al Seadi, T. and Oleskowicz-Popiel, P. 2009. The Future of Anaerobic Digestion and Biogas Utilization. *Bioresour. Technol.,* **100(22):** 5478-5484.
33. IBM Corp. 2017. IBM SPSS Statistics for Windows, Version 25.0. IBM Corp., Armonk, NY.
34. Insam, H., Franke-Whittle, I. H., Knapp, B. A. and Plank, R. 2009. Use of Wood Ash and Anaerobic Sludge for Grassland Fertilization: Effects on Plants and Microbes. *Die Bodenkultur,* **60(2):** 39-50.
35. Jackson, M. L. 1979. Soil Chemical Analysis: Advanced Course. Dept. of Soil Science, University of Wisconsin, Madison, WI, USA.
36. Jia, Y., Sun, G. X., Huang, H. and Zhu, Y. G. 2013. Biogas Slurry Application Elevated Arsenic Accumulation in Rice Plant through Increased Arsenic Release and Methylation in Paddy Soil. *Plant Soil,* **365(1):** 387-396.
37. Jurgutis, L., Šlepetienė, A., Amalevičiūtė-Volungė, K., Volungevičius, J. and

Šlepetys, J. 2021. The Effect of Digestate Fertilisation on Grass Biogas Yield and Soil Properties in Field-Biomass-Biogas-Field Renewable Energy Production Approach in Lithuania. *Biomass Bioenergy*, **153**: 106211.
38. Kacar, B. and İnal, A. 2010. *Bitki Analizleri*. Nobel Yayın Dağıtım.
39. Karimi, B., Sadet-Bourgeteau, S., Cannavacciuolo, M., Chauvin, C., Flamin, C., Haumont, A., Jean-Baptiste, V., Reibel, A., Vrignaud, G. and Ranjard, L. 2022. Impact of Biogas Digestates on Soil Microbiota in Agriculture: A Review. *Environ. Chem. Lett.,* **20(5):** 3265-3288.
40. Köster, J. R., Cárdenas, L., Senbayram, M., Bol, R., Well, R., Butler, M., Mühling, K. H. and Dittert, K. 2011. Rapid Shift from Denitrification to Nitrification in Soil After Biogas Residue Application as Indicated by Nitrous Oxide Isotopomers. *Soil Biol. Biochem.,* **43(8):** 1671-1677.
41. Loeppert, R. H. and Suarez, D. L. 1996. Carbonate and Gypsum. In: "Methods of soil Analysis: Part 3- Chemical Methods", (Eds.): Sparks, D. L., Page, A. L., Helmke, P. A., Loeppert, R. H., Soltanpour, P. N., Tabatabai, M. A., Johnston, C. T. and Sumner, M. E. ASA and SSSA, Madison, PP. 437-474.
42. Marschner, P., Kandeler, E. and Marschner, B. 2003. Structure and Function of the Soil Microbial Community in a Long-Term Fertilizer Experiment. *Soil Biol. Biochem.,* **35(3):** 453-461.
43. Massé, D. I., Croteau, F. and Masse, L. 2007. The Fate of Crop Nutrients during Digestion of Swine Manure in Psychrophilic Anaerobic Sequencing Batch Reactors. *Bioresour. Technol.,* **98(15):** 2819-2823.
44. TSMS (Turkish State Meteorological Service). 2022. Official Statistics. Retrieved from: https://www.mgm.gov.tr/veridegerlendirme/il-ve-ilceler-istatistik.aspx?k=Aandm=KIRKLARELI
45. Moll, R. H., Kamprath, E. J. and Jackson, W. A. 1982. Analysis and Interpretation of Factors which Contribute to Efficiency of Nitrogen Utilization. *Agron. J.,* **74(3):** 562-564.
46. Möller, K. 2015. Effects of Anaerobic Digestion on Soil Carbon and Nitrogen Turnover, N Emissions, and Soil Biological Activity. A Review. *Agron. Sustain. Dev.,* **35(3):** 1021-1041.
47. Möller, K. and Müller, T. 2012. Effects of Anaerobic Digestion on Digestate Nutrient Availability and Crop Growth: A Review. *Eng. Life Sci.,* **12(3):** 242-257.
48. Nkoa, R. 2014. Agricultural Benefits and Environmental Risks of Soil Fertilization with Anaerobic Digestates: A Review. *Agron. Sustain. Dev.,* **34(2):** 473-492.
49. Nyberg, K., Sundh, I., Johansson, M. and Schnürer, A. 2004. Presence of Potential Ammonia Oxidation (PAO) Inhibiting Substances in Anaerobic Digestion Residues. *Appl. Soil Ecol.,* **26(2):** 107-112.
50. Pan, W. L., Camberato, J. J., Moll, R. H., Kamprath, E. J., and Jackson, W. A. 1995. Altering Source–Sink Relationships in Prolific Maize Hybrids: Consequences for Nitrogen Uptake and Remobilization. *Crop Sci.,* **35(3):** 836-845.
51. Panuccio, M. R., Romeo, F., Mallamaci, C. and Muscolo, A. 2021. Digestate application on two different soils: Agricultural benefit and risk. *Waste Biomass Valori.,* **12(8):** 4341-4353.
52. Piccoli, I., Francioso, O., Camarotto, C., Delle Vedove, G., Lazzaro, B., Giandon, P. and Morari, F. 2022. Assessment of the Short-Term Impact of Anaerobic Digestate on Soil C Stock and CO2 Emissions in Shallow Water Table Conditions. *Agron.,* **12(2):** 504.
53. Rawoof, S. A. A., Kumar, P. S., Vo, D. V. N. and Subramanian, S. 2021. Sequential Production of Hydrogen and Methane by Anaerobic Digestion of Organic Wastes: A Review. Environ. Chem. Lett., **19**: 1043-1063.
54. Ren, T., Yu, X., Liao, J., Du, Y., Zhu, Y., Jin, L., Wang, B., Xu, H., Xiao, W., Chen, H. Y. H., Jin, F. and Ruan, H. 2020. Application of Biogas Slurry Rather than Biochar Increases Soil Microbial Functional Gene Signal Intensity and Diversity in a

