TOWARDS SUSTAINABLE WASTE MANAGEMENT: REUSE AND ENERGY RECOVERY POTENTIALS FROM WASTE WATER SLUDGES AND AGRO-WASTES

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Aim of this Study

to investigate thoroughly:

- the biogas production potential of the anaerobic co-digestion of wastewater sludge with several agricultural products such as;
  - energy crops
    - cloverleaf, wheat, grass, barley and manure
  - agro-wastes and crops’ residuals
    - nutshell, potato peel, olive bagasse and maize silage

Why the biomass renewable energy sources are quite important for Turkey?

- ✓ **65 Mtons** of agricultural wastes generated annually from cultivation

- ✓ The predictions show that **the annual sludge production will reach up to 911 ktons by year 2040.**

Biomass Energy Potential

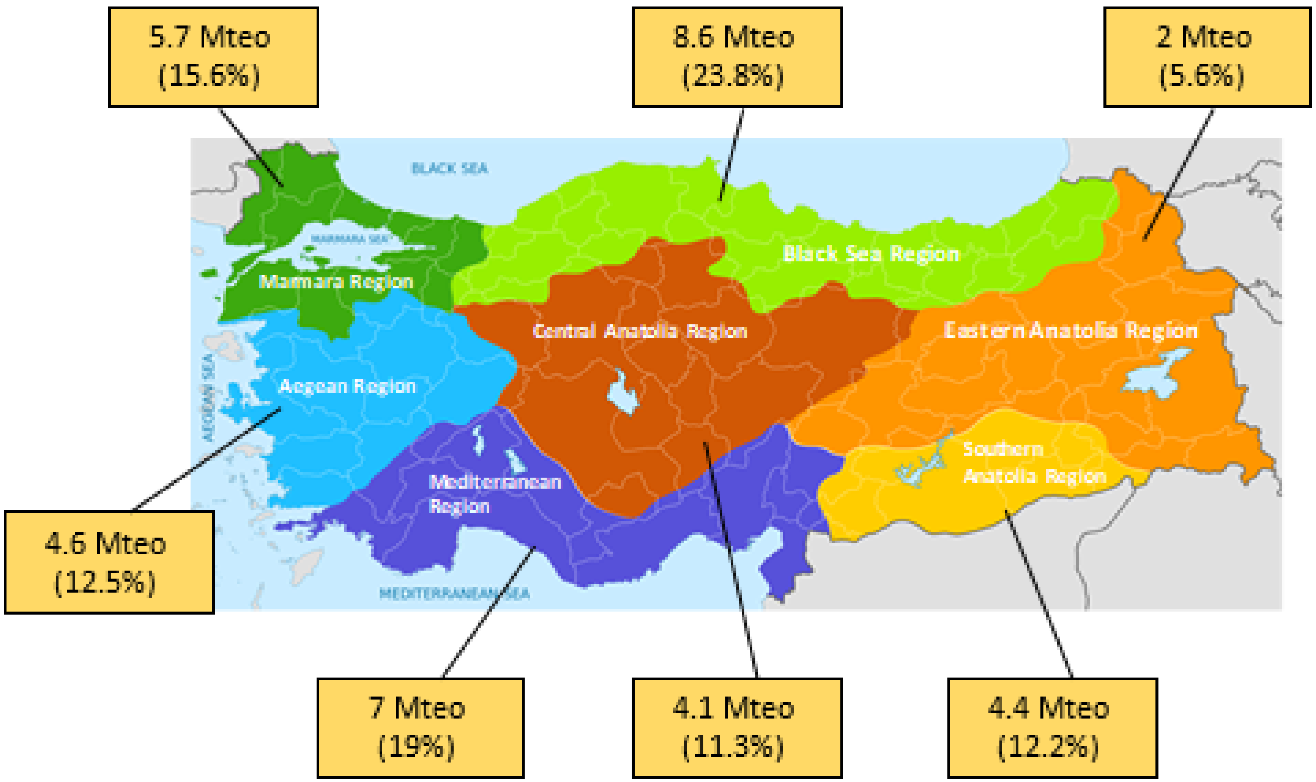
Turkey possesses a variety of biomass resources like forests, agriculture and animals. Although traditionally animal dung has been used for heating and cooking purposes for many years, it is slowly being converted to modern uses of biomass energy.

Type of Biomass	Annual biomass potential (million tons)	Energy potential (Mtoe)*
Annual crops	55	**14.9**
Perennial crops	16	**4.4**
Forest residues	18	**5.4**
Residues from agro-industry	10	**3.0**
Residues from wood industry	6	**1.8**
Animal wastes	7	**1.5**
Other	5	**1.3**
Total	117	**32.0**

Biogas Around the World

- World Bioenergy Association estimates the global substrate potential for biogas production 10,000 TWh.
- Total World Production is estimated to between 300-400 TWh.

