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DETERMINING THE EFFECT OF DIGESTATE RECEIVED FROM BIOGAS PRODUCTION AND IMPACT ON YIELD AND QUALITY OF CROP PRODUCTION

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Abstract: The shortage of electricity in Bulgaria requires demand for renewable energy sources. Interest in the production of biogas from organic waste has intensified in recent years. Anaerobic fermentation during biogas production is associated with obtaining the digestate. Several studies have found that digestate is rich in micro and macro nutrients and can be used as an organic reserve in agricultural practice. The aim of this study is to determine the effect of digestate on yield and quality of crop production at the ratio of raw materials the input of biogas installation – pig manure and markets waste 70:30. The indicator culture is lettuce. The studies were carried out on two soil types. Different percentage of digestate was tested in comparison with untreated soils as controls.
Keywords: digestate, biogas, anaerobic fermentation

1. INTRODUCTION

The shortage of electricity in Bulgaria requires renewable energy sources. In recent years there has been increased interest in biogas production from organic waste (*Zaharinov, 2011*). Currently, potential raw materials for biogas production are underutilized. Their improper treatment or deposition leads to pollution of the environment. In our country, there are still no installations for biogas production.

Anaerobic fermentation (AF) is a microbiological process of organic matter decomposition in the absence of oxygen and is commonly found in many natural environments (*Galabova et al., 2003*). Nowadays, AF is used mainly for the production of biogas in airtight tanks-reactor, usually called bioreactors (*Schink, 2001*). Wide range of microorganisms is involved in the anaerobic process as main end products are biogas and digestate. Biogas is a combustible gas containing methane, carbon dioxide and small amounts of other gases as well as small amount of other elements (*Simeonov, 2012; Zaharinov, 2013; Rychtera et al., 1983*).

During anaerobic fermentation for biogas production is obtained secondary biomass also known as digestate. This requires seeking of its realization. Several studies have found that digestate is rich in micro and macro nutrients and can be used as an organic reserve in agricultural practice (*Shaffer et al., 2001; Marinova et al., 2012; Baykov, et al., 2007*).

The interest of farmers associated with utilization of digestate is related to the shortage of organic sources in our country, imbalance of organic matter in Bulgarian soils and the availability of large quantities of organic waste nationwide. The aim of this study is to establish the effect of digestate for use in agricultural practice and its impact on yield and quality of crop production at the ratio of the raw materials into biogas pilot plant - pig manure and markets waste 70:30.

2. MATERIAL AND METHODS

Conducting the vegetation experiment

Testing different variations and identification of the most suitable soil for plants require to conduct vegetation experiments. These studies will establish the most appropriate and economic norms for utilization in field conditions (*Demirbas, 2006*). Vegetation experiments were conducted using digestate from model installation for biogas production with raw material comprising pig manure: wastes from

market in ratio 70%: 30%. The experiments are laid out on two soil types: fluvisols from the area of Kubratovo and vertisols from Bojurishte. The following variants were tested: control - clean soil, control - soil with mineral fertilization and variants with 5%, 15%, 25% and 35% of digestate by soil weight.
The variants with mineral fertilization are included to compare the used digestate, which is organic matter (gradually mineralized) and mineral fertilization (easily assimilated form plants). The lettuce (*Variety Gentilini*) was planted as a test crop. For establishment of content of macro and micro nutrients and cation exchange capacity digestate and soil types were analysed before experiment. Crop development is documented by photographs.

Determination of the yield and analysis of crop production and soil

Post-harvest crop yield was recorded and the information was subjected to mathematical and statistical analysis. The plant production is analysed for basic content of macro and micro nutrients and some heavy metals by standard methods used in ISSAPP, "N. Poushkarov".

