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Investigating the Potential of Biomethane Production from Blends of Cattle Waste with Switchgrass (*Panicum virgatum* L.) and Sugar Beet (*Beta vulgaris* L.) Foliage

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ABSTRACT

The research aimed to evaluate the biomethane (CH_4) content of biogas generated from various combinations of cattle waste (CW), three different varieties of Switchgrass (SG) (Panicum virgatum L.*) plants (Kanlow (SG1), Shawne (SG2), Alamo (SG3), and sugar beet (Beta Vulgaris* L.*) leaves (BL). A laboratory-scale biomethane application setup was established to determine the biomethane potential. Three different experimental designs were implemented as the 1st application group, 2nd application group, and 3rd application group within the research framework. Biogas produced in the setup was stored using valves and balloons under optimal storage conditions. The Optima Biogas - Portable Biogas Analyzer device was employed to analyze the biomethane content of biogas samples from the materials and mixtures in the application groups. Biogas values were recorded, and glass reactor-specific methane production values were calculated. The highest glass reactor-specific methane production value was found to be 7.28 m^3CH_4 m^{-3} Reactor day in the CW (50%)-SG (20%)-BL (30%) mixture. The components of the biogas produced from the treatment groups were identified, and the highest CH_4 (biomethane) yield was obtained from BL (beet leaves) at 58.86% in materials and from the CW-BL mixture at 53.76% in mixtures. Biomethane yields of the materials in other mixtures ranged from 53.42% to 43.12%.*

Keywords: *Biomethane, Biogas, Switchgrass, Sugar Beet Leaf, Biomass*

INTRODUCTION

The energy demand is on the rise due to technological advancements both globally and locally. Consequently, there has been a shift towards various energy sources, especially recently. The inadequacy of exhaustible energy sources like oil, natural gas, and coal, along with their detrimental environmental impact, has prompted this change. However, there is a growing inclination towards renewable energy sources, which offer different and sustainable methods of energy production. Developed nations are actively diversifying their energy sources and exploring alternatives to reduce their reliance on specific energy types. Biofuels have emerged as a significant and rapidly expanding alternative energy source (Eser *et al*., 2007).

Despite the significant potential of agricultural and animal wastes, they are currently not being utilized effectively. Wastes are either incinerated or disposed of in nature, with only a small portion being used as fertilizer after being left in open areas for extended periods. Animal wastes are not being properly managed, leading to uncontrolled discharge into agricultural areas, pastures, open spaces, and waterways, resulting in soil pollution and detrimental effects on both human and environmental health, including strong odors and increased mosquito populations during summer (Avcıoğlu, 2011).

In our country, the regulation on the control of solid wastes, which came into effect in 1991, outlines various methods and criteria related to the subject with certain limitations. Among these methods is the decomposition of organic wastes by aerobic microorganisms. This process results in the production of methane gas, also known as biogas (Yaldız, 2004).

Türkiye is negatively affected by the fact that 92% of our oil needs are met through imports and our economy is dependent on imports. This is a problem for all countries that are at risk in terms of energy security.

In the context of sustainable energy development, there is growing interest in agriculture-based biofuels such as biodiesel, bioethanol, biomass, and biogas on a global scale. Among 37 plant species in the USA, switchgrass has been identified as a key candidate due to its potential as a feed source and its significant bioenergy capacity. Switchgrass is highly favored for its ability to produce high net energy per unit area, its cost-effective cultivation, low ash content, efficient water utilization, adaptability to diverse environments, ease of seed production, and its capacity for carbon storage in the soil (Samson and Omielan, 1992; Sanderson *et al*., 1996; Christian and Elbersen, 1998).

The key to successful Switchgrass cultivation lies in nurturing healthy plants. Therefore, it is crucial to focus on mechanization, soil preparation, and sowing techniques. Drawing on insights from past projects in our region, we aim to develop a system that optimizes the use of existing agricultural tools and machinery for the cultivation and establishment of this plant (Soylu *et al*., 2010).