The regional distribution of biomass energy potential of Turkey

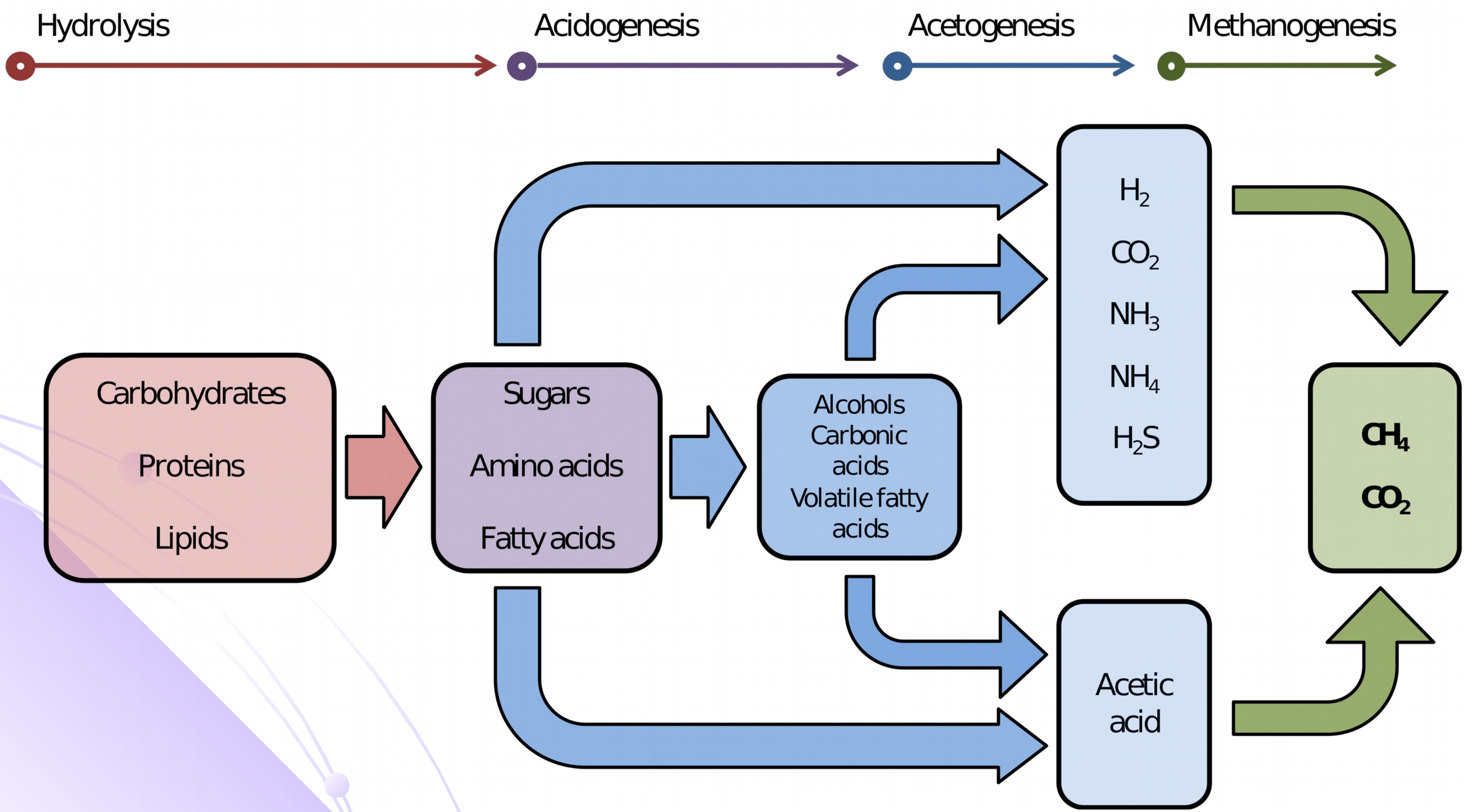


The agricultural biomass energy potential of Turkey

Annual Crops	Annual production (mtons)	Energy Potential (mtoe)
Wheat straw	26.4	7.2
Barley straw	13.5	3.9
Maize stalk	4.2	1.2
Cotton cocoon shell	2.9	0.9
Sunflower shell	2.7	0.8
Sugar beet waste	2.3	0.7
Hazelnut shell	0.8	0.3
Oat straw	0.4	0.1
Rye straw	0.4	0.1
Fruit shell	0.3	0.1
Olive cake	0.75	0.3
Total	54.4	15.5

Anaerobic Digestion

- Producing renewable energy
- Preventing transmission of disease
- Lower capital cost
- Production of an odorless, humus-like, biologically stable end product



Benefits of Co-digestion

Crop or Crop residues		**Wastewater Sludge**
High C/N ratio– high carbon content Low alkalinity Lack of macro/micro nutrient	+	Lower C/N ratio– high ammonia Higher alkalinity Rich in macro/micro nutrient

Improve the C/N ratio, buffering capacity and more biodegradable substrate

MATERIALS AND METHODS

- Sludge Substrates:
  - Seed Sludge (Inoculum)
  - Wastewater Sludge
- Inoculum: from the full-scale anaerobic digester of a big yeast factory in İzmit-Turkey
- Wastewater Sludge : from the recycling line of one of the largest advanced biological wastewater treatment plant located in İstanbul

