生物能源环境科学与技术研究室
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Ensiling excessively wilted maize stover with biogas slurry: Effects on storage performance and subsequent biogas potential

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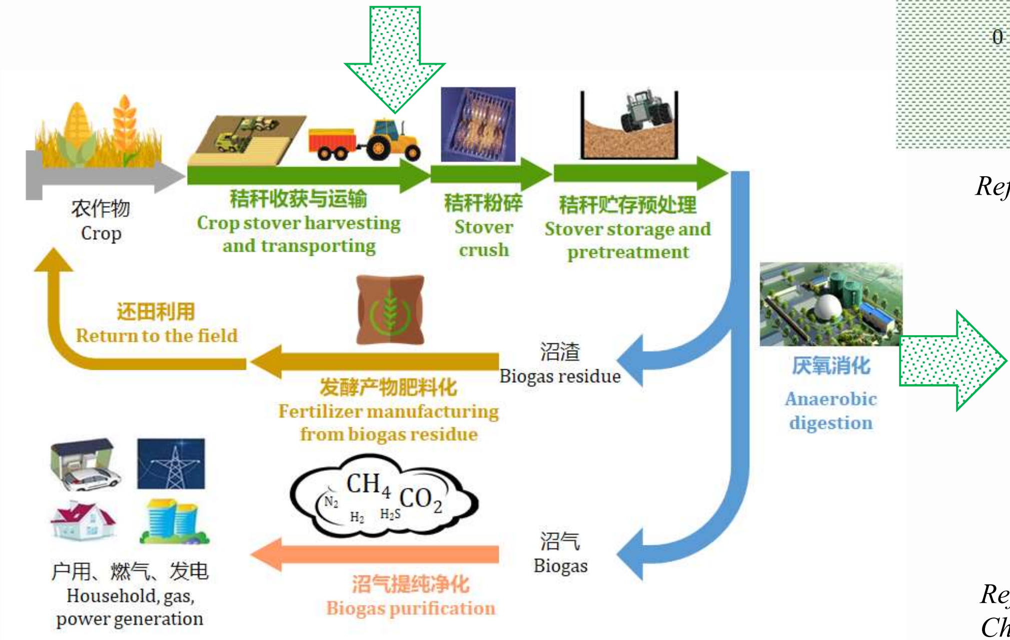
Outline

I. Introduction

Huge crop residue yield: ~970 million t/a

Potential biomethane yield: ~82 billion m³/a



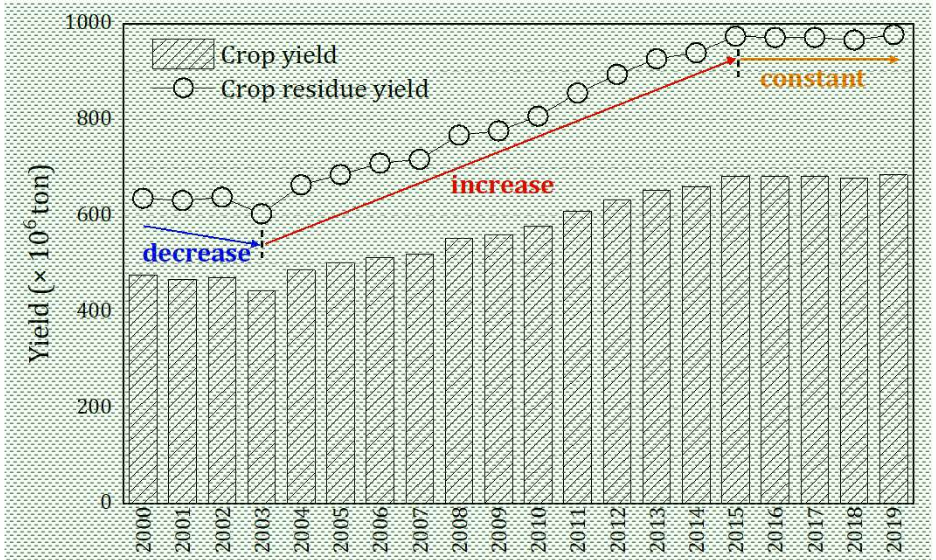


Fig. Crop and crop residue yield in China

Ref.: Unpublished

- Renewable energy
- Organic fertilizer
- GHG emission reduction
- Rural area development

Ref.: National Bureau of Statistics of People's Republic of China, 2020. China Statistical Yearbook. China Statistics Press, Beijing.