In the research project titled "*Adaptation of Switchgrass* (*Panicum virgatum* L.)*, Creating Adaptation Maps, Determining Mechanization Characteristics, Energy Balance Sheet, and Biogas Production from Bioethanol Wastes*" with reference number 114O941 from TÜBİTAK. It was determined that the Kanlow variety of Switchgrass displayed the most favorable results for green biomass and dry grass in the Karapınar district of Konya province. However, in the Haymana district of

Ankara province, the Cave in Rock, Shawnee, and Shelter varieties showed promise for green biomass, while the Kanlow variety was found promising for dry herbage yield. Additionally, the Alamo variety was recommended for green biomass and hay yield at the Simav location. Although Switchgrass is a current plant that attracts attention for biofuel production all over the world, it is not sufficiently recognized in our country. If its cultivation is realized on a producer basis, it will provide significant gains in terms of energy production as it is an energy source in the coming years (Soylu *et al*., 2010).

Sugar beet is an important agricultural crop with economic potential attributable to its high yield capacity. From literature sources, sugar beet yields range from 40 to 90 t ha $^{-1}$ and beyond (Ungai and Győri, 2007).

In a study conducted by Pospišil *et al.* (2006), the production of 42 sugar beet hybrids was investigated. The results revealed a wide range of yields, varying from 61 t ha^{-1} to an exceptional high of 101.54 t ha^{-1}.

Annual weather conditions significantly influence the yield and technological quality of sugar beet, as demonstrated by Pospišil *et al.* (1999) when identical sugar beet varieties were utilized throughout the years of research.

In the context of sugar beet by-products, in addition to primary sugar production, sugar beet energy by-processing includes dry or wet sugar beet pulp, molasses, saturation sludge and approximately 60% of the green mass of sugar beet leaves. Previously used as cattle feed, the leaves and heads are now used as green manure on arable land. Given the global energy crisis, sugar beet is increasingly seen as a suitable energy crop for biofuel production (Szakál *et al*., 2007). Sugar beet production in Turkey reached 18.9 million tons in 2023. Consequently, 756 thousand tons of sugar beet-derived agricultural waste was generated. The energy equivalent value of this agricultural waste is quantified as 265,881.2 TOE year^{-1} (Anonymous, 2023). In this context, it is anticipated that the utilization of agricultural wastes from sugar beet as a substrate in biogas production will yield significant energy gains.

This research aimed to evaluate the biomethane potential of biogas produced from various combinations of cattle waste (CW), three different switchgrass (*Panicum virgatum* L.) varieties (SG1 (Kanlow), SG2 (Shawnee), SG3 (Alamo)) and sugar beet leaves (BL).

MATERIALS and METHODS

Material

Organic Materials Used in Biogas Production

The switchgrass varieties Kanlow, Shawnee, and Alamo were acquired from Konya Selçuk University, Faculty of Agriculture, Department of Field Crops. The switchgrass samples were finely ground and stored under optimal conditions. Similarly, sugar beet leaf samples used in biogas production studies were sourced from various regions in Konya province and stored under optimal conditions.

Establishment of Application Setup and Determination of Application Pattern to Determine Biogas Potential

In order to assess the biogas potential, the experimental setup illustrated in Figure 1 was utilized. The setup comprised a glass jar, a 10x7 polyurethane hose (Blue) with a length of 10 meters, 5 10 mm hose inlet ball valves, 5 pneumatic tees, and 20 1/4 - 10 pneumatic rotary elbows.