Sludge Characteristics

Parameter	Unit	Inoculum	Sewage Sludge
TS	mg/L	38331	20992
VS	mg/L	25360	12385
MLSS	mg/L	37250	15480
MLVSS	mg/L	24000	9570
COD	mg/L	38470	16750
sCOD	mg/L	5154	927
TKN	mg/L	870	980
NH^{4+}	mg/L	294.00	51.75
TP	mg/L	430	410
PO_4^{-3}	mg/L	1310	1260
SO_4^{-2}	mg/L	110	5
Alkalinity (as $CaCO_3$)	mg/L	5302.5	1155.0
pH	-	7.3	6.72
Conductivity	mS/cm	20.10	3.02
Salinity	‰	14.0	1.8
Total Coliform	cfu/100mL	$2*10^6$	$2x10^6$
Fecal Coliform	cfu/100mL	$2.2*10^5$	$1.6x10^5$
Fecal Streptococ	cfu/100mL	$3.2*10^4$	$4.4x10^4$

Characteristics of Biomass Products

Biomass	TS (%)	VS (%)	Nitrogen Weight (%)	Carbon Weight (%)	Hydrogen Weight (%)
Clover	87.6	75.2	9.8	47.0	6.3
Wheat	90.2	73.3	7.5	42.3	7.0
Nutshell	89.8	67.9	7.8	50.0	6.1
Potato Peel	23.1	21.4	6.0	44.8	6.5
Olive Bagasse	91.7	72.5	10.4	52.0	7.3
Maize Silage	26.4	23.6	7.9	46.6	6.41
Grass	44.6	27.9	1.4	26.6	4.7
Barley Silage	22.4	18.8	2.0	56.9	8.3
Manure	5.1	4.0	7.0	40.0	5.6

Analytical Methods

Parameter	Method and Special Instruments
pH	4500-H B Method Electrometric (APHA, AWWA-WPCF-2006) ORION SA 520 pH meter
ORP	2580 B Method (APHA, AWWA-WPCF-2006) ORION SA 520 pH meter
Conductivity	2510 B Method (APHA, AWWA-WPCF-2006) WTW LF 320 Conductivity meter
COD	5220 D Method Closed Reflux, Colorimetric (APHA, AWWA-WPCF-2006) HACH COD Digester, HACH DR/3 Spectrophotometer
TOC	5310 A Method (APHA, AWWA-WPCF-2006)
TS/VS	2540 B (APHA, AWWA-WPCF-2006)
VSS	2540 D and E (APHA, AWWA-WPCF-2006)
TVS	2540 G (APHA, AWWA-WPCF-2006)
Alkalinity	2320 B Method Titration (APHA, AWWA-WPCF-2006)

Parameter	Method and Special Instruments
TKN	4500 E Method Titration (APHA, AWWA-WPCF-2006) Gerhardt Vapodest Digester Apparatus
Ammonia-N	4500 E Method Titration (APHA, AWWA-WPCF-2006) Gerhardt Vapodest 12 Distillation Apparatus
Nitrite, nitrate	4500 Method (APHA, AWWA-WPCF-2006)
Phosphate	4500-P E Method Ascorbic Acid (APHA, AWWA-WPCF-2006) HACH DR/3 Spectrophotometer
Chloride	4500-Cl B Method Argentometric (APHA, AWWA-WPCF-2006)
Sulfate	4500-SO4-2 E Method Turbidimetric (APHA, AWWA-WPCF-2006) HACH DR/3 Spectrophotometer
CST	CST Instrument (Vesilind, 1988)
VFA	Gas Chromatograph HP 5890
CH_4, CO_2, O_2	Gas Chromatograph HP 6850

Reactor Conditions for Batch Tests

Batch fed anaerobic reactors (pH around 7)

⇩

2.5 L with 1.6 L active volume

⇩

40 days of digestion

⇩

Mesophilic conditions at 37 °C

⇩

6.5% of initial TS contents of the reactors

⇩

Inoculum to Substrate Ratio: 1/1

- The bottles equipped with a V shape gas collection ports at the top.
- One opening for MiliGascounter® (MGC) to measure the amount of biogas produced.
- One opening to take samples for gas composition (CH_4 and CO_2) analysis by HP 6850 Gas Chromatograph.
- (Carboxen 1010 plot GC column 30 m x 0.53 mm) equipped with a thermal conductivity detector.