I. Introduction

Crop residues → anaerobic digestion → Biomethane → Clean energy

→ Biogas slurry → Fertilize

Seasonal production

Produced in harvested period.

Stable operation

Biogas plant annual work.

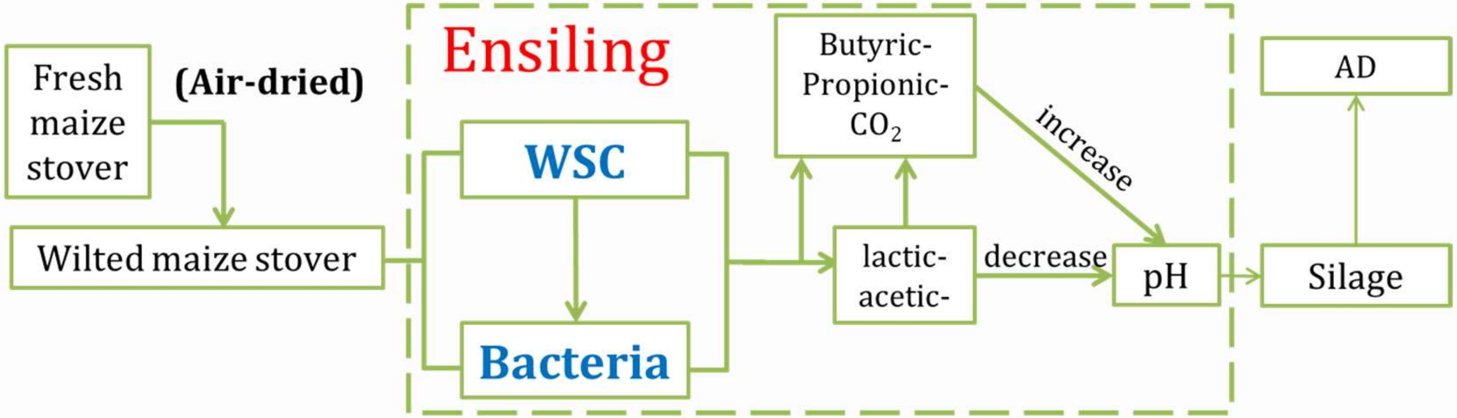
Storage

Ensiling

- Low storage loss
- Long-term stable storage
- No risk of fire
- Independent of weather
- Digestibility enhancement

The principle of ensiling:

Key words: Anaerobic fermentation; Organic acid; Biological acidification; Stable storage.



Usual ensiling condition:

- Adequate WSC: ~5% of dry matter
- Humidity : 50%~80%
- Partial size, temperature ......

Ref.: McDonald, P., Henderson, A.R., Heron, S.J.E., 1991. The Biochemistry of Silage, second ed. Chalcombe Publications, Marlow, England.

Dry yellow maize stover

- low residual WSC content: 1%~3% of dry matter
- Low humidity： ~10%

Initial composition adjusting

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Effect of glucose and cellulase addition on wet-storage of excessively wilted maize stover and biogas production

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Synergetic effect of combined ensiling of freshly harvested and excessively wilted maize stover for efficient biogas production

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I. Introduction

Feedstock with low humidity

Digestates liquid

Potential positive benefits:

- Reduce the water demand for humidity adjusting;
- Reduce the discharge of digestates liquid;
- Adjust the C/N ratio;

Possible negative effects:

- Improved buffer capacity prevent biological acidification;
- Microbial community changed by microbes on digestates;
- Resulting high storage loss

II. Material and Methods

2.1 Raw material

Excessively wilted maize stover

From a test farm in CAU

Chicken manure biogas slurry (C)
Pig manure biogas slurry (P)

From two stable operation plants

Centrifuging

$3040 \times g$
10 min

Chicken...supernatant (CS)
Pig...supernatant (PS)

From two stable operation plants

Table 1
Characteristics of raw materials used in present study (mean ± standard deviation).