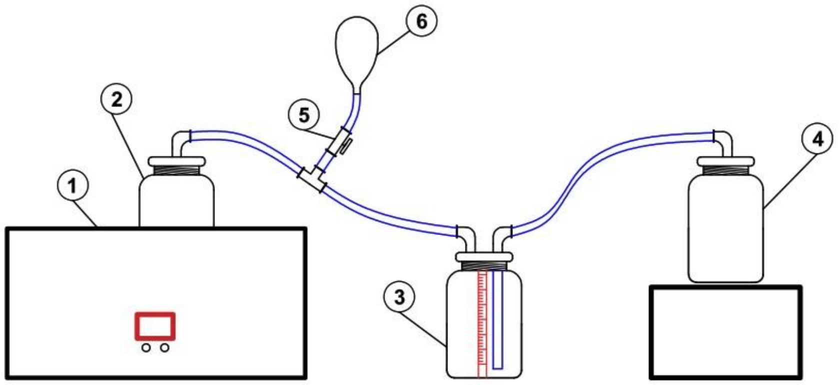

Figure 1. *Application setup (1. Water Bath Device, 2. Reactor (Glass Jar), 3. Acidified Water (Gas Outlet), 4. Water Inlet, 5. Gas Sampling Valve, 6. Gas Storage Balloon).*

In the context of this research, an application design was developed, consisting of three application groups: the 1st application group, the 2nd application group, and the 3rd application group. The implementation design can be found in Figure 2.

1stApplication					2nd Application				3rd Application		
CW	SG1 (Kanlow)	SG2 (Shawne)	SG3 (Alamo)	BL	CW-SG1	CW-SG2	CW-SG3	CW-BL	CW(%50)- SG(%25)-BL(%25)	CW(%50)- SG(%30)-BL(%20)	CW(%50)-SG(%20)-BL(%30)

Figure 2. *Application design.*

Instruments and Devices Used in Experiments

Water bath devices

JSR - JSIB-22T Series Circulating Water Bath device and BW-10H Heating Bath (11.5L) device were used to maintain the reactor operating temperature as mesophilic (37±1) in the biogas setup. The BW-10H Heating Bath (11.5L) represents an economically viable solution for maintaining optimal temperature control in laboratory settings. This digital water bath exhibits remarkable temperature stability, making it a dependable choice for scientific and research applications.

Precision balance

Weighing of the samples and mixtures prepared to be used in the determination of biogas potentials was carried out with the help of "Denver Instrument" brand precision measuring balance with a maximum capacity and sensitivity of 0.1 mg and 210 g, respectively.

pH measurement paper

The pH 0-14 pH indicator strip, universal indicator MColorpHast pH paper, was employed to ascertain the pH levels of the substances and combinations within the experimental groups during the treatment process.

OPTIMA Biogas - Portable Biogas Analyzer

The biomethane content of biogas samples collected from the materials and mixtures in the treatment groups was determined using the Optima Biogas - Portable Biogas Analyzer device.

Method

Performing Basic Characterization Analyses

We conducted basic characterization analyses (dry matter, organic matter) to determine the quantities of energy crops such as switchgrass, sugar beet leaves, and cattle wastes to add to the experimental setup. This setup was established to measure biogas yield and achieve the desired solids amount in the reactor (refer to Table 1).

Table 1. *Analysis of Basic Characterization (dry matter, organic matter).*

Sample Name	Organic Matter (%)	Sample (g)	Oven Dry (g)	Dry Matter (%)
SG-1 (Kanlow)	6.92	4.6506	4.3286	93.08
SG-2 (Aloma)	6.42	3.1603	2.9573	93.58
SG-3 (Shelter)	6.30	3.7667	3.5295	93.70
Sugar Beet Leaf	85.71	20.4167	2.9174	14.29
Cattle Waste	90.12	14.8338	1.4657	9.88

Determination of Mixture Ratios Used in Applications

It is essential to maintain specific reactor conditions to optimize the fermentation of bacteria in an anaerobic environment for the production of biogas and methane.

Achieving the ideal dry matter level in the feed materials is crucial for this process (Von Mitzlaff, 1988; Nagamani and Ramasamy, 1999). Research indicates that biogas production is most efficient when the total dry matter content of the feed materials falls within the range of 6-13% (Šarapatka, 1993).

The Department of Soil Science and Plant Nutrition at the Faculty of Agriculture, Selçuk University, conducted comprehensive analyses to determine the dry matter ratio and optimized different mixing ratios of three Switchgrass varieties and beet leaf samples with constant cattle waste samples.

