

**ENHANCING BIOGAS PRODUCTION BY CO-DIGESTION OF
LIVESTOCK MANURES**

CHINTALAPATI GOWTHAM VARMA

(15-MVM-15)



DEPARTMENT OF LIVESTOCK PRODUCTION MANAGEMENT

COLLEGE OF VETERINARY AND ANIMAL SCIENCES

MANNUTHY, THRISSUR- 680 651

KERALA, INDIA

2017

**ENHANCING BIOGAS PRODUCTION BY CO-DIGESTION OF
LIVESTOCK MANURES**

**CHINTALAPATI GOWTHAM VARMA
(15-MVM-15)**

THESIS

Submitted in partial fulfilment of the requirement for the degree of

**MASTER OF VETERINARY SCIENCE
(Livestock Production Management)**

2017

**Faculty of Veterinary and Animal Sciences
Kerala Veterinary and Animal Sciences University**



**DEPARTMENT OF LIVESTOCK PRODUCTION MANAGEMENT
COLLEGE OF VETERINARY AND ANIMAL SCIENCES
MANNUTHY, THRISSUR - 680 651
KERALA, INDIA**

DECLARATION

I hereby declare that this thesis, entitled “**Enhancing biogas production by co-digestion of livestock manures**” is a bonafide record of research work done by me during the course of research and that the thesis has not previously formed the basis for the award to me of any degree, diploma, fellowship or other similar title, of any other University or Society.

Mannuthy

Date:

Dr. C. GOWTHAM VARMA

(15-MVM-15)

Dr. A. Kannan

Associate Professor
Department of Livestock Production Management
College of Veterinary and Animal Sciences
Mannuthy, Thrissur, Kerala 680 651

CERTIFICATE

Certified that this thesis, entitled “**Enhancing biogas production by co-digestion of livestock manures**” is a record of research work done independently by **Dr. Chintalapati Gowtham Varma (15-MVM-15)** under my guidance and supervision and it has not previously formed the basis for the award of any degree, diploma, fellowship or associateship to him.

Mannuthy
Date:

Dr. A. Kannan
Chairman
Advisory Committee

CERTIFICATE

We, the undersigned members of the advisory committee of **Dr. Chintalapati Gowtham Varma (15-MVM-15)**, a candidate for the degree of Master of Veterinary Science in Livestock Production Management, agree that this thesis entitled “**Enhancing biogas production by co-digestion of livestock manures**” may be submitted by **Dr. Chintalapati Gowtham Varma (15-MVM-15)** in partial fulfillment of the requirement for the degree.

Dr. A. Kannan

Associate Professor,
Department of Livestock Production Management,
College of Veterinary and Animal Sciences,
Mannuthy, Thrissur – 680651
(Chairman)

Dr. Anil. K.S

Professor and Head,
Department of Livestock Production
Management,
College of Veterinary and Animal Sciences,
Mannuthy, Thrissur – 680 651
(Member)

Dr. N. Geetha

Assistant Professor,
Department of Livestock Production
Management,
College of Veterinary and Animal
Sciences, Pookode, Wayanad – 673 576
(Member)

Dr. Shyama K

Assistant Professor (SS),
Department of Animal Nutrition,
College of Veterinary and Animal Sciences,
Mannuthy, Thrissur – 680 651
(Member)

External Examiner

ACKNOWLEDGEMENTS

A great teacher takes a hand, opens a mind and touches a heart. I am always blessed in my life to have great teachers at each and every moment of my life. I bow to all of them who had molded me from a young lad to post-graduate.

*I place on record my heartfelt thanks to the Chairman of my advisory committee, **Dr. A. Kannan**, Associate Professor, Department of LPM, for his meticulous guidance and parental help throughout the academic and research programme. As ancient literature says “Guru” is the “dispeller of darkness”, He is the one who had helped me to perceive various dimensions which I am unable to untangle. I would also remain indebted for his valid thoughts which had enlightened and helped me in modeling my views for my future aspirations. Without his support and co-operation, the successful completion of this work would not have been possible.*

*I am hereby expressing my profound gratitude for **Dr. Anil K. S.** Professor and Head, Department of LPM, for his critical supervision and liberty offered to me from the initiation of work to the ship-shaping of the manuscript.*

*I would like to express my special thanks to **Dr. N. Geetha**, Assistant Professor, Department of LPM, for her guidance and professional help during the course of study. I will never forget the special attention and personal affection rendered by her.*

*I wish to express my sincere thanks to **Dr. Shyama**, Assistant Professor (SS), Department of Animal nutrition, for her sustained interest, propitious help and valuable concrete suggestions throughout the course of study.*

*I am extremely grateful to **Prof. P. C. Saseendran** (Retd.) for his expert advice and help offered for selecting the area of research.*

*There are no words to pay my gratefulness and gratitude to **Dr. Deepak Mathew and Dr. Justin Davis** for their valuable guidance and constructive criticism throughout the course of my work. I will remain thankful for the affectionate concern and professional support provided by **Dr. Manju Sasidharan, Dr. Biju S., Dr. Hari Kumar, Dr. Prasad, Dr. Sabin George, Dr. Biya Ann Joseph and Dr. Suraj P.T.** Suggestions made by them during the critical situations was quiet helpful and aided in successful completion of curriculum.*

*I humbly place on record my gratitude to **Dr. Rajeev T.S.** Assistant Professor, Department of AHE. His classes had facilitated for my personal development and journey to different pooram's were good opportunities to relish the culture of God's own country.*

*I wish to express my sincere thanks to **Dr. Thennerasu**, MVC, TANUVAS, Chennai for his concrete suggestions during the course of research programme.*

*I am extremely thankful to **Dr. Gleeja V.L.** Assistant Professor, Department of Statistics, for her suggestions and keen interest shown during the statistical analysis.*

*I sincerely acknowledge the affection shown by my colleagues **Dr. Govind, Dr. Keyho, Dr. Sunitha and Dr. Sudharsan.** Two years of journey and critical differences with them at times, aided me in changing and rectifying myself. I would remain thankful to **Dr. Tomlal, Dr. Prabul** for their meticulous support during the research programme. I thank **Dr. Kamalhasan, Dr. Jonathan, Dr. Pooja and Dr. Sasikala** for their support.*

*I am greatly indebted to **Dr. Abhijith, Dr. Naveen, Dr. Rishikesh , Dr. Ajith and Dr. Santhosh** for the love and affection showered on me. Being from different states distance might separate us but they will always remain close to my heart. I sincerely thank **Dr. Sudheer** for his continuous support since my undergraduate days.*

*I extend my sincere thanks to my friends **Dharani, Davuddin, Sai, Murali, Dr. Anand, Anupama and Aditya** for their whole hearted support, love and care during those days. I thank them all and their friendship is invaluable to me. I wish to express my gratitude to **Dr. Banakar and Dr. Nayan** for their unstinted help during the curriculum.*

