PHOSPHOGYPSUM VALORISATION IN ANAEROBIC DIGESTION ENHANCES DIGESTATE NUTRIENT QUALITY AND SEEDLING VIGOR

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Introduction

Phosphogypsum (PG), a calcium sulfate dihydrate byproduct of wet-process phosphoric acid production, is generated in excess of 200 million tonnes annually worldwide, with cumulative stockpiles exceeding 7 billion tonnes. Due to residual acidity and trace contaminants, large-scale PG accumulation poses long-term environmental management challenges. A potential valorization pathway for PG is in the enrichment of digestate; a biofertilizer resulting from the anaerobic digestion of organic waste

Recent studies indicate that PG addition can enrich digestates with calcium and sulfur, although excessive sulfate loading may stimulate sulfate-reducing bacteria and increase hydrogen sulfide formation, potentially competing with methanogenesis

AIM: to **evaluates the addition of low-dose PG during anaerobic digestion of sugarcane bagasse to improve biogas quality and digestate nutrient composition, while identifying a biologically tolerable dosage range and associated sulfate-driven limitations**

Results

Table 1. Digestate elemental composition (mg/kg dry weight) from ICP-OES

Nutrient	IN (control)	SB	SBPGa	SBPGb
K	81,786 ± 20,395	59,432 ± 1,772	49,933 ± 2,825	53,017 ± 599
P	10,436 ± 3,790	12,692 ± 341	13,274 ± 538	12,863 ± 351
Ca	19,586 ± 1,065	20,038 ± 267	24,706 ± 826	27,803 ± 195
Mg	9,406 ± 2,082	10,707 ± 300	11,679 ± 475	11,484 ± 122
S	9,189 ± 202	7,962 ± 193	9,020 ± 176	9,721 ± 130
Fe	5,409 ± 740	5,713 ± 40	5,940 ± 246	5,807 ± 9
Zn	702 ± 78	647 ± 21	594 ± 13	605 ± 22
Cu	110 ± 7	89 ± 3	79 ± 2	81 ± 2
Pb	2.50 ± 1.97	3.51 ± 0.04	3.24 ± 0.12	3.38 ± 0.06
Sr	71.6 ± 2.3	69.9 ± 1.1	86.2 ± 1.7	99.8 ± 1.0

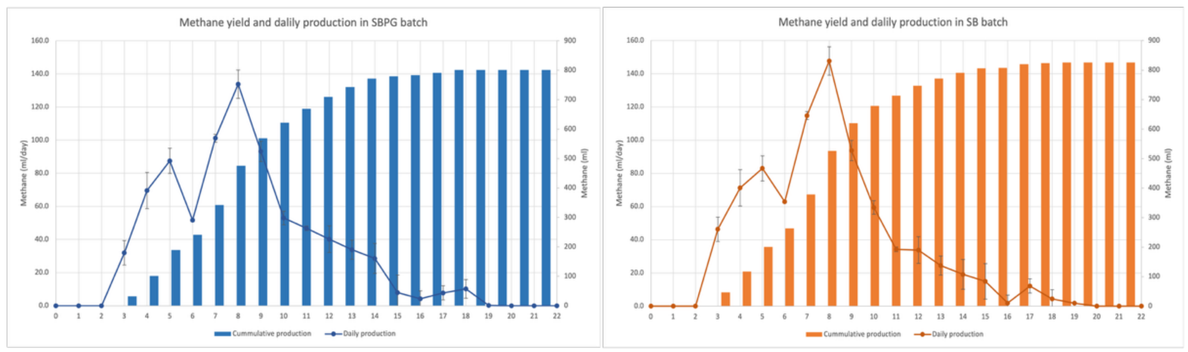


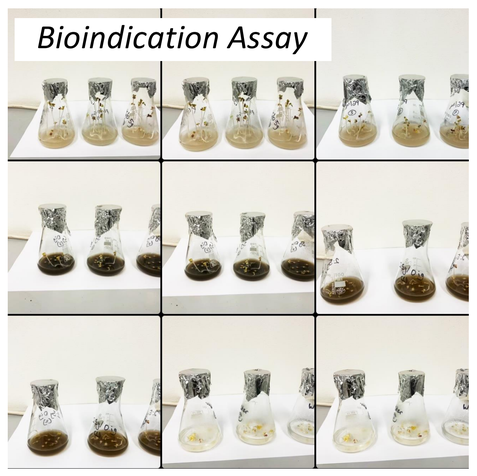
Fig. 1. Cumulative and daily CH_4 yield of the biogas AD trials

Key findings:

- SBPGa (0.25g PG) produced max SVI significantly outperforming the standard Murashige–Skoog nutrient control ($p < 0.05$).
- Higher PG dosages (≥ 3g) severely inhibited germination and growth due to osmotic stress and elevated salinity.
- SBPGa increased methane content from ~33% to ~40%, improving the calorific value of the biogas.
- H_2S rose in a dose-dependent manner: ~3000 ppm in SBPGa, ~4400 ppm in SBPGb, due to sulfate-reducing bacteria activity.
- ICP-OES confirmed substantial Ca (+23%) and S (+13%) enrichment in PG-amended digestates without heavy metal accumulation.

Methods

PG Preparation: PG from Sumy region (Ukraine), air-dried and homogenized



Bioindication Assay: Lepidium sativum L. (garden cress) was performed on 1.5% (w/v) water-agar medium. Molten agar (25 mL per 90 mm Petri dish) was amended with PG at final concentrations ranging from 0.1 t 5 g/L. Seedling vigor index (SVI) was calculated from germination percentage and shoot elongation.

Batch AD Trials: Conducted in 1 L reactors under mesophilic conditions (38 ± 1 °C) for a 22-day retention period. Sugarcane bagasse (SB) was the primary biomass with a substrate-to-inoculum ratio of 0.5:1 (VS basis).

Treatments: SB (0 g PG, control), SBPGa (0.25 g PG), SBPGb (0.5 g PG) and inoculum (IN) as blank. All treatments were setup in triplicates.

Biogas Analysis: Biogas composition (CH_4, CO_2, H_2S, O_2, CO) was measured with a Biogas 5000 portable analyzer (Geotech/QED Environmental Systems, USA).

Digestate Analysis: Elemental composition (Ca, S, P, K and trace metals) determined by ICP-OES following microwave-assisted acid digestion.

Statistics: One-way ANOVA and Tukey's HSD ($p < 0.05$).

- Germination Percentage = $\left(\frac{Number\ of\ Germinated\ Seeds}{Total\ Number\ of\ Seeds\ Tested} \times 100\right)$
- SVI = Germination Percentage × Average Shoot Length (cm)

PG	Mean Height (cm)	Mean GP (%)	SVI	Weight (g)
0.1	4.73	96.67	457.56	1.3
0.25	5.07	93.33	472.89	1.40
0.5	3.13	90.00	282.00	1.01

PG	Mean Height (cm)	Mean GP (%)	SVI	Weight (g)
1	4.60	90.00	414.00	1.27
3	3.03	96.67	293.22	0.97
5	2.27	86.67	196.44	0.81
MS	4.10	100.00	410.00	1.06

Effect of Different PG ranges on Plant Growth Parameters

Conclusion

Low-dose PG addition can be effectively integrated into mesophilic batch AD of sugarcane bagasse to improve methane quality and enrich the nutrient profile of the digestate with secondary macronutrients (Ca and S). The increase in H_2S in the biogas requires desulfurization measures in large-scale applications. Future research should focus on the long-term agronomic performance of this organomineral digestate and the assessment of radiological safety markers based on specific jurisdictional requirements.

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