Determination of Biomethane Potential (BMP)

Please take note of the following information: In our experiments, we used 1000 ml glass jar bottles as reactors to determine the biomethane potential. The experimental setup was positioned in a secluded area to shield it from sunlight. The reactors were operated under mesophilic conditions at 37±°C. To maintain a constant temperature, we utilized a JSR - JSIB-22T Series circulating water bath device and a BW-10H heating bath (11.5l) device. To measure the biogas produced in the reactors, we connected two glass jars using pneumatic sealing elements, and the water displacement principle was employed. The first glass jar, connected to the reactor, was filled with water acidified with sulfuric acid (H_2SO_4) to a pH of less than 2, and then sealed (Durgut, 2020).

The volumes were determined by drawing on the glass jars from the SolidWorks program on the PC, and the volumes corresponding to each mm length were determined and added to the glass jars for readings. In order to measure the gas content of the gas between the reactor and the glass jar filled with acidified water, a valve was added to the connection line between the two glass jars. At the end of the experiments, the gas collected by means of the valve was removed from the gas containment flask and the gas content was determined. In order to determine the amount of biogas released as a result of the experiments, measurements were made with the help of scales added on glass jars filled with water and recorded in computer environment.

At the end of the gas outputs, the gases collected in the balloons by means of the valve were preserved and the biogas contents were realized with the help of the measuring device.

Biogas Collection for Measurement of the Amount of Biogas Produced and Determination of Biogas Content

Daily readings were made with the help of the volume scale created to measure the amount of biogas produced in the anaerobic reactor by anaerobic fermentation of Switchgrass and beet leaves. The detected biogas values were recorded in computer environment. In the experimental setup, biogas storage was provided with the help of valves and balloons and biogas compositions (CH_4 (%), H_2S (ppm), CO_2 (%), O_2 (%), N_2 (%)) were determined.

Determination of Specific Biomethane Production Values of Materials

Biomethane production values were calculated for each sample as a result of the analysis to determine the amount of biogas and its components. During the calculation, the temperature at which the experiment was conducted, the temperature at which the biogas yield measurement was determined and the effect of the empty volume inside the glass reactor were taken into account. The following Equation 1 was used to determine the specific biomethane production values (Onursal, 2016).

$$\text{mL } CH_4 = [\frac{V_r * |M_2 - M_1|}{100} * \frac{273,15}{T_1 + 273,15}] * [\frac{V_g * |M_2 - M_1| * 0,5}{100} * \frac{273,15}{T_1 + 273,15}] \quad (1)$$

V_r: Void volume inside the biomethane reactor, (mL),
M_1: Biomethane value before measurement, (%),
M_2: Measurement day biomethane value, (%).

Where; 273,15: Kelvin, T1 is the temperature of the biomethane at which the measurement was made and 36°C was taken, T_2 is the temperature of the biogas amount at which the measurement was made and 25°C and Vg is the amount of biogas (mL) used in the formula.

Glass Reactor Specific Methane Production

The amount of methane production per glass reactor volume for one day is expressed as specific methane production. The glass reactor specific methane production amount was calculated through the Equation 2 below (Onursal, 2016).

$$R_{grm} = \frac{V_g}{V_r} \quad (2)$$

R_{grm}: Glass reactor specific methane production value (m^3CH_4 m^{-3} glass reactor day),
V_g: Amount of methane produced during one day (m^3CH_4),
V_r: Total volume of the glass reactor (m^3).

Statistical Evaluation of Biomethane Values

The biomethane values obtained as a result of the trials were analyzed with the analysis of variance test to determine whether there was a significant difference between the materials in the statistical package program. LSD results were used to show that there was a relevant comparison among the materials.

RESULTS AND DISCUSSION

Material and Mixtures Potential Production of Methane

The actual methane production amount of the materials in the experiments was 5916.35 mL CH_4 in the mixture of CW (50%) - SG (20%) - BL (30%). The overall amount of original methane yield of the materials obtained during the 1st, 2nd and 3rd treatments (mL) is presented in Table 2.