*I am thankful to my well-wishers **Dr. Siva Sagar and Dr. Vinod** (my anna), VAS's, Anantapur Dist. A.P. Their blessings and constant support during my hardships will be remembered for ever.*

*I take this opportunity to thank all the staffs and students of **Department of Animal nutrition, CIL (CVAS, Mannuthy), RTL (KAU, Vellanikara)** for their valuable guidance in carrying out the laboratory analysis.*

*I sincerely acknowledge the technical support and guidance rendered by **Shri. Ajith** (Programme officer), **Staff and Stakeholders** of **ANERT**, Thrissur during the research programme.*

*The co-operation and help extended by **Mr. Shiju V. Mathai**, **Mr. Velayudhan**, Ecofarm, and the **non-teaching staff** of LPM department are thankfully acknowledged for the invaluable services rendered during the research programme.*

*I do remember with gratitude and indebtedness, all those faculty, staff, colleagues and friends of **SVVU** and **KVASU** who kept my spirits high and in goodstead during my career as a student in Veterinary Science.*

*Words possess no enough strength to reflect my respect for my beloved teacher **Shri. Mohan Rao** and his family for personal attention, persuasion, encouragement, and selfless backing. I would remain indebted to his daughters for treating me as their brother and allowed me to share their father's love and affection.*

*Words are inadequate to express my deep sense of honor to my loving **Parents** and the family of my uncle **Adv. C. Sekhar** whose overwhelming encouragement and endurance had always provided inspiration to me. I am none without them in my life.*

Above all, I bow before the Almighty for the blessings showered on me throughout my whole life.

Dr. C. Gowtham Varma

Dedicated to the Indian farming community...

CONTENTS

Chapter	Title	Page No.
1	INTRODUCTION	1
2	REVIEW OF LITERATURE	3
	2.1 ANAEROBIC DIGESTION	3
	2.1.1 Biogas	4
	2.2 FACTORS EFFECTING ANAEROBIC DIGESTION	5
	2.2.1 Substrate	5
	2.2.2 Anaerobic digesters	8
	2.2.3 Temperature	10
	2.2.4 pH	13
	2.2.5 Hydraulic retention time (HRT)	14
	2.2.6 Organic loading rate (OLR)	15
	2.2.7 Factors Limiting AD	16
	2.3 BIOGAS PRODUCTION	17
	2.4.BIOGAS PRODUCTION POTENTIAL OF ANIMAL MANURES	18
	2.4.1 Cattle manure	18
	2.4.2 Goat manure	19
	2.4.3 Sheep manure	20
	2.4.4 Swine manure	20
	2.4.5 Poultry manure	21
	2.4.6 Rabbit manure	22
	2.4.7 Horse manure	23
	2.4.8 Elephant dung	23

	2.5 ANAEROBIC CO-DIGESTION OF SUBSTRATES	23
	2.5.1 Anaerobic co-digestion of manures	24
	2.6 MANURIAL VALUE OF SLURRY	26
	2.7 CARBON SEQUESTRATION THROUGH AD	28
	2.8 ECONOMICS OF ANAEROBIC DIGESTION	28
3	MATERIALS AND METHODS	29
	3.1 LOCATION OF STUDY	29
	3.2 PERIOD OF STUDY	29
	3.3 CLIMATOLOGICAL DATA	29
	3.4 DESIGN OF EXPERIMENT	30
	3.4.1 Biogas plants	30
	3.4.2 Substrates	30
	3.4.3 Treatments	30
	3.4.4 Dilution	30
	3.5 PHYSICO-CHEMICAL CHARACTERS OF SUBSTRATES	31
	3.5.1 Temperature	31
	3.5.2 Chemical analysis of substrates	31
	3.5.3 Manurial value	31
	3.6 BIOGAS PRODUCTION	31
	3.6.1 Hydraulic Retention Time (HRT)	32
	3.6.2 Biogas production	32
	3.6.3 Composition of biogas	32
	3.7 SLURRY	32
	3.7.1 Physico-chemical characters of slurry	32
	3.8 CARBON CREDIT POTENTIAL	33
	3.9 ECONOMICS OF BIOGAS PRODUCTION	33
	3.10 STATISTICAL ANALYSIS	34

4	RESULTS	38
	4.1 CLIMATOLOGICAL DATA	38
	4.2 PHYSICO - CHEMICAL CHARACTERS OF SUBSTRATES	38
	4.2.1 Temperature	38
	4.2.2 Chemical composition	39
	4.3 BIOGAS YIELD	42
	4.3.1 Hydraulic retention time	42
	4.3.2 Trend in Biogas production	42
	4.3.3 Average daily yield	42
	4.3.4 Cumulative biogas yield	44
	4.4 COMPOSITION OF BIOGAS	44
	4.4.1 Temperature	45
	4.4.2 R.H	45
	4.4.3 CH₄ and CO₂	45
	4.4.4 Other gases	47
	4.5. PHYSICO-CHEMICAL CHARACTERS OF SLURRY	47
	4.5.1 Quantity	47
	4.5.2 Temperature	47
	4.5.3 Chemical composition	48
	4.6 CORRELATION OF CLIMATOLOGICAL PARAMETERS ON BIOGAS YIELD	51
	4.7 MANURIAL VALUE OF SUBSTRATE AND SLURRY	51
	4.8 CARBON CREDIT POTENTIAL OF ANAEROBIC DIGESTION	51
	4.9 ECONOMICS OF BIOGAS PRODUCTION	52

5	DISCUSSION	62
	5.1 CLIMATOLOGICAL DATA	62
	5.2 PHYSICO-CHEMICAL CHARECTERISTICS OF SUBSTRATE	62
	5.3 BIOGAS YIELD	65
	5.4 COMPOSITION OF BIOGAS	67
	5.5.PHYSICO-CHEMICAL CHARACTERS OF SLURRY	68
	5.6 CORRELATION OF CLIMATOLOGICAL PARAMETERS ON BIOGAS YIELD	70
	5.7 MANURIAL VALUE OF SUBSTRATE AND SLURRY	71
	5.8 CARBON CREDIT POTENTIAL OF ANAEROBIC DIGESTION	71
	5.9 ECONOMICS OF BIOGAS PRODUCTION	72
6	SUMMARY	73
7	REFERENCES	78
	ABSTRACT	

LIST OF TABLES

Table No.	Title	Page No.
4.1	Physico-Chemical properties of substrate	40
4.2	Biogas yield from different substrates	43
4.3	Composition of biogas	46
4.4	Physico-Chemical properties of slurry	49
4.5	Correlation of climatological factors on biogas production	51
4.6	Carbon credit potential of biogas yield	52
4.7	Economics of biogas production	52
4.8	Manurial value of substrate and slurry (Season-I)	53
4.9	Manurial value of substrate and slurry (Season-II)	54