Raw materials		TS (g/kg)	VS (g/kg)	TAN (g/L)	WSC (g/kg DM)	C/N ratio
EWMS	Excessively wilted maize stover	912.9 ± 1.6	729.4 ± 1.3	/	10.3 ± 0.02	49.6:1
C	Chicken manure biogas slurry	19.4 ± 0.1	9.3 ± 0.1	7.27 ± 0.03	/	/
CS	Chicken manure biogas slurry supernatant	17.0 ± 0.1	8.0 ± 0.1	6.98 ± 0.03	/	/
P	Pig manure biogas slurry	9.0 ± 0.1	5.4 ± 0.2	1.51 ± 0.01	/	/
PS	Pig manure biogas slurry supernatant	5.3 ± 0.1	2.8 ± 0.1	1.48 ± 0.01	/	/

(1) TS, total solid; VS, volatile solid; TAN, total ammonia nitrogen; DM, dry matter; ODM, organic dry matter; WSC, water soluble carbohydrate.

II. Material and Methods

2.2 Preparation, ensiling, analysis

Collecting and transport

Cutting
1~2 cm pieces

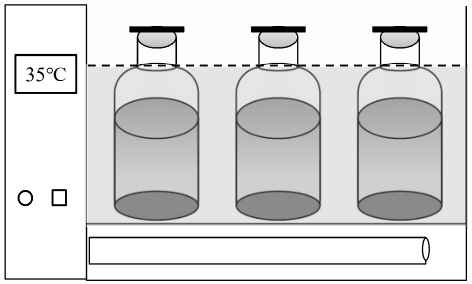
Mixing
Humidity to 60%

Filling
Polyethylene bags
(250 mm × 300mm)

Five treatments: **W** (water) as control,
C (chicken manure biogas slurry), **CS** (chicken manure biogas slurry supernatant),
P (pig manure biogas slurry), **PS** (pig manure biogas slurry supernatant),

Storing
25°C ± 1°C
60 days

Analyzing
pH values, organic acid, lignocellulose, storage loss, microbial community



Batch BMP test
Mesophilic (37°C ± 1°C)
up to 50 days

III. Results and Discussion

3.1 pH values and storage loss

Table 2
Ensiling performance of 60 d ensiled maize stover affected by ensiling with biogas slurry and additives (mean ± standard deviation).

Treatment	pH	Storage ODM loss (%)	Total organic acid (g/kg DM)
W	5.62 ± 0.03[c]	4.9 ± 0.4[d]	55.4 ± 2.5[c]
C	6.23 ± 0.02[b]	6.7 ± 0.4[b]	78.1 ± 2.9[a]
CS	6.32 ± 0.02[a]	7.3 ± 0.2[a]	53.8 ± 0.3[c]
P	5.54 ± 0.03[d]	5.9 ± 0.1[c]	63.7 ± 1.4[b]
PS	5.50 ± 0.03[d]	5.0 ± 0.2[d]	56.4 ± 3.8[c]

(1) Maize stover were ensiled for 60 d with distilled water (W), chicken manure biogas slurry (C), chicken manure biogas slurry supernatant (CS), pig manure biogas slurry (P), pig manure biogas slurry supernatant (PS).
(2) DM, dry matter; ODM, organic dry matter.
(3) Total organic acid is the sum of lactic, acetic, propionic, and butyric acids in silage.
(4) a, b, c, and d indicate a significant difference ($p < 0.05$) between treatments.

- pH values: 5.50~6.32；
- Storage ODM loss: 4.9%~7.3%;
- Higher in chicken's treatments;

- Higher buffer capacity in C and CS
- Higher ammonia nitrogen content from chick manure biogas slurry

