

# Biogas production from codigestión of corn silage and sheep and goat manure

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**INTRODUCTION.** Mexico ranks tenth in global primary livestock production, with a contribution from small ruminants that generates approximately 10,560,000 tons of manure per year, which, in practice, is dumped on the field. Despite this, environmental regulations establish that manure must be properly managed and treated to mitigate health and environmental risks. Anaerobic digestion is used in various parts of the world to produce methane from manure, but its low carbon content and excess nitrogen cause ammonia accumulation in the reactors, limiting the efficiency of the process (Lian et al., 2022). Anaerobic co-digestion reduces these problems due to a balance in pH, nutrients, moisture content, C:N ratio, and increased biodegradability of the substrate, which can improve methane production and reaction rate (Almomani et al., 2020; Singh et al., 2023).

Corn silage (*Zea mays L.*), a widely spread form of conservation, is an essential feed for livestock and undergoes a biochemical process that minimizes nutrient and energy loss through lactic fermentation (Teixeira et al., 2016). However, it faces the challenge of wastage due to fungal growth from poor silage management, making it a high-carbon, low-nitrogen biomass suitable for co-digestion with manure. Corn silage has been widely used for energy production in Europe and North America (Veluchamy et al., 2019). In this work, anaerobic co-digestion of corn silage and sheep and goat manure was carried out in different combinations to determine the one that favors the highest biogas production with high methane generation rate.

**METHODOLOGY.** The characteristics of corn silage and the combination of sheep and goat manure were determined. Six different mixtures were made: The first consisted of pure manure (100% manure:0% silage); the other combinations were the manure-to-silage ratios (80:20, 60:40, 40:60, 20:80), and the pure silage (0:100). From each of these combinations, methane production tests were carried out, adjusting the initial amounts to 1, 2, 3, 4, and 5 g<sub>TS</sub>, corresponding to concentrations of 2.5, 5, 7.5, 10, and 12.5 g<sub>TS</sub>/L. The test substrates were placed in 400 mL flasks together with anaerobic sludge (8 g<sub>VS</sub>/L in every flask) from the wastewater treatment plant of a large brewery in Mexico City, phosphate buffer for a pH of 7.0, and micronutrients. Methanization was performed at 35°C, and the biogas production was recorded using an AMPTS II (Bioprocess Control, Sweden). The biogas composition was determined by gas chromatography. The specific methane production was calculated according to the methodology of Jojoa-Unigarro and González-Martínez (2023). The methanization kinetics was performed using the initial methane production rates and the Michaelis and Menten model.

**RESULTS.** According to Table 1, manure had a pH of 7.9, and silage had a pH of 3.9, which indicates the importance of combining them to reduce the adverse pH effects. Volatile solids (VS) were high for both substrates, 81% for manure and 91% for silage, reflecting their potential to produce biogas. COD from manure was 812 g/kg<sub>VS</sub> and 318 g/kg<sub>VS</sub> for silage; the last is low due to its previous fermentation. Manure had the lowest C/N ratio of 20, which is attributed to its high nitrogen content, compared to corn silage, which had a higher C/N ratio of 43. This ratio increased with the percentage of silage.

Table 1. Characteristics of maize silage and manure, specific methane production (SMP), and Michaelis-Menten kinetic parameters.

| Manure:Silage ratio | pH  | VS/TS | COD g/kg <sub>VS</sub> | TOC g/kg <sub>VS</sub> | TN g/kg <sub>VS</sub> | C/N | SMP NL <sub>CH<sub>4</sub></sub> /g <sub>VS</sub> | Vmax NmL/L·d | Km g/L |
|---------------------|-----|-------|------------------------|------------------------|-----------------------|-----|---------------------------------------------------|--------------|--------|
| 100:0               | 7.9 | 0.81  | 812                    | 342                    | 1.7                   | 20  | 95                                                | 42           | 5      |
| 80:20               | 7.2 | 0.83  | 732                    | 357                    | 1.4                   | 25  | 112                                               | 500          | 7      |
| 60:40               | 6.2 | 0.84  | 617                    | 365                    | 1.3                   | 29  | 157                                               | 1250         | 24     |
| 40:60               | 5.6 | 0.86  | 545                    | 368                    | 1.1                   | 32  | 175                                               | 833          | 10     |
| 20:80               | 4.7 | 0.88  | 446                    | 376                    | 1                     | 37  | 204                                               | 556          | 6      |
| 0:100               | 3.9 | 0.91  | 318                    | 383                    | 0.9                   | 43  | 244                                               | 1111         | 9      |

VS/TS, volatile to total solids ratio; TOC, total organic carbon, TN, total nitrogen (Kjeldahl); SMP, specific methane production; Vmax, maximal reaction rate; Km, Michaelis-Menten constant.