Poplar Plantation. *Soil Biol. Biochem.,* **146:** 107825.

55. Robles-Aguilar, A. A., Temperton, V. M. and Jablonowski, N. D. 2019. Maize Silage Digestate Application Affecting Germination and Early Growth of Maize Modulated by Soil Type. *Agronomy*, **9(8):** 473.
56. Rohila, A. K., Maan, D., Kumar, A. and Kumar, K. 2017. Impact of Agricultural Practices on Environment. *Asian J. Microbiol. Environ. Sci.,* **19(2):** 145-148.
57. SAPEA. 2012. *Facheverhan Biogas.* Retrieved from: http://www.biogas.org/edcom/webfvb.nsf/id/DE_Branchenzahlen
58. Shi, L., Simplicio, W. S., Wu, G., Hu, Z., Hu, H. and Zhan, X. 2018. Nutrient Recovery from Digestate of Anaerobic Digestion of Livestock Manure: A Review. *Curr. Pollut. Rep.,* **4**: 74-83.
59. Singh, A., Agrawal, M. and Marshall, F. M. 2010. The Role of Organic vs. Inorganic Fertilizers in Reducing Phytoavailability of Heavy Metals in a Wastewater-Irrigated Area. *Ecol. Eng.,* **36(12):** 1733-1740.
60. Soil Survey Lab Staff, USDA. 1975. Soil Taxonomy: A Basic System of Soil Classification for Making and Interpreting Soil Surveys (No. 436.4 So3). US Govt. Print. Off.
61. Sutherland, R. A. 2018. Guidelines for the Use of ICP-OES for the Characterisation of Urban Road-Deposited Sediment Particle Size Fractions. *Environ. Pollut.,* **238:** 926–939.
62. Sürmen, M. and Kara, E. 2022. High-Quality Fertilizers from Biogas Digestate. In: "*Environment and Climate-Smart Food Production*", (Ed.): Galanakis, C. M. Springer, Cham., PP. 319-347.
63. Urra, J., Alkorta, I. and Garbisu, C. 2019. Potential Benefits and Risks for Soil Health Derived from the Use of Organic Amendments in Agriculture. *Agronomy*, **9(9):** 542.
64. Yakan, H. and Sağlam, T. 1997. Kırklareli Koşullarında Yetiştirilen Hıbrıt Mısır Azotlu ve Fosforlu Gübrelemenin Dane Verimi ve Bazı Kalite Özelliklerine Etkisi Doctoral Thesis, Faculty of Agriculture, Trakya University, Edirne.
65. Yaraşır, N. 2018. The Effect Of Different Doses of Liquıd Biogas Wastes on Yield and Quality of Wheat (*Triticum aestivum* L.). Master's Thesis, Graduate School of Natural and Applied Sciences, Adnan Menderes University.
66. Zhao, Q., Cheng, J., Zhang, T., Cai, Y., Sun, F., Li, X. and Zhang, C. 2023. Biogas Slurry Increases the Reproductive Growth of Oilseed Rape by Decreasing Root Exudation Rates at Bolting and Flowering Stages. *Plant Soil,* 482: 369–384.
67. Zhong, W., Gu, T., Wang, W., Zhang, B., Lin, X., Huang, Q., and Shen, W. 2010. The Effects of Mineral Fertilizer and Organic Manure on Soil Microbial Community and Diversity. *Plant Soil,* **326(1):** 511–522.