Table 2. *Original methane production values of materials (mL).*

Material	CH_4 (mL)
CW	2844.29
SG1	1594.29
SG2	618.25
SG3	667.63
BL	1744.2
CW-BL	327.52
CW-SG1	574.54
CW-SG2	96.59
CW-SG3	160.71
CW(%50)- SG(%25)-BL(%25)	442.03
CW(%50)- SG(%30)-BL(%20)	1887.25
CW(%50)- SG(%20)-BL(%30)	5916.35

Glass Reactor Original Methane Production Values

Reactor related methane produced by using a particular formula. After the calculation, it was determined that the highest reactor-specific methane production value was 7.28 m^3CH_4 m^{-3} reactor day for the CW (50%)-SG (20%)-BL (30%) mixture. You can refer to Table 3 for the specific methane production values of all materials and mixtures in the experimental groups.

Table 3. *Glass reactor specific methane production values (m^3CH_4 m^{-3}) glass reactor day).*

Material	$R_{ömü}$ (m^3CH_4 m^{-3} Glass Reactor day)
CW	3.50
SG1	1.97
SG2	0.76
SG3	0.82
BL	2.15
CW-BL	0.40
CW-SG1	0.71
CW-SG2	0.12
CW-SG3	0.2
CW(%50)- SG(%25)-BL(%25)	0.54
CW(%50)- SG(%30)-BL(%20)	2.32
CW(%50)- SG(%20)-BL(%30)	7.28

In their study, Jin *et al.* (2012) investigated the effect of semi-feeding and continuous anaerobic reactors on the yield of pearl Switchgrass and municipal wastewater biomasses at the laboratory level. They found that the unique methane production value was found in finely Switchgrass, 2%-loaded pearl Switchgrass from the October harvest (0.317 m^3 CH_4 kg^{-1} pearl Switchgrass and 0.359 317 m^3 CH_4 kg VKM^{-1}).

Components of Biogas Produced from Materials and Mixtures

The components of the biogas produced from the treatment groups were determined and the highest CH_4 (methane) yield was determined as 58.86% in BL (beet leaves) and 53.76% in BHA-BL mixture. Methane yields of other mixtures and materials in the treatments varied between 53.22% and 43.12% (Table 4).

Table 4. Components of biogas produced from materials.

Material	CH_4 (%)	H_2S (ppm)	CO_2 (%)	O_2 (%)	N_2(%)
CW	53.42	12	15.6	11.36	19.61
SG1	47.4	6	20.5	6.85	25.25
SG2	46.76	5	21.26	6.81	25.17
SG3	43.12	5	23.25	6.83	26.8
BL	58.86	9	16.85	7.36	24.92
CW-BL	49.78	9	16.48	7.26	26.18
CW-SG1	48.43	8	16.62	7.16	27.79
CW-SG2	44.86	7	16.06	6.98	32.1
CW-SG3	53.76	10	16.37	9.19	20.68
CW(%50)- SG(%25)-BL(%25)	51.74	9	16.85	7.49	23.92
CW(%50)- SG(%30)-BL(%20)	50.86	9	16.85	7.36	24.92
CW(%50)- SG(%20)-BL(%30)	53.22	10	16.68	8.27	21.84

In Treatment 1, the highest biomethane yield was determined in BL with 58.86%. Among the other materials, CW, SG1, SG2 and SG3 yielded 53.42%, 47.4%, 46.76% and 43.12%, respectively (Figure 3). In their study, Sheets *et al.* (2015) also looked at the effect of dry matter ratio on methane yield from switchgrass plants in mixtures with hot. In biomethane production, the highest biomethane yields of 13% and 22% were obtained under mesophilic conditions in the reactor operating as solid fermentation.