TAN of C and CS: ~7.0 g/L

TAN of P and PS: ~1.5 g/L

3.2 Lignocellulose content and degradation rate

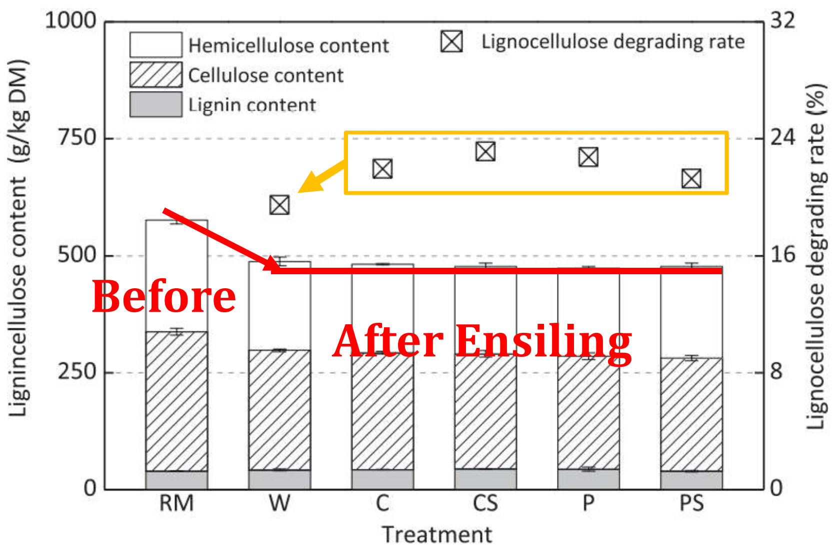


Fig. 1. Lignocellulose content and degradation rate of 60 d ensiled maize stover affected by biogas slurry. RM: raw material prior to ensiling; maize stover were ensiled for 60 d with distilled water (W), chicken manure biogas slurry (C), chicken manure biogas slurry supernatant (CS), pig manure biogas slurry (P), or pig manure biogas slurry supernatant (PS); DM: dry matter.

- Initial lignocellulose content: ~58% of DM,
  Stored lignocellulose content: ~48% of DM;
- Degradation rate in control (W): ~19.5%,
  Degradation rate in C, CS, P, PS: ~22%.

- Beneficial for subsequent bioconversion;
- Higher buffering capacity conditions (pH values) and adjusted C/N ratio could favor the microbes for lignocellulose degradation.

3.3 Production of organic acids

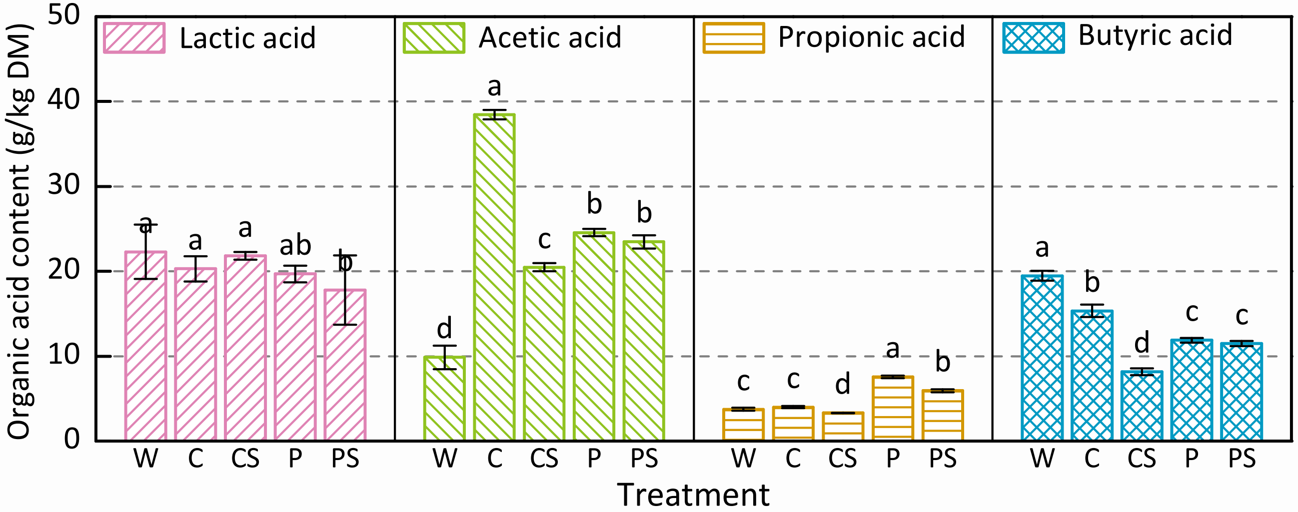


Fig. 2. Content of organic acids in 60 d ensiled maize stover affected by biogas slurry. Maize stover were ensiled for 60 d with distilled water (W), chicken manure biogas slurry (C), chicken manure biogas slurry supernatant (CS), pig manure biogas slurry (P), or pig manure biogas slurry supernatant (PS); DM: dry matter; a, b, c, and d indicate a significant difference ($p < 0.05$) between treatments.