Reactor Contents

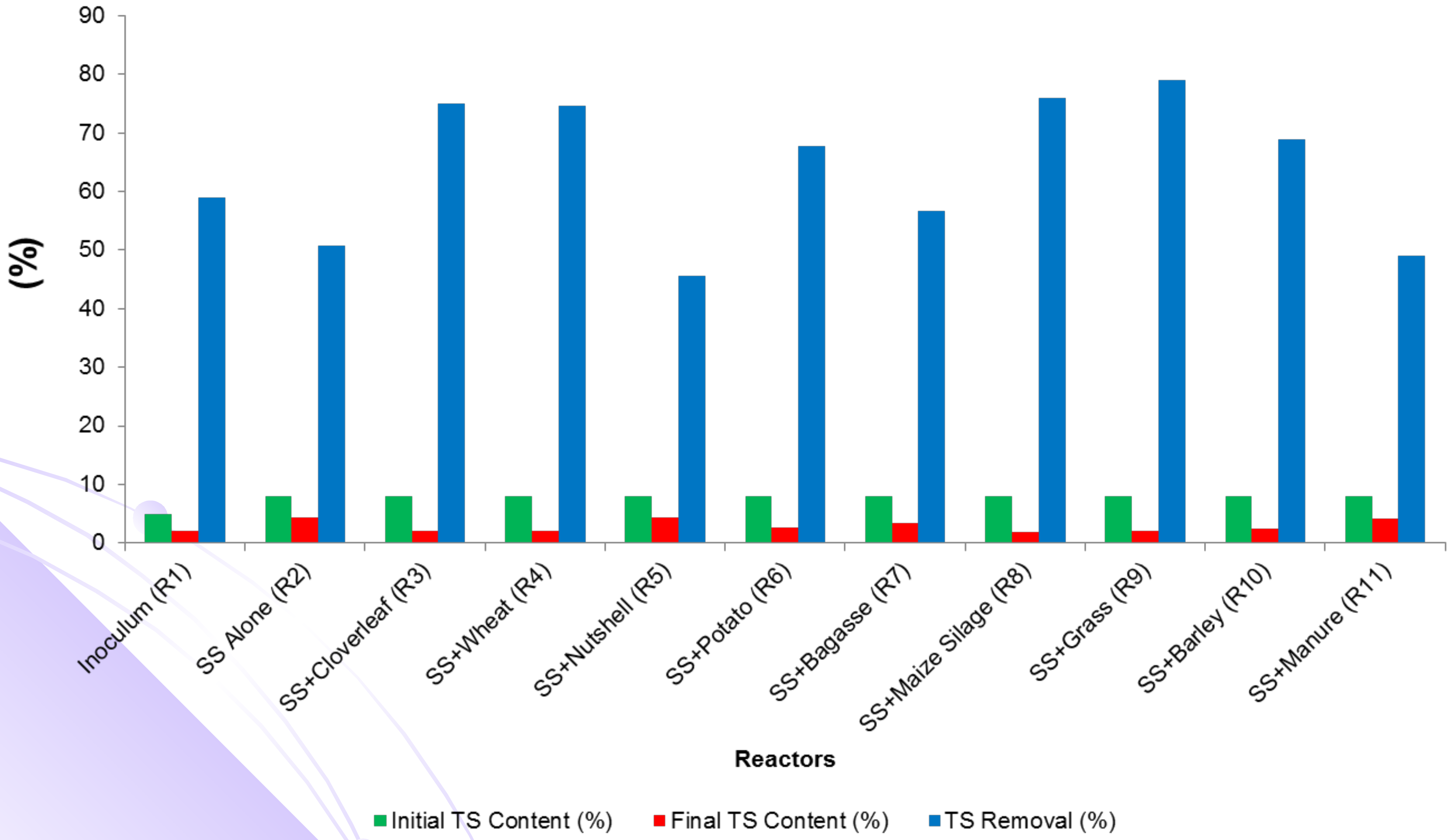
Reactors	Content
R1	Inoculum
R2	Inoculum + WAS
R3	Inoculum + WAS + Cloverleaf
R4	Inoculum + WAS + Wheat
R5	Inoculum + WAS + Nutshell
R6	Inoculum + WAS + Potato Peel
R7	Inoculum + WAS + Olive Bagasse
R8	Inoculum + WAS + Maize Silage
R9	Inoculum + WAS + Grass
R10	Inoculum + WAS + Barley Silage
R11	Inoculum + WAS + Manure