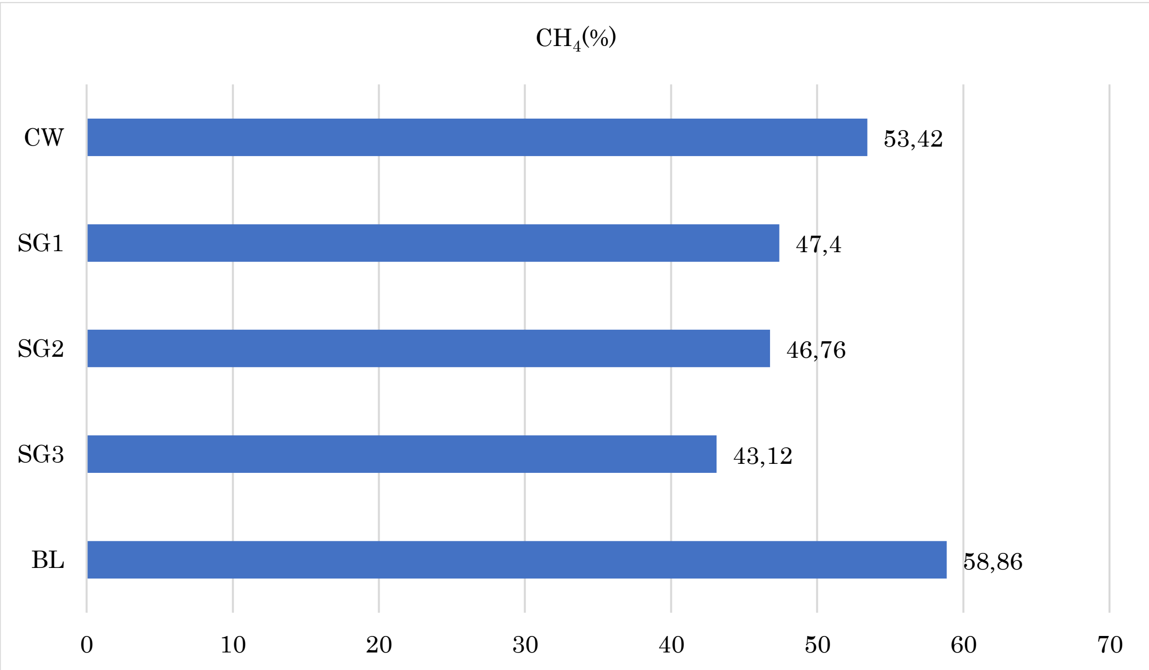

Figure 3. *1st Application biomethane yield values (%).*

In the 2nd treatment, the highest biomethane yield was determined in CW-BL with 53.76%. Among the other materials, CW-SG1, CW-SG2 and CW-SG3 yielded 49.78%, 48.43% and 44.86%, respectively (Figure 4).