- Total nitrogen - Kjeldahl,
- Microelements - method of Hess with atomic-absorption spectrophotometer.
- Ammonium and nitrate nitrogen – colorimetrically.
- Mobile forms of phosphorus - colorimetrically by a modification of the method of P. Ivanov.
- Mobile forms of potassium – with a flame photometer.
- Total content of heavy metals - aqua regia method.
- Mobile forms of microelements (heavy metals)-EDTA-method.
- pH (H_2O, KCl) - potentiometrically.
- Mechanical composition - pipette method with dispersant - sodium pyrophosphate, in Kaczynski.
- Hygroscopic humidity - a thermostatically-weight method.
- Soluble salts - weight method.
- Electrical conductivity – conductometrically.

3. RESULTS AND DISCUSSION

Characterization and evaluation of digestate used in vegetation experiments.

Agrochemical and chemical characteristics of digestate obtained from 70% pig manure: 30% fruit and vegetable waste is shown in Table 1. The data show that digestate is rich in macro and microelements and can be used in agricultural practices to improve soil properties and crops yield. The content of the common forms of nutrients - nitrogen, phosphorus and potassium are respectively 10.80%; 7.67% and 9.02% in absolute dry matter. Based on the dry matter content, reported in digestate (1%) the real values of total nitrogen were 0.11%; 0.08% total phosphorus and 0.099% total potassium. The pH activity is neutral- 7.62.

Table 1. Chemical and agrochemical characteristics of digestate from vegetative experiments

Elements	70:30 pig manure: markets waste	Elements	70:30 pig manure: markets waste
pH –H_2O	7.62	Mobile P %	0.54
Moisture %	98.9	Mobile K %	1.25
Dry residue %	1.1	S (as SO_4) %	0.1
Organic C %	24.88	As mg/kg	< 5.0
Total P_2O_5 %	7.67	Cd mg/kg	< 1.0
Total N %	10.8	Cr mg/kg	13
Total K_2O %	9.02	Ni mg/kg	26
Total CaO %	7.6	Cu mg/kg	411
Total MgO %	2.89	Zn mg/kg	1409
Mobile N–NH_4 %	5.48	Pb mg/kg	8
Mobile N–NO_3 %	0.53	Hg mg/kg	<1

The content of heavy metals (Table 1) shows that values are under maximum allowable concentration (MAC) and digestate is not hazard for use in agriculture. The data on chemical composition and physicochemical properties of digestate shows that it can be a source of important plant nutrients such as nitrogen, phosphorus, potassium, magnesium, calcium, iron, sodium, etc.

Characterization and evaluation of experimental soil types

- **Agrochemical physical-chemical characteristics of fluvisol from Kubratovo**

Data from agrochemical analysis show that the soil is very well supplied with mobile phosphorus (23.2 mg P_2O_5/100g soil) well preserved with mobile potassium (27,4 mg K_2O/100g soil) and mineral nitrogen in dominant ammonium form. Conductivity is low and amount of soluble salts is also very low. The total amount of heavy metals in the soil is below MAC (Table 2).
A physic-chemical characterization of soils, used in vegetation experiments was also made. Data on Fluvisols is presented in Table 3. According to the constitution bases, when the bases are <Tca (T 8.2%)

and pH <6 the soil is podzolic. According to the buffer systems the soil is medium acid and the ion exchange capacity (T 8.2 = 35 g soil meqv. /100) define it as medium colloidal. The predominant clay minerals determine soil as montmorillonite-illite (81.43% TCA = 8.2 T) with evolution to illite-montmorillonite (base = 80.29%). Physical and mechanical properties of Fluvisol (Table 4) show that fraction <0, 001 dominates.

Table 2. Chemical analysis of vertisol and fluvisol of the vegetation experiments

Elements	Vertisols	Fluvisol	Elements	Vertisols	Fluvisol
pH –H_2O	6.1	5,5	Exchange Mg mg/100g	108	57
pH – KCl	-	5,5	Conductivity mS/cm	0.042	0.077
Total N %	0.12	0,21	Water soluble salts g/100g	0.013	0.024
Total Ca%	-	0,14	As mg/100g	<1	< 1
Total Mg %	-	0,58	Cd mg/100g	<1	< 1
Total Fe %	2.77	3,51	Cu mg/100g	185	210
Total P %	-	0,14	Pb mg/100g	2	42
N – NH_4 mg/kg	8.2	11,8	Ni mg/100g	22	18
N –NO_3 mg/kg	5.8	7,1	Zn mg/100g	1170	132
Mobile P_2O_5 mg/100g	0.22	23,2	Cr mg/100g	7	11
Mobile K_2O mg/100g	36.9	27,4	Humus %	3.36	-
Exchange Ca mg/100g	696	430			