LIST OF PLATES

Plate No.	Title	Page No.
1	Schematic sketch of portable floating drum biogas plant	35
2A	Experimental shed	36
2B	HOBO Temperature humidity data logger with its base station and cable for down loading	36
3A	Titan MPS Microwave Sample Preparation System	37
3B	ICPOES OPTIMA 8000	37

LIST OF FIGURES

Figure No	Title	Page No.
1.	Biogas yield from different treatments in season - I	55
2.	Biogas yield from different treatments in season - II	56
3.	Correlation between temperature and biogas yield during season - I	57
4.	Correlation between temperature and biogas yield during season - II	57
5.	Correlation between THI and biogas yield during season - I	58
6.	Correlation between THI and biogas yield during season - II	58
7.	Composition of biogas between seasons	59
8.	Manurial value of Substrate and Slurry in S-I	60
9.	Manurial value of Substrate and Slurry in S-II	60
10.	Economics of biogas production from different treatments	61

1. INTRODUCTION

A tremendous increase in human population had occurred across the length and breadth of the globe. Ever growing population is causing an acute stress and depletion of existing resources to meet the wants of people. Rapid growth of industrialization and increased demand for energy resulted in exploitation of non-renewable sources like fossil fuels which caused climate change. Simultaneously, intensification of farm activities to ensure global food security had resulted in increased generation of wastes per unit area. Livestock manure is being produced in huge quantities, improper and unscientific disposal of manure is causing pollution of air, water and land with an impact on climate change. In this regard, all the techniques which help to convert waste to energy (WTE) can be utilized for mitigating climate change by decreasing the dependency on fossil fuels.

Livestock manure is a good source of plant nutrients. Hence, it was used for direct application in agriculture. Techniques like aerobic composting were developed and adopted for nutrient recycling to the maximum extent. But, the energy potential of manures remained unexploited by composting. Hence, anaerobic digestion (AD) of livestock manure was an optimistic solution to harness the energy potential of animal manure without any damage to the nutrients present. Biogas, the main end product of AD will serve as an efficient source of renewable energy and helps to gain carbon credits.

In India, anaerobic digestion was initiated in 1859 at Bombay and after World war II, small scale anaerobic digesters had flourished in India and China to cope up energy demand. Many types of anaerobic digesters like Deenabandhu and Janatha models were developed during this time. National biogas and manure management programme (NBMMP) is being instigated under Ministry of new and renewable energy (MNRE), Government of India, with the help of nodal

agencies like KVIC (Khadi and Village Industries Commission). Till date, around 4.75 million digesters with a volume ranging from one to six cubic metric have been fixed across the country. But non-functioning anaerobic digesters are great in number, hampering the further development due to numerous limitations in its application. Various factors such as quality of the substrate, design of digester, operational conditions, climatological factors etc., are swaying the efficiency of methanogens and limiting its application at farm level. To overcome this, there is a need to understand the different factors affecting anaerobic digestion and to find out the optimized standards for substrate, digesters and operating conditions for the sustainability of biogas production. Earlier studies have revealed that mono-digestion of animal manure had certain curbs with hindrances in the manure treatment. Therefore, co-digestion of manures is supposed to have better bio-methanation potential (BMP) due to the synergistic effect of nutrients between the substrates and can increase the economic returns of farm. It is also necessary to assess the performance of the anaerobic digesters in the prevailing agro-climatic conditions for better adoption levels by the farmers.

Hence, the present study is carried out with the following objectives,

1. To estimate:
 - a) Biogas production by anaerobic co-digestion of different livestock manures
 - b) Manurial value of the slurry obtained
2. To study the effect of season on the production potential of biogas

2. REVIEW OF LITERATURE

Anaerobic digestion (AD) was proved to be an efficient technology among the renewable energy technologies available for effective utilization and management of animal manures. It gained a lot of importance and vast research was carried out in this arena to study the various factors affecting biogas production. Exclusive studies were undertaken regarding the optimization of the operational parameters for the evolution of a sustainable mechanism, which contributes towards the green economy of developing nations. Hence, an attempt has been made to review the literature available regarding the AD of animal manures.

2.1 ANAEROBIC DIGESTION

Anaerobic digestion is a cascade of metabolic reactions of the microorganisms inside the digester under anaerobic condition. It has four key biochemical stages *i.e.*, hydrolysis, acidogenesis, acetogenesis and methanogenesis (Salminen and Rintala, 2002). Four stages in the AD could be broadly classified into two phases based on the type of end products *viz.*, acidogenic phase and methanogenic phase (Nijaguna, 2002). It had major limitations like sluggish processing rate, failure of the digester in winter season and a lower recovery rate after failure (Sreekrishnan *et al.*, 2004).

Anaerobic digestion helped in the management of odor, acted as a source of bioenergy for farm activities and mitigated greenhouse gas (GHG) emissions during the disposal of waste. It also helped in increasing the economic returns of the farm (Clemens *et al.*, 2006). Cuellar and Webber (2008) concluded that mitigation of GHG by AD had propelled the peer communities to review and optimize the existing AD process for evolving a highly efficient technology.

“Anaerobic digestion (AD) is a practice of organic waste treatment in which biodegradable material is broken down in the absence of dissolved oxygen or its

precursors into biogas, a mixture of methane, carbon dioxide and traces of H₂S, NH₃ and water vapor”. Microbial digestion occurred during AD was a sluggish process and at least three weeks were needed for acclimatizing to new conditions after a change in the temperature or substrate (Dueblein and Steinhauser, 2008).

Anaerobic digestion yielded biogas as main product and digestate (slurry) as byproduct which had a high manurial value (Seadi *et al.*, 2008). Rajendran *et al.* (2012) opined that a symbiotic relation should be established between acetogens (H₂ producers) and methanogens (H₂ consumers). Christy *et al.* (2014) reported that microorganisms belonging to the two kingdoms of Bacteria and Archae had a predominant role in AD of organic substances. Adekunle and Okolie (2015) reviewed the different stages of AD and opined that rate limiting step was hydrolysis and methanogenesis for complex and easily degradable substrates respectively.

2.1.1 Biogas

Nagamani and Ramasamy (1999) opined that in rural India, biogas technology emerged as non-conventional energy source and was employed widely for cooking. Porras (2003) reported that under suitable conditions biogas would be an apt source for future energy requirement of developing countries like India. He also stated that the standards of hygiene at farm level had improved due to the immediate disposal of dung into the digester.

Biogas was produced due to the activity of bacterial consortium and it was an unstable process influenced by the operating conditions. (Sreekrishnan *et al.*, 2004). It was a renewable fuel and it could be applied for household cooking, to generate electricity and after upgradation could be used as fuel cells (Cantrell *et al.*, 2008). The CH₄ content of biogas ranges between 55 and 70 per cent (Dueblein and Steinhauser, 2008).

2.2 FACTORS EFFECTING ANAEROBIC DIGESTION

2.2.1 Substrate

Organic wastes generated from agriculture and allied sectors could be utilized as a good substrate for AD. Animal manure maintained nutrient balance and could be degraded easily (Thy, 2003). Substrates with more cellulose content would result in higher gas production (Wijeyamohan, 2003). Biogas yield depended on the energy density and bio-degradability of the applied substrates. Cellulose present in the cell components of plant material would be utilized by the microbial consortium for production of biogas (Weiland, 2010).