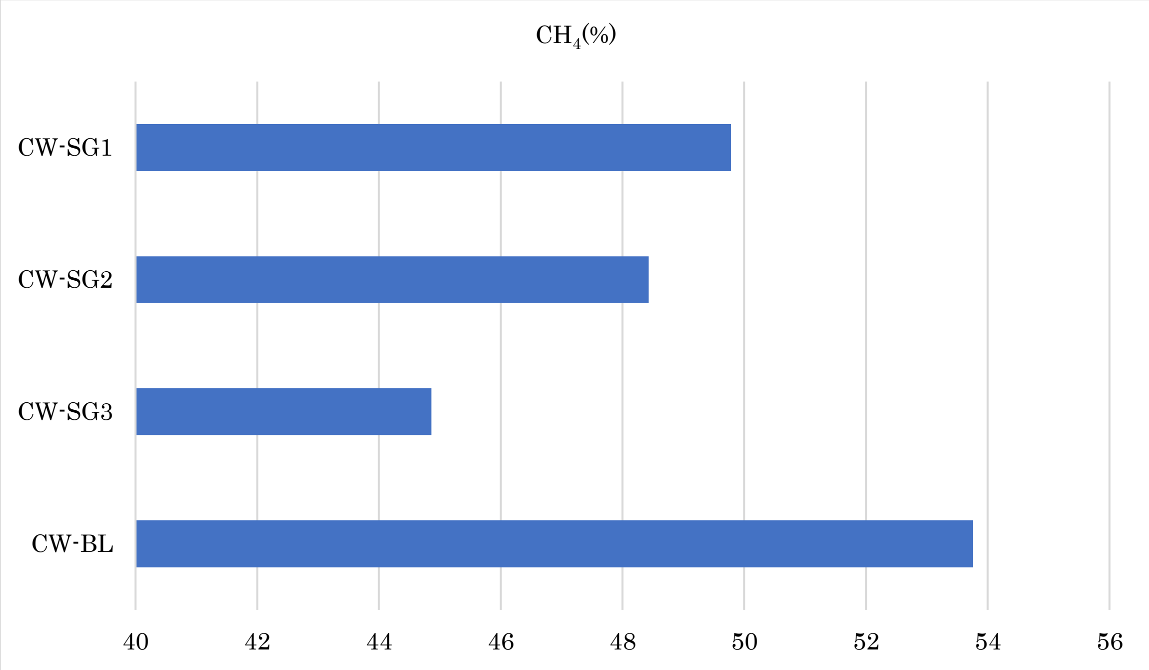

Figure 4. *2nd Application biomethane yield values (%).*

In the 3rd treatment, the highest biomethane yield was found in the mixture of CW (50%)-SG (20%)-BL (30%) with 53.22%. Among the other materials, it was determined as 51.74% in CW (50%)-SG (25%)-BL (25%) mixture and 50.86% in CW (50%)-SG (30%)-BL (20%) mixture, respectively (Figure 5). Ciggin (2016), in his study, mixed switchgrass with process sludge. According to the results of the experiment, the highest methane yield was found in the mixture of 0.4-0.6 ratio. In their study, Liew *et al.* (2012) investigated methane production from corn cobs, wheat straw, garden waste and leaves by anaerobic fermentation. The highest methane yield of 81.2 L $kgVKM^{-1}$ was observed in corn cobs, followed by wheat straw (66.9 L $kgVKM^{-1}$), leaves (55.4 L $kgVKM^{-1}$), and garden waste (40.8 L $kgVKM^{-1}$).

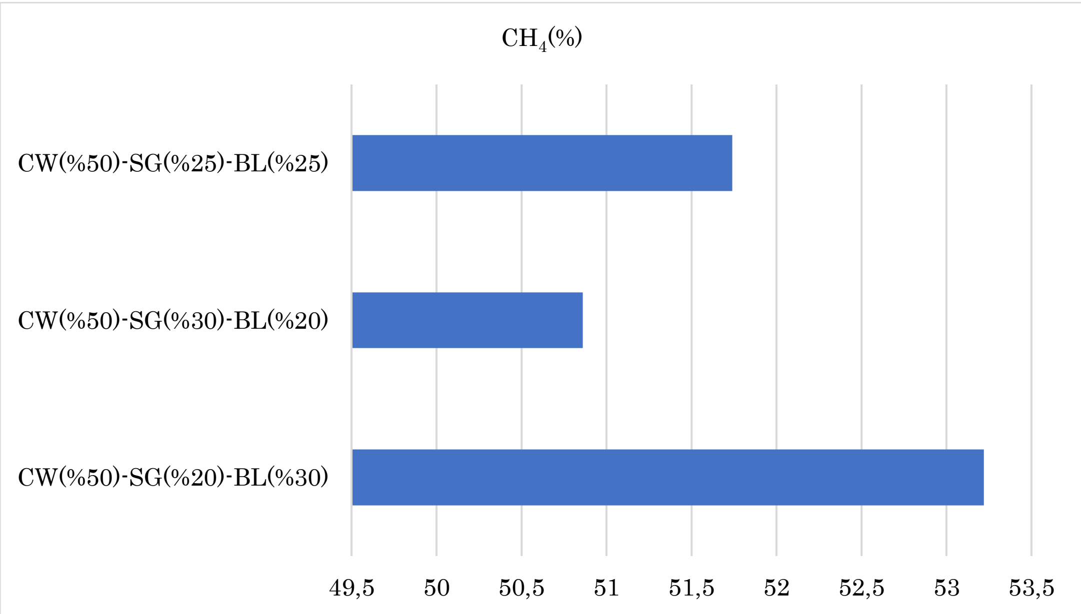

Figure 5. *3rd Application group biomethane yield values (%).*

Evaluation of Statistical Analysis

Variance analysis was performed for the treatments and biomethane ratios were found to be significant at $p<0.05$ level in variance analysis (Table 5). LSD test was performed on these significant values (Table 6).