Table 3. Cation exchange capacity and base saturation in studied fluvisol

Materials	pH/ H_2O	$T_{8,2}$	T_{CA}	T_A	Exch. $H_{8,2}$	Exch. Al+H	Exch. Ca	Exch. Mg
		meqv/ 100 g.						
Soil	5.5	35.0	28.5	6.5	6.9	0.4	24.0	3.9

T_{CA}	T_A	Exch.$H_{8,2}$	Exch.Al	Exch.Ca	Exch.Mg	base saturation
% $T_{8,2}$						%
81.43	18.57	19.71	1.43	68.57	10.86	80.29

Table 4. Mechanical composition of Fluvisol from the vegetation experiments

Variants	Particle size (mm)							
	Amount > 1	1 – 0.025	0.25 – 0.05	0.05 – 0.01	0.01 – 0.005	0.005 – 0.001	<0.001	Amount < 0.01
Soil	0.0	16.7	19.73	13.72	15.04	6.71	28.10	49.85

» **Agrochemical and physical-chemical characteristics of Vertisols in the region of Bojurishte**

Soil from Bojurishte region - Sofia that is provided for vegetation experiment is, classified as Smolnitsa according to the Bulgarian Soil Classification, which correspond to vertisol in the World Reference Base for Soil Resources (*IUSS Working Group WRB, 2006*).

Data from agrochemical analysis of the soil shows that it is very well supplied with mobile potassium- 36, 92 mg K_2O / 100 g soil, and very low, almost poor in the plants absorbable phosphorus- 0, 22 mg P_2O_5 /100 g soil. Mineral nitrogen is in predominance of ammonium form. The amount of soluble salts is very small due to the low conductivity. The total amount of heavy metals is below the limit (Table 2). Data for physical and chemical characteristics of the soil is presented in Table 5. The ranges of variation of the magnitude of cation sorption capacity ($T_{8,2}$) and the average percentage of strong (T_{CA}) and weak (T_A) acidoid is determined using the Ganev and Arsova method.

Table 5. Cation exchange capacity and base saturation in studied vertisol

Materials	pH/ H_2O	$T_{8,2}$	T_{CA}	T_A	Exch. $H_{8,2}$	Exch. Al+H	Exch. Ca	Exch. Mg
		meqv/ 100 g.						
Soil	6.1	50.7	43.86	6.9	3.9	0.0	34.7	9.04

T_{CA}	T_A	Exch. $H_{8,2}$	Exch. Al	Exch. Ca	Exch. Mg	base saturation
% $T_{8,2}$						%
86.39	13.61	7.69	0.0	72.39	17.89	92.31

Table 6. Mechanical composition of vertisols for vegetation experiments

Variants	Particle size (mm)							
	Amount > 1	1– 0.25	0.25– 0.05	0.05– 0.01	0.01– 0.005	0.005– 0.001	<0.001	Amount < 0.01
Soil	0.0	1.8	9.8	13.0	11.5	8.8	53.3	73.6

Constitution bases soil (A horizon) with pH = 6.1, bases = T_{CA} confirms that the soil is leached. According to the acid and buffer systems, vertisol is a weak acid (A horizon). Colloidal reactivity ($T_{8.2}$ = 44, meqv/100g) shows that the soil is poorly colloid. The prevalent clay mineralogy (T_{CA} = 43.86 meqv/100g) determine soil as montmorillonite-illite. It was also determined the mechanical composition of the vertisol. The results are presented in Table 6. The data shows that dominated participation have a size fraction less than 0.001 (finest fraction).