Mateescu and Constantinescu (2011) opined that performance of AD loaded with animal manure had greater fluctuation due to more concentration of acidogens than methanogens in the substrate. Deshmukh (2012) stated that organic wastes generated from distilleries, sugar factories, dairies, slaughter houses and food industries served as substrates for AD. Anaerobic digestion of protein rich substrates had resulted in higher gas yield.

2.2.1.1 *Composition of substrate*

Moller *et al.* (2004) studied the theoretical and ultimate methane yield from swine and dairy cattle manure. He reported that the variation in methane yield (theoretical and ultimate) between dairy cattle of different farms was very high due to variation in the management practices. Methane yield from cows fed only on roughages had lower yields than those fed with the combination of roughage and concentrates because of the increased amount of volatile solids (VS) with slow degradability in the former.

Neves *et al.* (2009) opined lipids were more potent with higher biogas yields because of more C and H atoms in their molecular structure. But, high lipid content posed problems of retarded microbial growth and sludge flotation. Hence, frequent

sludge removal should be carried when high lipid content substrates were employed for anaerobic digestion.

Costa *et al.* (2012) reported that biogas production from cattle manure varied with the feeding pattern. He observed lesser quantity of gas production because of the higher amount of structural carbohydrates (cell wall components) produced after the consumption of bulky feed by the cattle. An inversion in the forage to concentrate ratio in the intensive system of rearing had stimulated the potential of biogas production.

Esposito *et al.* (2012) had reported a variation in gas yield with the composition of carbohydrates, proteins and lipids in the substrate. Lipids required a longer hydraulic retention due to their slow biodegradability but had highest biogas yielding potential. Biogas yield was less from carbohydrates and proteins in spite of their rapid anaerobic degradation. But, Kallistova *et al.* (2014) reported an increase in the methane content during the AD of protein rich substrates when compared to that of other substrates.

2.2.1.1.1 Carbon –Nitrogen (C/N) ratio

Carbon-Nitrogen ratio elucidated the relationship between C and N present in the substrate and it was an important parameter affecting the AD. Lower C/N ratio would result in inhibition due to ammonia production and a high C/N ratio would result in deficiency of N (Mata-Alvarez *et al.*, 2000).

Singh and Mandal (2011) reported that increase in C/N ratio to more than 25 would result in increased NH₃ concentration which inhibited the bacterial growth. Raheman and Mondal (2012) reported that an excess carbon had resulted in rapid utilization of nitrogen and decreased lyses of organic matter. He also observed that excess nitrogen would cause accumulation of NH₃ which was toxic for bacterial growth. C/N ratio should be between 16:1 to 25:1 and an increase or decrease would

finally affect the biogas production (Rajendran *et al.*, 2012). But, Wang *et al.* (2012) reported a C/N ratio of 20:1 to 30:1 for an optimum and effective operation of an anaerobic digester.

Dioha *et al.* (2013) reported that an increase in the C content of the substrate had resulted in increased CO₂ production and simultaneous decrease in the pH of digester. Similarly, an increase in N content had enhanced production of NH₃ with an increased pH of the digester.

Divya *et al.* (2015) reported the C/N ratio of various animal manures. Her findings were as follows *viz.*, Cattle (16-25), Poultry (5-15), Pig (6-14), Sheep (30-33).

Carbon helped in the formation of cytoplasm and acted as an energy source for bacterial metabolism. Nitrogen content of substrate helped in building the cell structure of micro-organisms. Nitrogen would be converted to NH₃ and neutralized the pH altered due to VFA production. Four different substrates of de-oiled karanja cake and cow dung in different proportions mainly S1 (75:25), S2 (50:50), S3 (25:75) and S4 (0:100) were considered for the study. Observed biogas yield (C/N ratio in parenthesis) was in the order of S3 (24.74:1) > S2 (21.62:1) > S4 (21.76:1) > S1 (19.74:1) (Barik and Murugan, 2015).

2.2.1.1.2 Total solids (TS)

Iyagba *et al.* (2009) observed that anaerobic digester with lower TS had greater significance and loading rate of seven to nine per cent TS had increased the biogas yield. Budiyo *et al.* (2010) found better performance of the digester with TS content of 7.4 per cent (184.09 mL gVS⁻¹) and 9.2 per cent (186.28 mL gVS⁻¹). While the other TS content of 2.6, 4.6, 6.2, 12.3 and 18.4 per cent gave the biogas yield of 115.78, 122.33, 172.34, 137.99 and 54.87 mL gVS⁻¹ respectively.

Rajendran *et al.* (2012) reported TS content of seven to ten per cent should be maintained and the substrate should undergo slow degradation to avoid a sudden drop in pH. Raheman and Mondal (2012) reported that TS content of substrate should be maintained between 15 and 20 per cent for enhanced biogas yields.

Divya *et al.*, (2015) opined that the process of AD would be affected if the loading rate was more. She had classified the loading rate into three categories *i.e.*, high (22 - 40 per cent), medium (15 - 20 per cent) and lower solids (< 10 per cent).

Fresh dung should be diluted with water in 1:1 ratio of for an optimum AD and the dilution could be increased to 1:2 depending on the moisture content of the manure. Over dilution would cause settling down of substrate and under dilution would cause an obstruction to the flow of slurry (Tucho *et al.*, 2016).

2.2.1.1.3 Volatile solids (VS)

Ghani and Idris (2009) opined that the biogas yield and methane production was always dependent on the volatile solid content of the substrate used for AD. He had reviewed that organic loading rate for a standard anaerobic digester should be between 0.5-1.6 kg/m³/day and a digester with high loading rate should have OLR of 1.6-4.8 kg/ m³/day.

Andrade *et al.* (2016) reported the VS content of different livestock manures (DM basis). The findings were as follows, dairy cows (79.46 per cent), sheep (76.49 per cent), swine (60.66 per cent) and poultry (59.31 per cent).

2.2.2 Anaerobic digesters

Anaerobic digesters were small man-made ecosystems enclosed in a chamber in which the parameters of anaerobic fermentation are optimized to yield a steady and predictable supply of usable gas. A simple apparatus or plant was enough to produce biogas (Mital, 1996).

According to Singh *et al.* (1997), the main types of anaerobic digesters were floating drum type, fixed dome (Chinese or hydraulic) type, Plug flow digesters and flexi type. The fixed dome type digesters were usually built underground. Floating drum type biogas plants mainly consisted of two parts, digester and a floating drum to collect the gas.

Babatola (2008) observed smaller space inside the digester was highly advantageous as the anaerobic conditions could be easily maintained in smaller digesters. Duration of one month was required for an anaerobic digester to achieve a stabilized rate of biogas production (Suryawanshi *et al.*, 2013).