تأثیر استفاده‌های تک و تجمعی از محلول هضم بیوگاز(Biogas Liquid Digestate) بر خاک و گیاه

ولکان آتاو، اورهان یوکسل، و آیتنناملی

چکیده

افزایش تولید انرژی بیوگاز منجر به انباشت پساب مایع (LD) شده است، که یک محصول جانبی با قابلیت استفاده در کشاورزی است. به منظور تشخیص مزایا و معایب آن، یک آزمایش میدانی انجام شد تا اثرات مقادیر مختلف LD بر عملکرد ذرت، شوری خاک، و محتوای نیتروژن (N) برگ و دانه ارزیابی شود. این مطالعه شامل کاربرد کود نیتروژن (LD) به صورت تک ساله و دو ساله متوالی با مقادیر ۱۰، ۳۰، ۵۰ و ۷۰ تن در هکتار بود. بر اساس نیاز ذرت به نیتروژن، هرگونه کمبود نیتروژن با کودهای شیمیایی جبران شد. برای آزمایش یک ساله، بالاترین عملکرد دانه از تیمار کود شیمیایی و مقدار ۷۰ تن در هکتار کود LD به دست آمد. در دو سال متوالی، دوز ۷۰ تن در هکتار بالاترین عملکرد دانه را به همراه داشت. کود LD به طور مؤثری نیتروژن را به خاک می‌رساند و pH خاک را تقریباً در عرض ۱ ماه تثبیت کرد.با این حال، مقادیر بالای هضم (high doses of digestate) منجر به افزایش شوری خاک و کاهش راندمان استفاده از نیتروژن (NUE) شد. کاربرد متوالی دو ساله، رسانایی و هدایت الکتریکی (EC) و تثبیت pH در خاک را به میزان بیشتری نسبت به کاربردهای یک ساله افزایش داد. با این حال، هیچ تفاوتی در محتوای نیتروژن گیاه بین کاربرد یک ساله و دو ساله متوالی وجود نداشت. به طور خلاصه، کود کم مصرف مزایای کشاورزی قابل توجهی مانند تثبیت pH و افزایش سطح نیتروژن معدنی را فراهم می‌کند. با این حال، یافته‌های ما نشان می‌دهد که استفاده بیش از حد می‌تواند منجر به شوری خاک و هدررفت نیتروژن شود، که بر اهمیت کاربرد متعادل برای به حداکثر رساندن مزایای آن و در عین حال به حداقل رساندن معایب احتمالی تأکید می‌کند.