» **Development of plants during vegetation**

As we noted above, vegetation experiments are conducted with digestate from biogas production in pilot installation with raw materials in ratio 70% pig manure: 30% vegetable waste. *(Simeonov* *et al, 2012*). Vegetation experiments are set on 31 October 2011 on already mentioned two soil types (Fluvisols and Vertisols). Sowing of lettuce was carried out. Plants germinated normally on 10 November 2011. 20 days later lettuce was thinned. Daily watering of plants, according to the field capacity (FC) was fulfilled. 46 days after sowing the plants, different variants were photographed on both soil types.

Lettuce

» **Yield and chemical analysis of lettuce plant production**

Vegetation experiments show that lettuce develops normally on both soil types. The obtained data from lettuce yield on fluvisol (figure 1) and leaching vertisol (figure 2) show that quantity of biomass is higher on the first soil type for all variants.

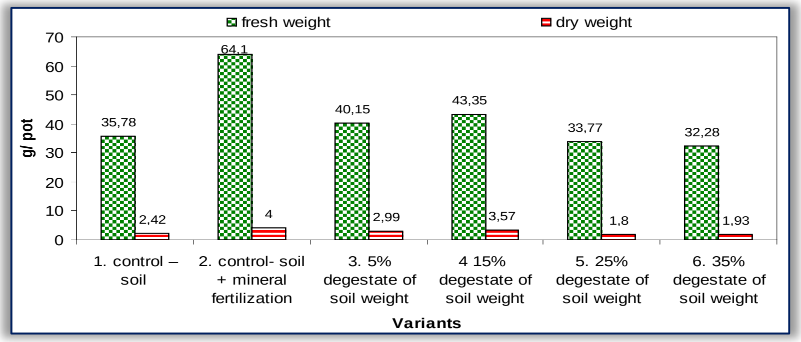

Figure 1 - Yield of lettuce from fluvisol on experiments with digestate

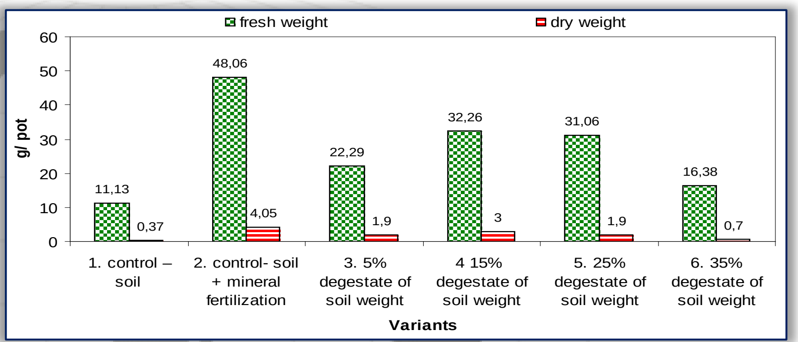

Figure 2 - Yield of lettuce from vertisol on experiments with digestate

The high value of lettuce yield on Fluvisol is probably due to the very good soil preservation with N, P and K. The trend in yield by increasing the amount of digestate for both soil types is similar. The best lettuce developing is observed in variants with mineral fertilization and the yield is highest. Biomass of lettuce in control variant (clean soil) remains low compared to other variants and it is similar in both soil types. For variants with digestate the largest biomass was measured in variants with 15% digestate compared to control variant.

High doses of digestate have suppressive effects on plant development and yield probably due to excessive high levels of digestible nitrogen, phosphorus and potassium. Higher doses of digestate obtain the soil compaction, which affects the optimal development of lettuce root system. On the other hand digestate values higher than 15% are not environmentally friendly and cost effective. The highest yield of lettuce in both soils was obtained with mineral fertilization variants – 4g / pot in Fluvisol and 4.05 g / pot - Vertisols. The differences between each variant are greater than less permissible difference (LPD) 0.1%.