**Methane production.** Figure 1 shows the accumulated methane production curves for different sheep and goat manure concentrations. The points indicate where the exogenous methane production ends, and endogenous production continues as in the blank. The value for the end exogenous production is plotted against the substrate concentration to determine the specific methane production (SMP) (Table 1). The right side of Figure 1 shows the SMP plotted against the different manure-to-silage ratios (see Table 1). Methane production from manure (100:0) ended from day 8 to day 11 for the five concentrations; the SMP for this case is 95 NL/kg<sub>VS</sub> with a correlation

coefficient of 0.997, similar to that obtained by Achinas et al. (2018) of 89 NLCH<sub>4</sub>/kg<sub>VS</sub>. The SMP increased with increasing corn silage and decreasing manure, showing a linear behavior (Figure 1). The highest SMP belongs to only corn silage with 244 NL/kg<sub>VS</sub>, close to the 289 NL/kg<sub>VS</sub> reported by Amon et al. (2007), because corn silage is rich in organic matter. From the combinations, 20:80 had the highest SMP with 204 NLCH<sub>4</sub>/g<sub>VS</sub>.

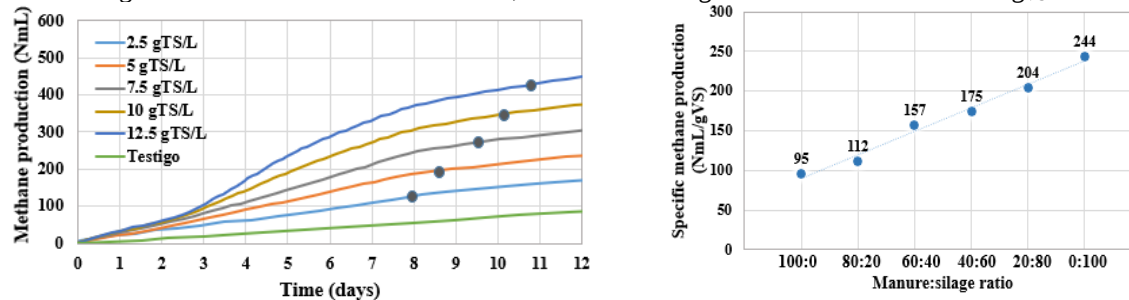


Figure 1. Left are the accumulated methane production curves from combined sheep and goat manure. Right is the specific methane production of the six tested manure and maize silage combinations.

Figure 2 shows the increase in V<sub>max</sub> with the addition of corn silage. The manure presented V<sub>max</sub> of 42, reflecting its low generation rate. In contrast, the corn silage showed a high V<sub>max</sub> of 1111 NmL/L·d due to its high carbon content. However, the 60:40 combination, with a C/N ratio of 29, reached a V<sub>max</sub> of 1250 NmL/L·d, indicating that higher C/N ratios increase methane generation rate. The 80:20 and 20:80 combinations produce similar methane rates, and no impact of one substrate on the other makes methane production faster in these combinations.

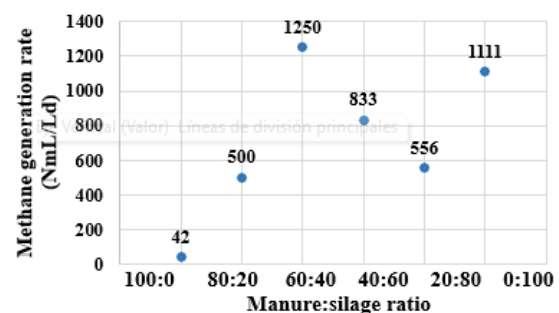


Figure 2. V<sub>max</sub> from the Michaelis-Menten model

**CONCLUSIONS.** Due to its readily available carbon concentration, specific methane production increases linearly with increasing corn silage. Co-digestion of manure (sheep and goat) with corn silage increases methane production by combining the characteristics of both substrates. The 20:80 combination has the highest specific methane production, with 204 NL/kg<sub>VS</sub>. The 40:60 combination reports the highest methane generation rate with 1,250 NmLCH<sub>4</sub>/L·d, a specific methane production of 157 NmLCH<sub>4</sub>/g<sub>SV</sub> at a C/N ratio 29.

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