2.2.2.1 Floating drum type

Nagamani and Ramasamy (1999) reported that floating dome biogas plant were more efficient than fixed dome plant, with a 11.3 per cent increase in the biogas yield.

Rajendran *et al.* (2012) stated that floating drum model of India was more successful and the performance was superior till date. Gas flow was maintained at uniform rate due to the pressure exerted by inverted drum and the weight placed above. Hence, the floating drum had gained more popularity for the utilization in farming sector. He had concluded that house hold digesters were more expedient for the farming community and rural folk to decrease the dependency on fossil fuels and had advantage of reduced problems of waste disposal with increased returns of the farm.

Divya *et al.* (2014) reported that floating drum biogas plants had more gas production when compared to traditional fixed dome biogas plants.

2.2.3 Temperature

2.2.3.1 Environmental temperature

Khoiyangbam *et al.* (2004) reported a decreased methane yield in winter when compared to summer season in northern India. The extent of negative effect on the system was directly proportional to the magnitude of the temperature (El-Mashad *et al.*, 2004). Dramatic changes in the environmental temperature would have a great negative impact on the microbial digestion process inside the digesters and it took very long periods for the re-establishment and stabilization of the microbial activity inside the digester (Bouskova *et al.*, 2005).

Sommer *et al.* (2007) reported that mineralization of N and emission of C from animal manure pits were in positive correlation with environmental temperature.

Alvarez and Liden (2008) have reviewed that the chemical oxygen demand (COD) and biogas yield would decrease if there was a decrease in the environmental temperature. He also opined that decrease in the efficiency of the digester owed to the escalation in volatile fatty acids (VFA's) concentration with a consequential drop in pH. He had reported a respective decrease of 30 per cent and 50 per cent in the total biogas yield due to a decrease in the environmental temperature from 35 °C to 25 °C and 25 °C to 18 °C.

During summer, in University Livestock Farm (ULF), Mannuthy, temperature ranged from 24.2 °C to 34.12 °C and the relative humidity ranged from 52 to 83 per cent (Nishant, 2009).

Joseph (2011) classified the seasons in Mannuthy into summer (February – May), Monsoon (June – September) and post monsoon (October – January). The author had reported that ambient temperature (°C) during April, May, June, July and August months was 32.97, 31.52, 27.95, 26.74 and 28.04 respectively.

Anzar (2014) had reported a positive correlation between the ambient temperature and biogas yield, but a negative correlation was observed between the atmospheric R.H and biogas yield.

Pham *et al.* (2014) observed a significant difference in gas production between summer and winter with higher yield in the former. He reviewed that air-temperature had primarily influenced the temperature inside the digester and it also had an indirect influence on the temperature of substrate.

The average daily ambient temperature in ULF, Mannuthy ranged from 25.4 °C to 27.8 °C during monsoon and 25.2 °C to 31.9 °C during summer. The R.H. in ULF, Mannuthy ranged from 90 to 98 per cent during monsoon and 37 to 72 per cent during summer. High rainfall in monsoon was the major reason for decreased atmospheric temperature. A positive correlation was observed between the ambient temperature and biogas yield (Shejir, 2014).

Malini and Narayanan (2015) observed a qualitative and quantitative decrease in the biogas yield during the monsoon season under the agro-climatic conditions of Kerala. Yin *et al.* (2016) had reported that R.H had no effect on the biogas yield and composition.

2.2.3.2 Temperature of the digester

Methanogens could not tolerate abrupt thermal changes. Thus, radical changes of temperature had to be avoided inside the digester for an optimal biogas production throughout the experiment (Garba, 1996). Decrease in the slurry temperature during the winter season was observed due to a greater decrease in the ambient temperature. A significant shift from mesophilic to psychrophilic conditions was noticed inside the digester along with the air temperature (Khoiyangbam *et al.*, 2004).

According to Sreekrishnan *et al.* (2004) temperature had a major impact on AD. Anaerobic fermentation could be carried at different temperature ranges *viz.*,

psychrophilic ($< 30\text{ }^{\circ}\text{C}$), mesophilic ($30 - 40\text{ }^{\circ}\text{C}$) and thermophilic ($50 - 60\text{ }^{\circ}\text{C}$). Among the three, mesophilic and thermophilic were supposed to have enhanced gas yield due to the higher activity of methanogens when compared to psychrophilic conditions.

A linear correlation existed between the temperature and the biogas yield when the range of temperature was between $25 - 44\text{ }^{\circ}\text{C}$ (Ghani and Idris 2009). Solubilisation rates of 70 per cent and 62 per cent were found at $35\text{ }^{\circ}\text{C}$ and $25\text{ }^{\circ}\text{C}$ respectively when compared to psychrophilic conditions. Microorganism's activity under mesophilic conditions was high and solubilisation rates were also higher. A temperature of $15\text{ }^{\circ}\text{C}$ is highly disadvantageous for AD (Komemoto *et al.*, 2009).

Perrigault, (2012) reported that the temperature inside the anaerobic digester had followed a similar trend of ambient temperature. He opined an increase of $2.1\text{ }^{\circ}\text{C}$ due to the insulation provided. Olowoyeyey (2013) reported that temperature was one of the major factors affecting AD and he concluded that HRT decreased with increase in temperature and vice versa.

Substrate temperature had a positive relation with the digestate temperature. Hence it was advised to add the substrate during the hottest part of the day (Pham *et al.*, 2014). The mean temperature of the substrates was higher in summer season and lower in monsoon. Seasonal variation of substrate temperature was due to the influence of atmospheric temperature (Anzar, 2014).

Activity of methanogens was best at temperature range of $20 - 45\text{ }^{\circ}\text{C}$. Maximum biogas yield was obtained when the temperature is between $31 - 35\text{ }^{\circ}\text{C}$. Increased yield could be correlated to higher activity of methane forming bacteria in that temperature range (Seppala *et al.*, 2013).

Wante *et al.* (2016) observed that the biogas yield from the experiment carried out at psychrophilic conditions was much lower than that in mesophilic conditions.

Hence he opined that the digesters should be designed along with heated water jacket for a better yield during the seasons with lower temperatures.

2.2.4 pH

Liu *et al.* (2009) observed a cessation in the biogas yield on 10th day due to decrease in the pH inside the digester. He opined that the drop in pH was due to the higher rate of hydrolysis when compared to other stages and accordingly rapid accumulation of VFA was observed.

Tippayawong & Thanompongchart (2010) reported that at alkaline pH, CO₂ would be absorbed due to the transference from gaseous phase to gas/liquid interface and then into bulk of the digester. While, Singh and Mandal (2011) reported that increased NH₃ concentration caused a change in pH towards alkalinity. Growth of bacteria would be deteriorated with an ultimate decrease in the utilization of VFA and decreased methane yield.