In digestate variants, the maximum of yield is in 15% digestate by weight of soil. The difference between yields from variants of fluvisol is statistically proven (LPD 1%), and the vertisols - in (LPD 0.1%). There is a tendency to reduce yield at further increasing the amount of introduces digestate (with LPD 0, 1%). After lettuce harvesting some analyses for content of basic macro and microelements and heavy metals were made. The results of chemical analysis of plant production are presented in Table 7 and Table 8. The content of total nitrogen in plants varies between 1.40% and 2.40% on fluvisol and from 0.83% to 1.40% on vertisols. These values are comparable with data from studies of *Mitova and Marinova, (2012*) with enriched vermiculite on the same soil types and the same variety of lettuce. In fluvisol with increasing digestate amount, the phosphorus in plants is not changed, potassium increased slightly, while calcium and magnesium is varying (Table 7).

Table 7. Chemical characteristic of plant production by lettuce grown on Fluvisol

Variants	N %	P %	K%	Ca %	Mg %	Zn mg/kg	Cu mg/kg	Mn mg/kg	Fe mg/kg
1. Control	1.40	0.46	6.80	1.22	0.32	46	10	78	800
2. Soil+NPK	2.20	0.72	7.40	1.53	0.42	53	11	95	1200
3. 5% digestate	1.20	0.49	7.40	1.19	0.31	39	11	92	1650
4. 15% digestate	1.30	0.46	6.40	1.44	0.45	42	6	98	1050
5. 25% digestate	2.30	0.45	8.60	1.43	0.38	50	10	48	1000
6. 35% digestate	2.40	0.43	9.00	1.50	0.40	51	13	63	1400

Table 8. Chemical characteristic of plant production by lettuce grown on Vertisols

Variants	N%	P %	K%	Ca %	Mg %	Zn mg/kg	Cu mg/kg	Mn mg/kg	Fe mg/kg
1. Control	0.83	0.18	5.80	1.00	0.25	35	7	65	850
2. Soil+NPK	1.40	0.43	7.50	1.18	0.28	41	9	67	950
3. 5% digestate	1.20	0.25	6.00	0.92	0.23	36	7	71	900
4. 15% digestate	1.40	0.18	6.80	0.84	0.30	48	11	103	2000
5. 25% digestate	1.20	0.27	8.40	1.07	0.39	54	10	104	2500
6. 35% digestate	1.40	0.26	7.50	2.40	0.47	66	13	120	2300

Vertisols for the content of all nutrients expressed no clear trend with increasing amount of digestate, the concentrations in different variants slight vary (Table 8). Analyses for content of microelements Cu, Zn and Mn in plant production show that they are in optimal range for the species. The iron content in plant tissues at the end of the study have high values in Vertisols (from 850 to 2400 mg / kg), and from 800 to 1400 mg / kg in Fluvisol. Regardless of increased amounts of iron visible depression in lettuce is not noticeable.

» **Chemical & agrochemical characteristic of Fluvisol from Kubratovo after lettuce harvesting**

Agrochemical analysis of soil, after harvest lettuce show that increasing of digestate amount significantly leads to increased absorbable phosphorus for plants (Table 9).

Table 9. Agrochemical characteristic of Fluvisol with variant post-harvest vegetation experiments with lettuce

Variants	pH H_2O	Mineral nitrogen, mg/kg NH_4,	NO_3	P_2O_5 mg/100g	K_2O mg/100g
1. Control	5.8	66.70	16.80	23.20	28.40
2. Soil+NPK	5.3	62.10	44.70	76.60	39.20
3. 5% digestate	5.8	66.70	28.40	26.70	32.90
4. 15% digestate	5.9	60.90	38.90	32.30	34.00
5. 25% digestate	5.9	70.20	43.50	42.10	43.20
6. 35% digestate	6.0	52.80	45.80	50.30	45.20

Higher level of absorbed phosphorus supplied has the variant with 35% added digestate, which causes a decrease in yield. The degree of movable potassium increases with increasing the digestate amount in variants. In 35% digestate the potassium content reaches 45.2 mg K_2O / 100 g soil and it shows very high degree of supply with this nutrient.