Reactor Conditions

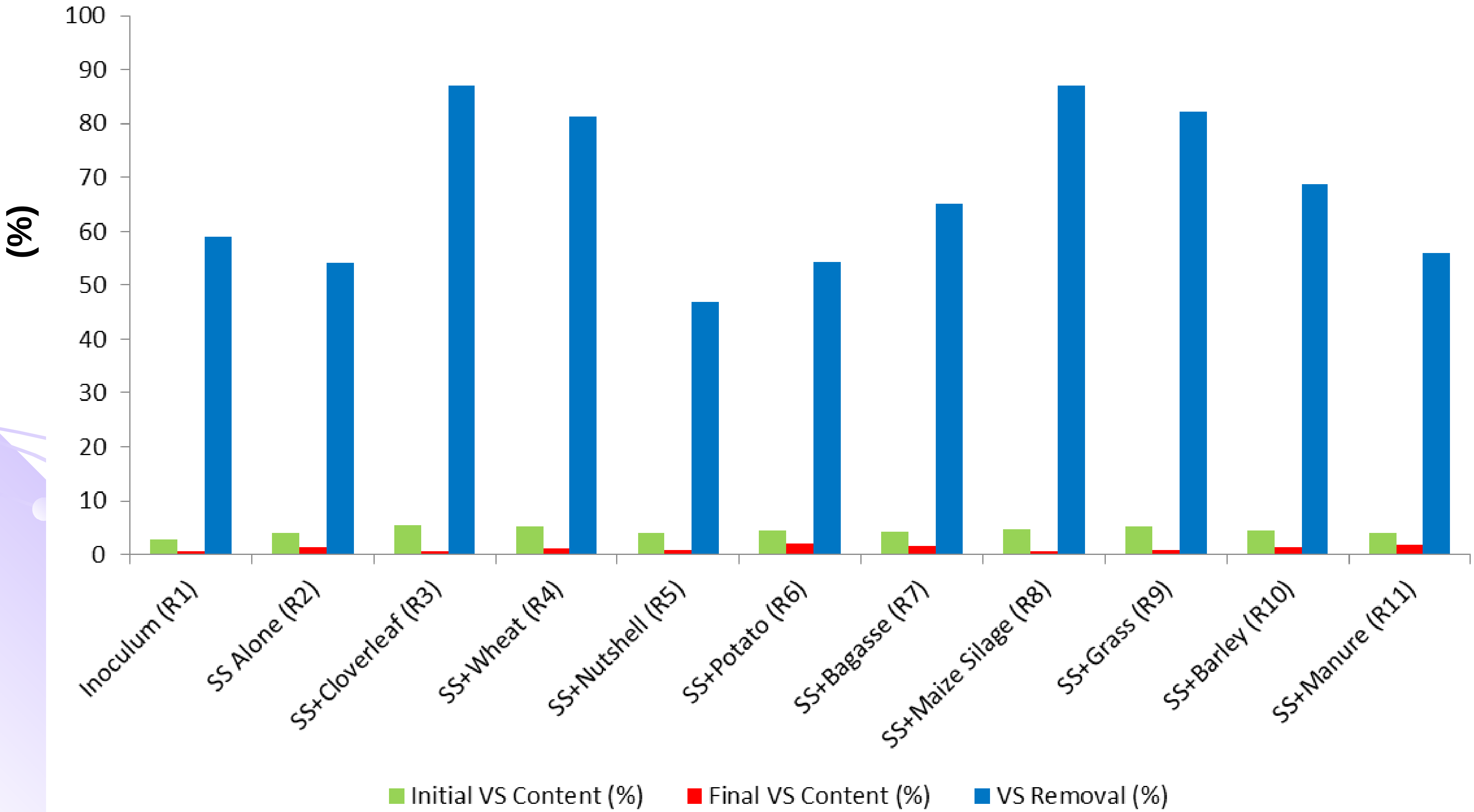
- Initial pH values of the reactors were adjusted to about 7.
- Final pH values of the reactors ranged between 6.75-7.42.
- The initial alkalinity concentrations in the reactors ranged between 2430-4700 mg $CaCO_3$/L.
- Final alkalinity concentrations ranged between 3250-6800 mg $CaCO_3$/L.

RESULTS AND DISCUSSION

TS Contents and Removals (%)



VS Contents and Removals (%)