Zhou *et al.* (2011) reported that loading of more fresh dung caused rapid accumulation of acids and drop in pH. It was due to the high concentration of acidogens producing VFA which could not be consumed by methanogens at the same rate of production. Babae *et al.* (2013) found that pH of the effluent from continuous anaerobic digester remained stable when the pH was 7.75 – 8.0 with a loading rate of 1.4 kg VS/m³/d. Li *et al.* (2014) opined that decrease in the pH to lower than 6.5 would cease the anaerobic digestion and thus a sudden drop in yield would be noticed.

Naik *et al.* (2014) reported that the substrate being loaded into the digester should be alkaline and it should not be easily hydrolyzed to avoid a sudden drop in pH because it results in cessation of gas production.

Arreola-vargas *et al.* (2015) reported that higher biogas yield was obtained from the digesters maintained at pH 7 when compared to digesters at pH 8. He also

observed increased methane content of biogas from the digester at pH 8 because of increased solubilisation of CO₂ at liquid phase.

Barik and Murugan (2015) reported that no adverse effects on AD were noticed when the substrates having pH of 6.3 - 7.0 were utilized for the study. He had also observed that pH during initial days of AD was around 5.2 to 5.5 due to higher activity of hydrolytic and acetogenic bacteria. Hence, Suryawanshi *et al.* (2013) opined that alkalis should be added to the digester to maintain the pH of the digester within an array of 6.8 – 7.2. Careful monitoring and control of pH should be done for an enhanced production.

2.2.5 Hydraulic Retention Time (HRT)

According to Tomar (1995), HRT was the time taken by the substrates for maximum gas production *i.e.*, 70 - 80 per cent of the substrate completed their digestion at hydraulic retention time. Hydraulic retention time of about 30 d and up to 55 d was under practice in India for warm climates and colder hilly regions respectively (Singh *et al.*, 1997). Ekama and Wentzel (2008) defined HRT with the following equation,

$$\text{HRT} = V/Q$$

Where, V is volume of digester and Q is the loading rate.

Adelekan and Bamgboye (2009) reviewed that at a given organic loading rate, HRT was lower for substrates which had higher water content than those with lower water content. Ghani and Idris (2009) opined that the retention time had little effect on the biogas yield when the operating temperature (°C) was between 25 and 44.

Komemoto *et al.* (2009) reported a decline in the biogas yield and methane content as the retention time reaches 18 d. He opined that CH₄ content increased at earlier phase because hydrogen was produced just after acidification of organic

materials. Hence, methane content tends to decrease without addition of new substrate.

Weiland (2010) stated that there was a negative correlation between HRT and operating temperature. A well-functioning thermophilic biodigester could have a lower HRT than a mesophilic one.

Digesters operated at mesophilic range required a retention time of 10-40 d. Loading of substrate with high solids had a retention time of 14 d. Shorter HRT will produce more biogas but degradation of the substrate was less when compared to longer HRT (Kangle *et al.*, 2012). Zupanic and Grilc (2012) reported that the time required for growth of acidogenic, acetogenic and methanogenic bacteria was 24-36 hours, 80 - 90 hours and 5 - 16 d respectively.

During initial stage of anaerobic digestion the biogas production was fluctuating and became constant after achieving hydraulic retention time (HRT). HRT was found to be 30 d in monsoon and 25 d in summer. After attaining HRT the composition remained stable with higher methane (58 - 68 per cent) and lower carbon dioxide (25 - 40 per cent) concentration (Shejir, 2014).

Mao *et al.* (2015) reviewed that “HRT was the time required to complete degradation of organic matter.” It had depended on the activity of microorganisms and varied with temperature. He also opined that lower loading rate with longer retention time would yield better results.

2.2.6 Organic loading rate (OLR)

Kiely *et al.*, (1997) reported an imbalance in the process of AD when the OLR was higher due to the production of VFA's at inhibitory concentrations.

Poliafico (2007) reported that OLR was an indicator of biological conversion efficiency of the digester. He reported that OLR of 0.5 - 3 kg VS/m³/d was optimum for a digester operating at mesophilic conditions.

Dueblein and Steinhauser (2008) reported that washing out of the system would occur if OLR was too high and microbial population would be lost with undigested substrate coming out at the slurry outlet.

Rincoin *et al.* (2009) observed a consistency in the performance of anaerobic digester when the loading rate was maintained uniform or near uniform. Whereas, Kangle *et al.* (2012) observed that feeding of the anaerobic digester above its capacity had increased the concentration of inhibitory substances like the fatty acids. He opined that OLR was an important parameter and the failure of many existing systems was due to overloading.

Naik *et al.* (2014) opined that an optimum OLR was required for maximizing the biogas production. He found that the peak performance of the digester could not be attained if the digester was underfed and Tucho *et al.* (2016) opined that OLR of two kg VS/m³/d with a TS content of 6 per cent to 10 per cent was recommended for a digester operating without a mixer.

2.2.7 Factors Limiting AD

Mahanta (2005) reported that the concentration of NH₃ inside the digester at 50 - 200 mg/L was stimulatory in nature but concentration above 1500 mg/L was inhibitory in nature. Accordingly, Atandi and Rahman (2012) found that the inhibition of AD due to the increased concentration of NH₃ was aggravated at elevated temperature. Sebola *et al.* (2015) reported that H₂S at concentration of 327.7 ppm had adversely affected biogas production, composition and the downstream process of AD.

Schnurer *et al.* (2008) reported the formation of ammonium ions during the AD of proteins. The formed ammonium ions were strongly inhibitory in nature and the stability of the digester was disturbed leading to failure. Hagos *et al.* (2016) had suggested that toxic effects could be minimized if a proper adjustment was made in the C/N ratio to an optimum.

2.3 BIOGAS PRODUCTION

Lalitha *et al.* (1994) studied the dynamics of biogas production and observed a constant variation in the daily biogas yields. The discrepancy in daily biogas production could be attributed to the metamorphic growth process undergone by the methanogens after intense utilization of methane predecessors produced by the initial activities.

Hansen *et al.* (1998) opined that inhibition by volatile fatty acids (VFA) and NH_3 produced had caused lesser ultimate methane yield than the theoretical methane yield. Moller *et al.* (2004) testified that ultimate yield was always lesser due to the utilization of some part of substrate for the synthesis of bacterial biomass, loss in the organic matter through the effluent and limited biodegradability of lignin compounds present in the substrate.

Agrahari and Tiwari (2011) in their studies using portable floating drum biogas plants found that gas production had begun from the third day of substrate loading. Rao *et al.* (2011) reviewed that poultry litter generated more biogas than pig manure and cow dung, when used as substrate for anaerobic digestion.

According to Paudel (2012) and Rajendran (2012) the amount of biogas produced in portable floating drum plant could be calculated by measuring the increase in height of the gas holder at 24 hour interval. Position of the drum was a clear indication about the quantity of gas inside the holder.