Table 10. Assessment salinity of Fluvisol from vegetation experiments with lettuce with different variants of digestate

Variants	Conductivity mS/cm	Water soluble salts g/100g
1. Control	0.098	0.030
2. Soil+NPK	0.308	0.100
3. 5% digestate	0.084	0.027
4. 15% digestate	0.098	0.031
5. 25% digestate	0.116	0.037
6. 35% digestate	0.135	0.043

The amount of mineral nitrogen was also increased with increasing dose of digestate. This is at the expense of a large increase of nitrogen from 16.83 mg / kg N-NO_3 var.1 up to 45.8 mg / kg N-NO_3 for var.6. The change of ammonia form of mineral nitrogen is weak and variable, but generally mineral nitrogen has very high values (Table 9). After harvesting the lettuce analyses of conductivity and presence of soluble salts in variants, show increasing amount of added compost gradually increasing conductivity and the amount of water-soluble salts, but they are within the limits of not salty soils. The highest values have variant 2, with incorporated mineral N, P, K fertilizers (Table 10).

» **Chemical & agrochemical characteristic of vertisols in Bojurishte after lettuce harvesting**

Studies on agrochemical characteristics of soil after harvesting the lettuce found that increasing of digestate dose leads to smoothly increasing of absorbable phosphorus for plants. The highest dose of digestate is P_2O_5/100 14.16 mg g soil (Table 11).

Table 11. Agrochemical characteristics of Vertisols after lettuce harvesting

Variants	pH H_2O	Mineral nitrogen mg/kg NH_4	NO_3	P_2O_5 mg/100g	K_2O mg/100g
1. Control	6.1	49.3	13.3	0.75	45.0
2. Soil+NPK	5.6	101.5	124.7	66.13	105.0
3. 5% digestate	6.1	63.2	33.1	3.13	46.0
4 15% digestate	6.0	58.6	55.1	6.38	51.0
5. 25% digestate	5.9	71.3	80.6	11.63	59.0
6. 35% digestate	6.1	53.9	94.5	14.16	101.1

In variant with 35% digestate is achieved moderate supply of absorbable phosphorus. The degree of movable potassium in vertisols is very good. In the variants with the highest amount of digestate content reaches 10, 1 mg K_2O / 100 g soil and it can lead to depression in yield. As noted above the amount of mineral nitrogen in non-treated soil is high with prevalence of the ammonia form. Significantly increasing of the digestate dose leads to increasing the amount of nitrate form of mineral nitrogen (Table 11). Analyses were conducted for the electrical conductivity and the presence of soluble salts on all variants after lettuce harvesting. It is found that with increasing amount of imported digestate slightly increases conductivity and quantity of water-soluble salts, but this does not lead to salinisation (Table 12). The highest values have both indicators, measured for variants with chemical fertilization (Table 12).

Table 12. Evaluation of Vertisols salinity after lettuce harvesting

Variants	pH H_2O	Conductivity mS/cm	Water soluble salts g/100g
1. Control	6.1	0.042	0.013
2. Soil+NPK	5.6	0.406	0.130
3. 5% digestate	6.1	0.084	0.027
4. 15% digestate	6.0	0.098	0.031
5. 25% digestate	5.9	0.116	0.037
6. 35% digestate	6.1	0.135	0.043

4. CONCLUSIONS

In the conducted experiments and the obtained results it was found that:

- Agrochemical and chemical characteristics define digestate as a biomass rich in macro and micronutrients that can be used in agriculture for increasing soil fertility. The content of heavy metals in initial digestate is below maximum allowable concentration and soil is not burdened with these elements.
- A positive effect of digestate utilization was established in vegetation experiments on the yield and quality of crop production. The results of lettuce at increasing doses of biomass indicates that plants have the best development and quality options with 15% digestate with 70% pig manure.
- The results for total nitrogen, phosphorus, potassium, calcium, magnesium and microelements copper, zinc and manganese in plant production of lettuce are within the normal range for the species. The values of iron content are higher in lettuce grown on vertisols.
- It is found that increasing of digestate dose significantly increased plants absorbable phosphorus and potassium in both soil types. The quantity of mineral nitrogen (nitrate form) also increases. The amount of soluble salts in the soil increases slightly, but there is no danger of salinization. The content of heavy metals in initial digestate is under the limits and soils are not burdened with these pollutants.

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