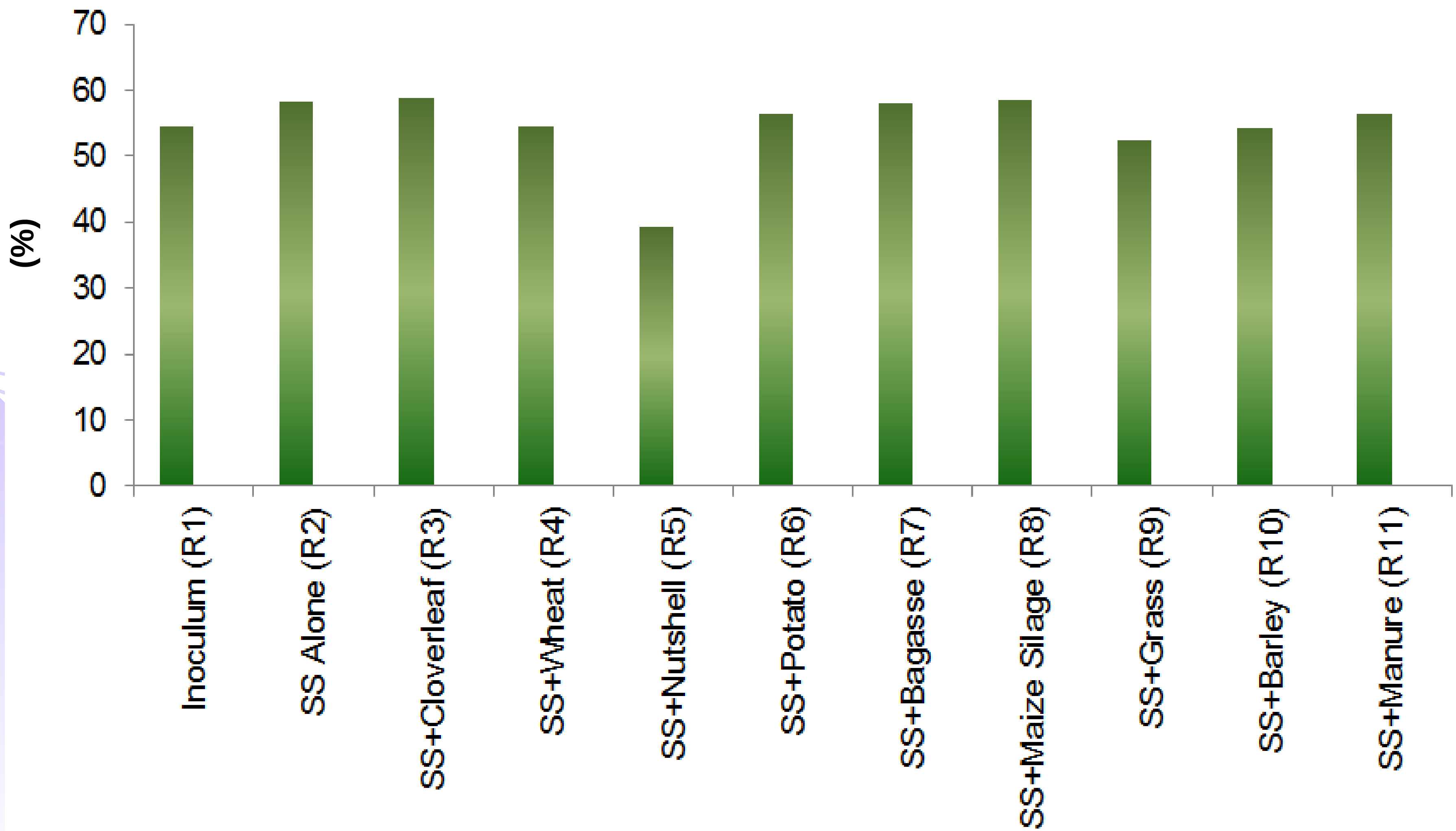
Microbiology Results of the Reactors

Reactors	Total Coliform Initial [cfu/100mL]	Total Coliform Final [cfu/100mL]	Fecal Coliform Initial [cfu/100mL]	Fecal Coliform Final [cfu/100mL]	Fecal Streptococ Initial [cfu/100mL]	Fecal Streptococ Final [cfu/100mL]
R1	2.0×10^6	1.1×10^2	2.2×10^5	≤1	3.2×10^4	42
R2	2.0×10^6	1.5×10^2	1.6×10^5	≤1	4.4×10^4	14
R3	2.5×10^6	4.1×10^2	3.8×10^5	1.4	1.4×10^4	≤1
R4	4.2×10^6	3.0×10^2	1.7×10^5	2.5	4.6×10^4	12
R5	1.8×10^6	5.0×10^2	1.2×10^5	1.0	2.0×10^4	10
R6	3.1×10^6	1.5×10^2	2.2×10^5	≤1	2.0×10^4	≤1
R7	2.0×10^6	≤ 1	1.5×10^5	2.3	5.4×10^4	≤1
R8	2.5×10^6	4.0×10^2	4.0×10^5	78	2.3×10^4	12
R9	5.0×10^6	2.0×10^2	1.8×10^5	51	8.0×10^4	7
R10	1.7×10^6	≤ 1	1.1×10^5	≤1	1.7×10^4	≤1
R11	2.5×10^6	2.2×10^2	1.8×10^5	≤1	3.3×10^4	≤1