2.4. BIOGAS PRODUCTION POTENTIAL OF ANIMAL MANURES

Nagamani and Ramaswami (1999) reported that manure from different species of livestock could be used as substrates for anaerobic digestion. While, Eggleston *et al.* (2006) opined that if animal manure was not employed for biogas generation, GHG would be released from the land application and caused a greater environmental impact.

According to Yasin and Wasim (2011), animal wastes and crop residues were excellent substrates for anaerobic digestion. These substrates can serve dual purpose by producing energy and providing valuable manure with increased nitrogen. Similarly, Dhanalakshmi and Ramanujam (2012) reported that biodegradable wastes like animal manures had essential nutrients in sufficient amount for the survival of methanogens.

Manure, unavoidable byproduct would become a valuable source of nutrients if properly managed. Improper management of manure resulted in environmental pollution and conflicts with neighbors due to nuisances created by the abnormal odor and increased vector prevalence. Hence, manure management in a proper sense should be followed by considering various aspects like when and how manure was produced and how was it stored and used ultimately (Yangin-Gomec and Ozturk, 2013).

Average total P in dairy, swine manure and broiler litter was 7.1 g P kg^{-1} , 31.9 g P kg^{-1} and 13.5 g P kg^{-1} respectively (Li *et al.*, 2014).

2.4.1 Cattle manure

Biogas yield from the anaerobic digestion of unscreened manure and screened had no significant difference in the digesters with longer HRT for the similar amount of volatile solids (VS) loaded into digesters. But, a major significant difference was noticed in the digesters with a shorter HRT (Lo and Liao, 1986).

Manure from ruminants, especially cattle was having great potential for beginning the fermentation phase during the AD because of the presence of the methanogenic microorganisms. But, monodigestion of the cattle dung would result in decreased biogas yield and lower methane content due to the moderate level of biodegradability *i.e.*, 40 - 50 per cent (Rico *et al.*, 2007).

Cuili *et al.* (2008) reported that cattle manure produced biogas of 0.398 L/gm of manure with a HRT of 74 d and Monteiro *et al.* (2011) opined that biogas production from cattle manure helped in fulfilling two major objectives of the present day world *i.e.*, it reduced the expenditure of energy on waste treatment and mitigated the release of CH₄ into the atmosphere which arised from disposal or burning of manure.

Abdulsalam *et al.* (2012) reported that C/N ratio of cattle dung was around 18.5:1. Hence, it was a limiting factor to utilize cattle dung as an only substrate in AD and the ultimate biogas yield was less. Olowoyeye, (2013) found that 50 grams of fresh cattle dung made up to one liter with water had an average total biogas yield of 1388 ml with a weekly average of 0.174 L and peak yield was attained at fifth week.

The N, P and K of cattle dung were analyzed and the values were 2.12, 1.45 and 0.85 per cent respectively. Similarly N, P and K values of slurry obtained from AD of cattle manure were 2.37, 1.14 and 0.82 per cent respectively (Shejir, 2014).

2.4.2 Goat manure

Olowoyeye (2013) found that 50 grams of Goat dung made upto one liter with water had an average total biogas yield of 3615.6 ml with a weekly average of 0.452 L and peak yield was attained at third week.

Goat manure was quantitavely and qualitatively superior in biogas production when compared to the cattle and buffalo manure. The N, P and K values of goat dung were 2.87, 1.88 and 1.16 per cent respectively. Similarly N, P and K values of slurry

obtained from AD of goat manure were 3.24, 1.43 and 1.12 per cent respectively (Shejir, 2014).

2.4.3 Sheep manure

Shan (1991) reported that during AD of sheep manure, scum formation in layers was noticed and the manure was floating as dry balls. He opined that subsequent planning with optimized operation protocol needed to be established.

Song *et al.* (2010) had reported that the sheep manure produced biogas of 0.273 m³ /kg TS and 0.206 m³ /kg TS at a constant temperature of 35 °C and 25 °C respectively. Whereas, Olowoyeye (2013) reported that 50 grams of fresh sheep dung made up to one liter with water had an average total biogas yield of 9188 ml with a weekly average of 1.149 L and peak yield was attained at third week.

2.4.4 Swine manure

Hansen *et al.* (1998) reported that high strength organic wastes such as pig slurry could be treated using biogas plants to produce renewable energy as well as digested residue which could be used as fertilizer and soil conditioner. Correspondingly, An and Preston (1999) stated that pig manure was a feasible substrate for AD. Their study using plug-flow bio digesters revealed that the efficiency of gas production was highest with a loading rate of two kg dry matter (DM) per m³.

Moller *et al.* (2004) studied the efficiency of swine and dairy cattle manure in anaerobic batch digesters. He observed that the plateau phase in AD was attained much earlier with swine manure and reported higher theoretical CH₄ yield in pig manure (516 ± 111 kg⁻¹ VS) than in dairy cattle manure (468 ± 61 kg⁻¹ VS) because of higher proportion of lipids and protein in pig manure. He had concluded that swine manure required less HRT when compared to the cattle manure.

Porras and Gebresenbet (2003) reported that the amount of biogas produced from one kilogram of pig manure was 0.040 – 0.059 m³ and Babatola (2008) studied the potential of pig manure as a suitable substrate for biogas production and found that the gas yield from it was higher than cow dung, under similar experimental conditions. Similarly, Cuili *et al.* (2008) reported that pig manure produced biogas of 0.495 L/gm of manure with a HRT of 81 d.

According to Ferreira *et al.* (2012), pig slurry was more suitable for biogas production due to higher buffering ability and diverse nutrients present in it which were necessary for the optimum growth of methanogens.

The N, P and K of swine excreta were analyzed and the values were 2.10, 1.20 and 0.86 per cent respectively. Similarly N, P and K values of slurry obtained from AD of swine manure were 2.16, 0.93 and 0.83 per cent respectively (Anzar, 2014).

2.4.5 Poultry manure

Kelleher *et al.* (2002) reported that poultry litter and manure had a high nutritional value and it was a suitable substrate for biogas production. Co-digestion of poultry waste with other manures was also beneficial. While, Porras and Gebresenbet (2003) reported that the amount of biogas produced from one kg each of poultry manure was 0.065 – 0.116 m³.

Hassan (2004) studied the relationship between different animal manure for biogas production and found that poultry manure had more biogas productivity than sheep manure and cow dung. Whereas, Babatola (2008) analyzed the suitability of different substrates for anaerobic digestion and opined that poultry waste could be used effectively for biogas production. Cuili *et al.* (2008) reported that chicken manure produced biogas of 0.324 L/gm of manure with a HRT of 73 d.

Ahn *et al.* (2010) opined that poultry manure had high potential as biomass for anaerobic digestion if appropriate digester designs were developed to prevent significant volatile fatty acid accumulation and pH drop.

Song *et al.* (2010) reported that the duck manure produced biogas of $0.441\text{m}^3/\text{kg TS}$ and $0.359\text{ m}^3/\text{kg TS}$ at a constant temperature of $35\text{ }^\circ\text{C}$ and $25\text{ }^\circ\text{C}$ respectively. According to Rao *et al.* (2011), poultry litter with biodegradable organic and inorganic matter was a very good material for biomethanation, without any pretreatment.