- Increased total organic acid content: +41% in C and +15% in P compared to W;
- Increased acetic acid: > 2-fold times than W;
- Decreased butyric acid: 0.8%~1.5% of DM (in C, CS, P, PS) *v.s.* 2.0% of DM in W.

- Heterofermentative lactic-acid fermentation

3.4 Microorganisms community

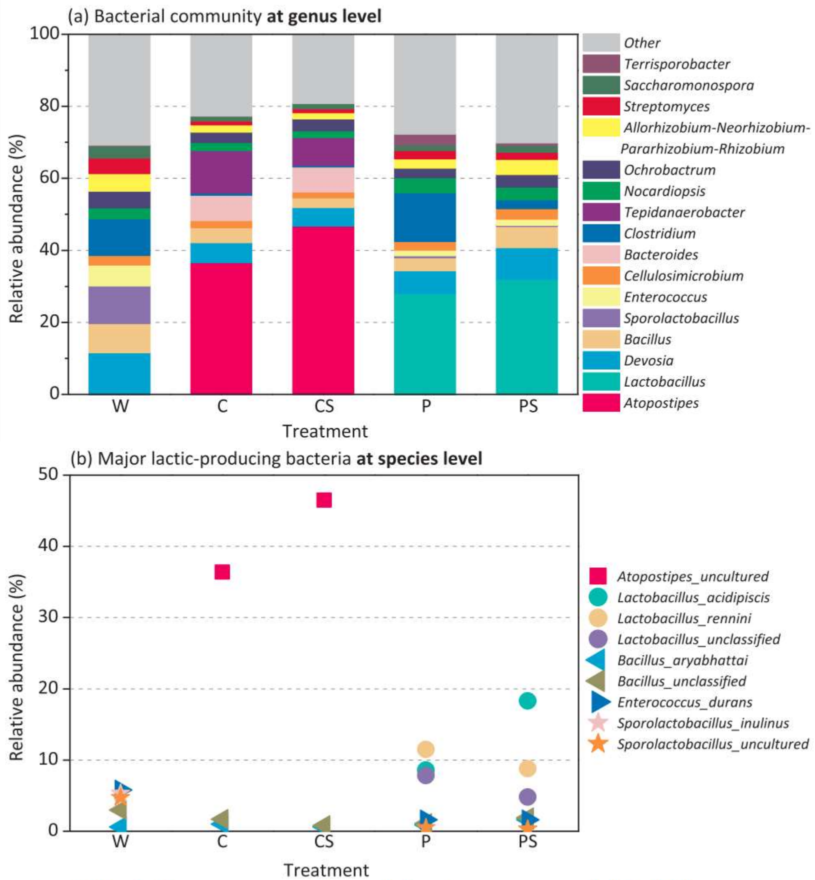
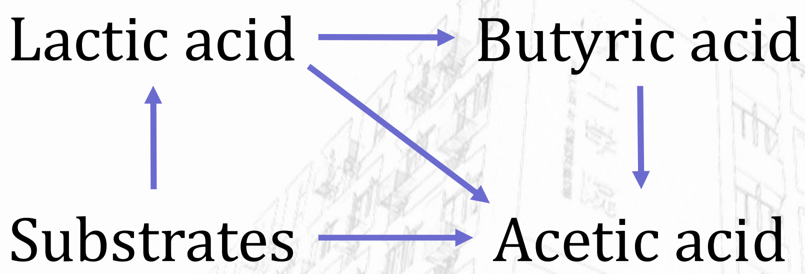


Fig. 3. Bacterial community in the ensiled maize stover revealed by high-throughput sequencing: (a) at genus level, (b) major lactic-producing bacteria at species level. Maize stover were ensiled for 60 d with distilled water (W), chicken manure biogas slurry (C), chicken manure biogas slurry supernatant (CS), pig manure biogas slurry (P), or pig manure biogas slurry supernatant (PS).

- *Atopostipes* dominated in chicken's treatments;
- *Lactobacillus* dominated pig's treatments;

- Derived from biogas slurry;
- Hetero-lactic-acid fermentation bacteria.



III. Results and Discussion

3.5 Specific methane yield

Table 3
Biomethane production of maize stover (0 and 60 d).