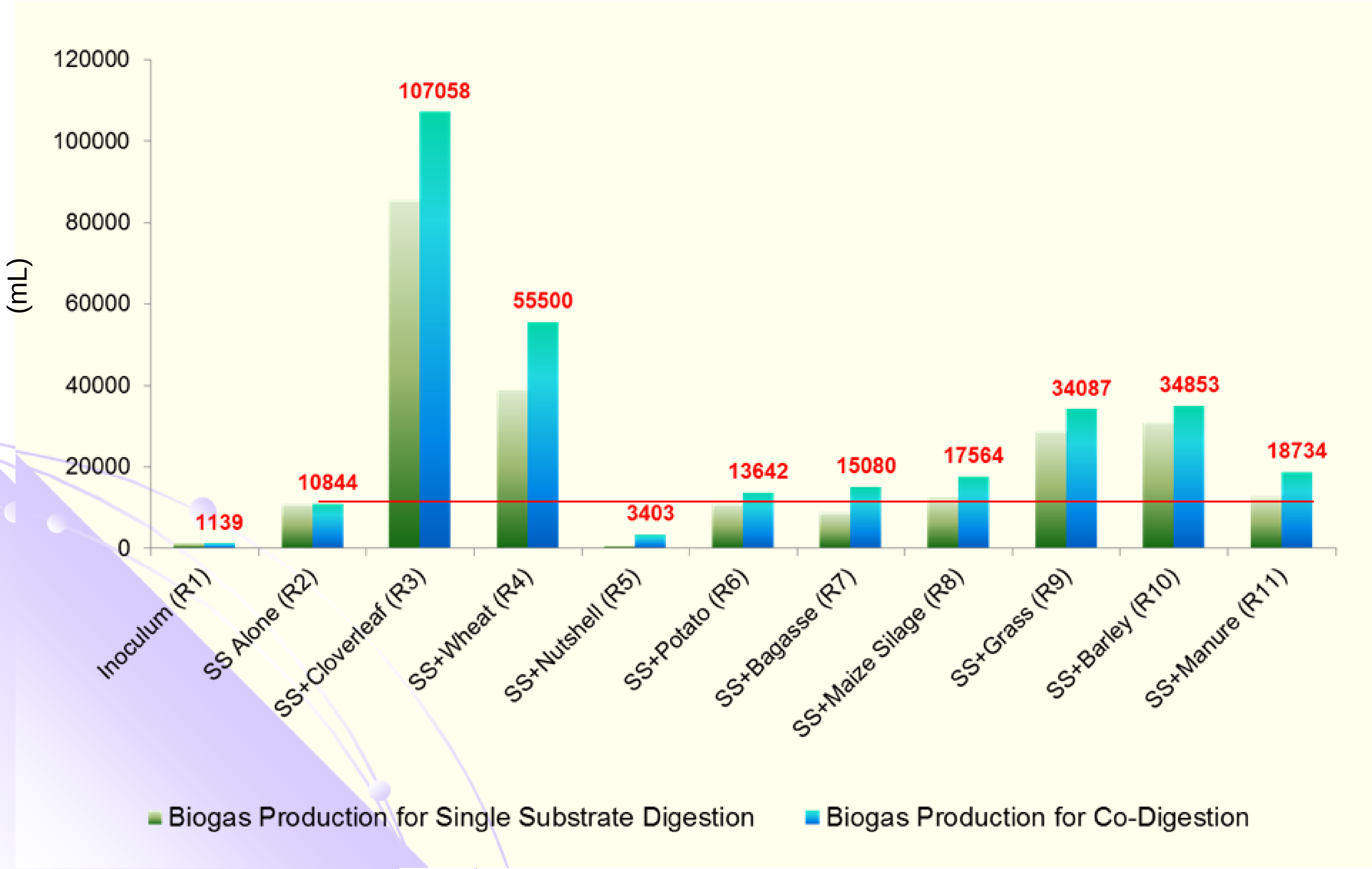
Gas Analyses

- The daily gas production and gas content (CO_2% and CH_4%) are the major parameters indicating the efficiency of anaerobic digestion process.
- The highest methane contents of **59**% and **58 %** were obtained in reactors **R3** and **R8** containing wastewater sludge and co-substrates **clover leaves** and **maize** respectively.
- The lowest methane content of 39% was obtained in reactor R5 having nutshells.

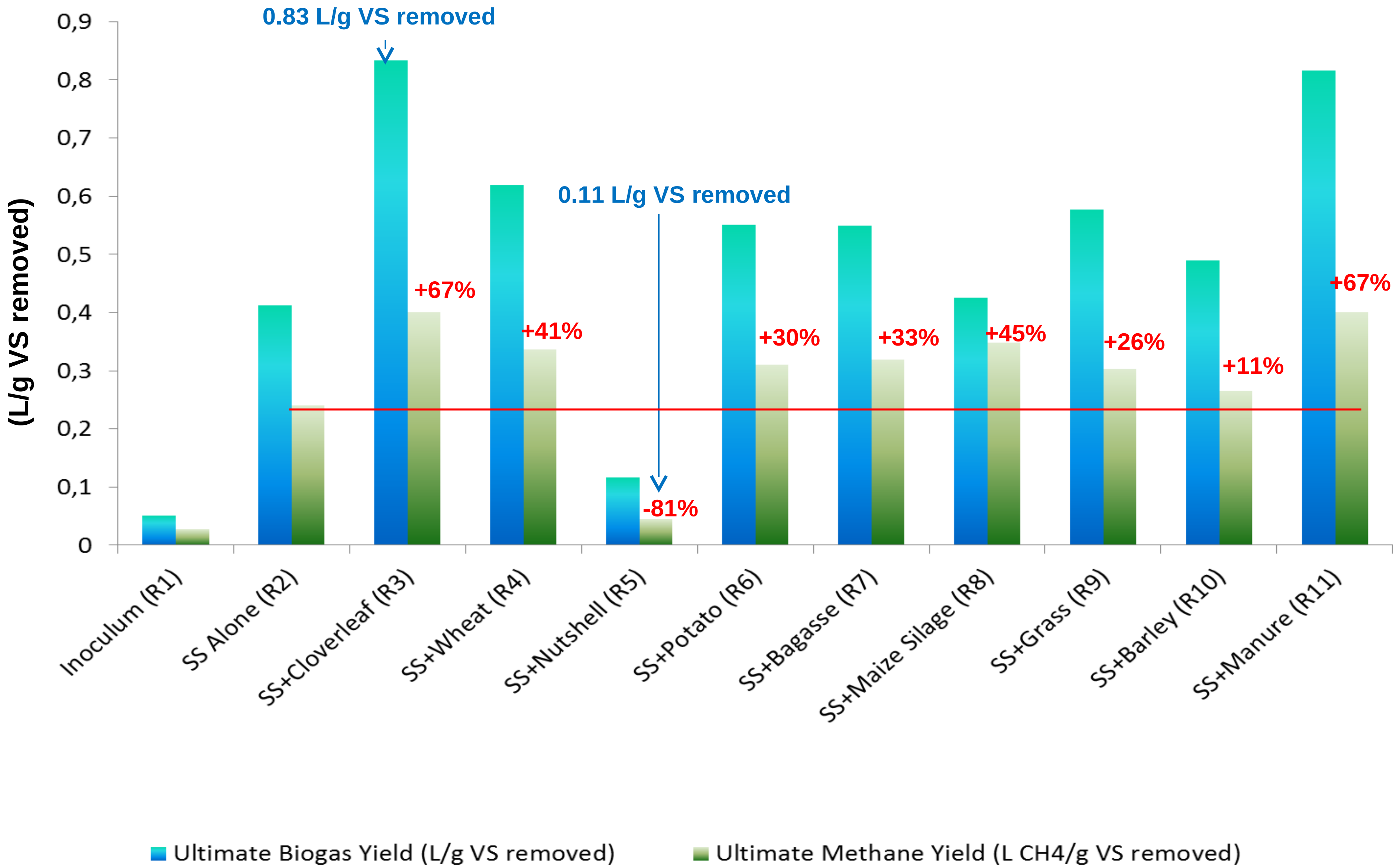
Methane Content of Biogas (%)



Cumulative Biogas Productions (mL)



Biogas and Methane Yields



CONCLUSIONS

- The anaerobic «co-digestion» of wastewater sludge with the agricultural biomass resulted in «higher methane yields» compared to that of a single-substrate digestion of the sludge (except nutshell).
    - Methane yields increased about 11-67% depending on the type of the biomass.
- The most efficient biodegradation and the highest biogas and methane yields were obtained in reactor R3 having the mixture of wastewater sludge and cloverleaf.
    - In the reactor biogas and methane yields were about 0.83 L/g VS removed and 0.40 L/g VS removed respectively.