Table 5. *Analysis of variance results.*

Application	Average Biogas Yield (ml/gDM)	Standard Deviation	Standard Deviation Square (Variance)	Minimum	Maximum
CW-SG1	49.16	0.82	0.67	48.2	49.78
CW-BL	52.49	1.28	1.63	51.2	53.76
CW-(50%) - SG (25%) - BL (25%)	50.48	1.37	1.88	49	51.74
CW- (50%) - SG (30%) - BL(20%)	48.92	1.78	3.17	47.3	50.86
CW- (50%) - SG 2(0%) - BL(30%)	52.00	1.28	1.63	50.7	53.22

Table 6. *LSD test results.*

Material	N	Standard Error Mean	Mean [(1)]
CW-SG1	4	0.48676	52.48$_{A}$
CW-BL	4	0.73904	52,006$_{A}$
CW-(50%) - SG (25%) - BL (25%)	3	0.79858	50.48$_{AB}$
CW- (50%) - SG (30%) - BL(20%)	3	1.04006	49.16$_{B}$
CW- (50%) - SG 2(0%)- BL(30%)	3	0.72896	48.92$_{B}$

[(1)] The difference between the means shown with different lowercase letters in the same column is statistically significant (A, B: $p<0.05$, LSD= 2.454).

When the table obtained according to the LSD results is examined, the highest yield was obtained in the BHA-SG1 mixture and the lowest biomethane yield was obtained in the CW (50%) - SG (20%) - BL (30%) mixtures.

CONCLUSION

The fact that our country is foreign-dependent in terms of energy supply makes renewable energy sources an important issue. In our research on the Switchgrass plant as part of the TÜBITAK project, we examined mechanization criteria for the first time. We discovered that by combining the sugar beet plant, abundant in Konya and its surrounding areas, with cattle waste, we could determine the biogas yield. During the study, we calculated the reactor based methane productivity using a specific formula. The highest reactor based methane production value obtained was 7.28 m^3CH_4 m^{-3} Reactor day for the CW (50%)- SG (20%)-BL (30%) mix.

The components of the biogas produced from the trial groups were determined and the highest CH_4 (methane) yield was determined as 58.86% in BL (beet leaves) in materials and 53.76% in CW-BL mixture in mixtures. Methane yields of other mixtures and materials of the experimental groups varied between 53.22% and 43.12%.

Agricultural and livestock mechanization plays a significant role in our economy today. However, the majority of the energy requirements for agricultural operations are currently met using non-renewable energy sources. The utilization of biogas, which is environmentally friendly and helps reduce production inputs, is becoming increasingly important for meeting energy needs in agricultural operations. Biogas can be produced from animal manure, various energy crops, and agricultural waste, offering the potential to enhance operational efficiency and decrease carbon dioxide (CO_2) emissions, thus mitigating environmental impact. As a result of the applications, high biomethane rates were obtained in BL mixtures. Beet leaves can be considered as an important waste in terms of agricultural waste in our country within the framework of production area and product obtained. Beet leaves generated from sugar beet agriculture, especially in Konya province and its surroundings, are used in some animal feed, but 100% disposal cannot be ensured. The huge biomass formed by beet leaves can be converted into biogas energy as a result of anaerobic fermentation and recovery can be achieved.

DECLARATION OF COMPETING INTEREST

We declare that we have no conflict of interest.

ACKNOWLEDGEMENT

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CREDIT AUTHORSHIP CONTRIBUTION STATEMENT

The authors declared that the following contributions are correct.

Cevat FİLİKCİ: Investigation, methodology, conceptualization, validation, writing - original draft, visualization,
Tamer MARAKOĞLU: Formal analysis, data curation, validation, review, and editing.

ETHICS COMMITTEE DECISION

This article does not require any Ethical Committee Decision.

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