Treatment	Storage period (d)	Specific methane yield (m^3/t ODM)			Methane content (%)
		$Yield_{measured}$	Increment	$Yield_{orig}$	
Raw material	0	280 ± 4[c]	/	280 ± 4[b]	53.5 ± 1.0[d]
W	60	298 ± 3[b]	6.4%	284 ± 3[ab]	55.0 ± 0.4[c]
C	60	300 ± 5[ab]	7.1%	280 ± 5[b]	58.7 ± 0.3[a]
CS	60	307 ± 4[a]	9.6%	285 ± 4[ab]	58.7 ± 0.4[a]
P	60	301 ± 5[ab]	7.5%	283 ± 5[ab]	56.7 ± 0.6[b]
PS	60	303 ± 3[ab]	8.2%	288 ± 3[a]	55.2 ± 0.1[c]

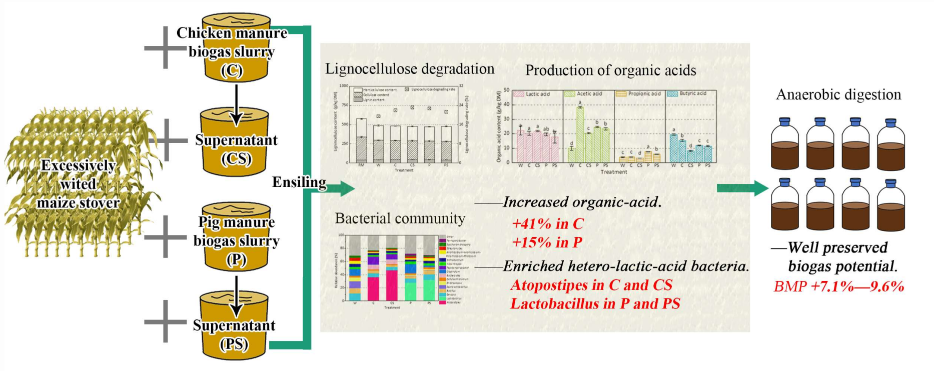
(1) Maize stover were ensiled for 60 d with distilled water (W), chicken manure biogas slurry (C), chicken manure biogas slurry supernatant (CS), pig manure biogas slurry (P), pig manure biogas slurry supernatant (PS).
(2) ODM, organic dry matter.
(3) $Yield_{measured}$ is the measured value of methane yield per unit of ODM in the maize stover, $Yield_{orig}$ is the theoretical methane yield per unit of ODM in the original material after ensiling (i.e., by considering storage losses). $Yield_{orig} = Yield_{measured} \times$ (1- ODM loss (%)).
(4) a, b, c, and d indicate a significant difference ($p < 0.05$) between treatments.

- Improved specific methane $yield_{measured}$ by ensiling: +6.4%~9.6%;
- Well preserved methane yield: Similar $yield_{orig}$ (considering storage loss);

- Possible reasons for increased $yield_{measured}$: (1) Hetero-lactic-acid fermentation; (2) Higher lignocellulose degradation rate; (3) Ammonolysis of lignocellulose;
- Trade-off between storage loss and improved methane production.

IV. Conclusion

- Ensiling wilted maize stover with digestate liquid for biogas production offers a efficient strategy that could well-preserve the BMP by recycling the digestates.
- Hetero-lactic-acid bacteria were enriched by the addition of biogas slurry.
- Higher organic-acid were produced with unseparated biogas slurry.
- Storage loss was completely offset by enhanced specific methane yield.



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V. Subsequent Research

- Buffer capacity

Xian Cui; Hui Sun; Mostafa Sobhi; Xinxin Ju; Jianbin Guo; Renjie Dong. Butyric Acid Fermentation during Ensiling of Wilted Maize Stover for Efficient Methane Production.ACS Sustainable Chemistry & Engineering. 2020, Vol.8(No.17)：6713-6721.

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- C/N ratio

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Urea-assisted ensiling process of wilted maize stover for profitable biomethane production

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- Mechanism to enhance biomethane yield by ensiling

Under review in Journal of Cleaner Production

Journal of Cleaner Production
How is the biogas potential of ensiled lignocellulosic substrates enhanced, by the behavior of acids or microbes?
--Manuscript Draft--

Manuscript Number:	
Article Type:	Original article
Keywords:	Ensiling; pretreatment; lignocellulose biomass; synergetic effect; biogas production
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The End.

Thanks!

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