CONCLUSIONS (cont.)

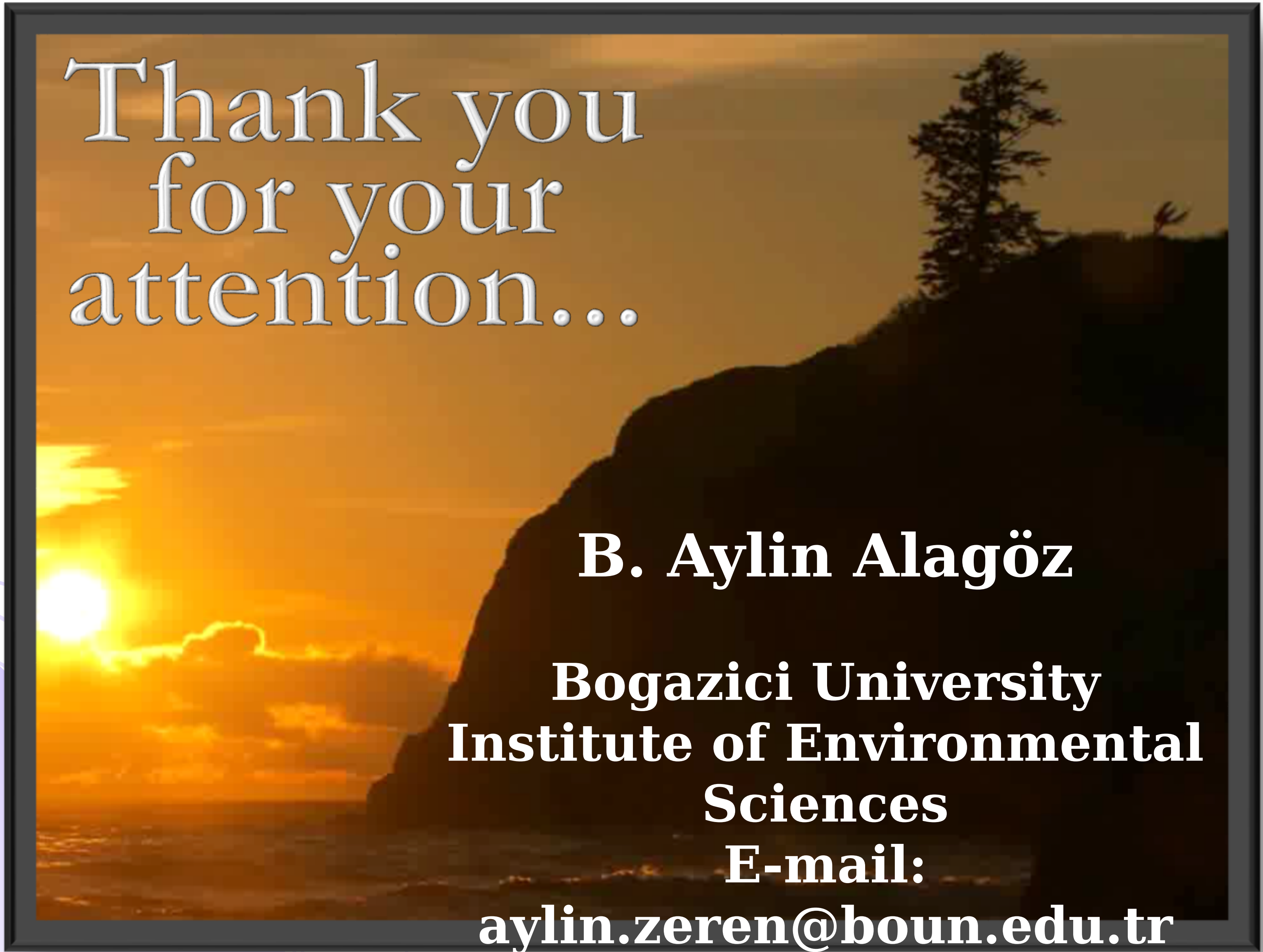
- In reactor R3, the cumulative biogas production was almost ten times and the methane yield was 2 times higher than those in reactor R2 containing wastewater sludge alone.

- Methane yields obtained from **agricultural waste materials were compatible with those obtained from energy crops** except cloverleaf.

CONCLUSIONS (cont.)

- Anaerobic «co-digestion» of the wastewater sludge and the agricultural biomass products was a viable alternative for the improvement of the biogas and methane production.

  - Also an alternative solution for the disposal problem of the wastewater sludges.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