Costa *et al.* (2012) studied the biochemical methane potential of raw poultry manure and opined that anaerobic digestion of poultry manure was an effective method for waste management, which also produced high volumes of biogas with significant methane concentration. Similarly, Olowoyeye (2013) reported that 50 grams of fresh chicken manure made upto one litre with water had an average total yield of 8240.2 ml and a weekly average of 1.03 L. Peak yield was attained in first week and alternate rise and fall was noticed in subsequent weeks.

Poultry manure was quantitatively and qualitatively superior in biogas production when compared to the swine manure. The N, P and K values of poultry manure were 2.85, 1.62 and 1.23 per cent respectively. Similarly N, P and K values of slurry obtained from AD of poultry manure were 2.76, 1.34 and 1.13 per cent respectively (Anzar, 2014).

2.4.6 Rabbit manure

Mahadevaswamy and Venkataraman (1988) evaluated an integrated system with production of biogas from rabbit manure and the utilization of effluent for carp production. He had observed a gas production of $0.24\text{ m}^3/\text{kg TS}$ and 8.9 kg of carp for 100 m^3 area of pond. While, Babatola (2008) reported that the rabbit droppings had higher biogas yield when compared to poultry and cow dung. Hence mixing of

wastes would be highly advantageous for achieving maximum yield.

Song *et al.* (2010) had reported that the rabbit manure produced biogas of $0.210 \text{ m}^3 / \text{kg TS}$ and $0.174 \text{ m}^3 / \text{kg TS}$ at a constant temperature of $35 \text{ }^\circ\text{C}$ and $25 \text{ }^\circ\text{C}$ respectively.

2.4.7 Horse manure

Fifty grams of fresh horse dung made up to one liter with water had an average total biogas yield of 253.5 ml with a weekly average of 0.032 L and gas production was nil after five weeks (Olowoyeye, 2013).

2.4.8 Elephant dung

Wijeyamohan (2003) had reported that elephant is a non-ruminant and its dung contained more fibers. Accordingly the biogas yield was higher when compared to cattle.

Abdulsalam *et al.* (2012) reported that the elephant dung produced more biogas (238.20 cm^3) when compared to cow dung (207.20 cm^3). He had also reported that C/N ratio of elephant dung was around 26:1 and it has favored towards more gas yield.

2.5 ANAEROBIC CO-DIGESTION (AcoD) OF SUBSTRATES

Macias-Corral *et al.* (2008) reported that digesters operating with two substrates always had a better performance than single substrate, with a higher methane yield of around 70 per cent and weight/volume reduction was comparatively higher. Co-digestion would avoid extreme acidification and maintained stable pH value. Hence, it was easier to preserve the pH of the digester in the anaerobic co-digestion of wastes (Monou *et al.*, 2008).

Li *et al.* (2009) suggested that dairy cattle manure was the prime co-substrate for AcoD due to its availability and distinctive properties like moisture content and buffering capacity. Presence of essential nutrients and trace elements in dairy manure made it more suitable for AD. Kacprzak *et al.* (2010) also opined that co-digestion of different organic wastes available in the same geographical area would enable an efficient integrated management with greater environmental benefits and decreased emission of CO₂.

Atandi and Rahman (2012) reported co-digestion had resulted in increased N content of the substrate and the chances of inhibition were more when compared to single substrate digestion. But, Wang *et al.* (2012) opined that co-digestion would facilitate the nutritional adjustment and avoided the sudden drop in pH by inhibiting the formation of ammonia.

Ye *et al.* (2013) reported that co-digestion was more economical for AD of agricultural byproducts than the pre-treatment methods because in AcoD there was a volumetric increase in the biogas yield.

2.5.1 Anaerobic co-digestion of manures

Kelleher *et al.* (2002) reviewed the anaerobic digestion of poultry manure and opined that the poultry litter had a greater variation in the pH during the AD which could be overcome by co-digestion with other manure. He also reported that there would be a considerable increase in the endogenous- ammonical nitrogen, while some of the ammonium ions were utilized by the bacteria and the excess caused destruction of the organic compounds produced during the anaerobic digestion.

Muyiyya and Kasisira (2009) carried an experiment to evaluate the anaerobic co-digestion of cow dung and swine manure. The gas production began in between seventh to eleventh day of the experiment from the majority of the digesters and the maximum biogas yield was observed in the treatment with 1:1 ratio of cow dung and

swine manure. The author also stated that the nutrient balance provided by the mixture of manures had a synergistic effect on the activity of the methanogens.

Nnabuchi *et al.* (2012) carried out the co-digestion of mixture of cattle and poultry manure in various proportions. The cumulative biogas yield was maximum at the proportion of 1:4. He observed that the yield was high from the mixture of manure than the gas yield of poultry or cattle manure alone. He had also reported that the mixture with 1:1 ratio of cattle and poultry manure had least biogas yield due to the imbalance of nutrients at this proportion of two manures.

Abdulsalam *et al.* (2012) reported that co-digestion of elephant dung with cow dung has yielded more biogas when compared to mono-digestion of manures because the C/N ratio was adjusted to 30:1 favoring more metabolic activity of bacteria.

Zhang *et al.* (2013) carried out anaerobic co-digestion of goat manure with crop residues and found that the initial gas yield was more in the digester with goat manure alone, but the cumulative yield is 22.5 per cent to 65 per cent more in the digesters with goat manure and crop residues. He also observed a significant delay in the attainment of peak yield during co-digestion when compared with mono-substrate digestion of goat manure.

Rico *et al.* (2015) reported that animal manure caused greater stability of AD due to its high moisture content and a great buffering capacity. Hence, animal manure had been opted as a substrate for the co-digestion of many complex organic substrates like the agriculture residues.

Ogunwande *et al.* (2015) studied the co-digestion of cow dung with chicken and swine manure in different proportions and reported an increase in the biogas yield from cow dung alone when compared to the mixture of manures. The author opined that the differing results when compared to earlier studies might be due to the

variation in the composition of the feed and ready availability of the total carbon in the cow dung.

Sebola *et al.* (2015) conducted co-digestion of cattle, swine and poultry manure with sewage sludge. He found that the treatments with higher proportion of cattle dung had lower methane yield than other treatments with equal proportion of all manures. The observed average methane yield was 58, 62, 58 and 52 per cent at a temperature ($^{\circ}\text{C}$) of 35, 40, 50 and 55 respectively.

Wante *et al.* (2016) studied the co-digestion of cattle and goat manure in different proportions *viz.*, D1 (0:100), D2 (75:25) and D3 (25:75). He reported that maximum yield was obtained in D3 with optimum pH in the digester throughout the experiment. He concluded that the anaerobic digestion of goat and cow dung alone was not a viable alternative for the waste treatment.

2.6 MANURIAL VALUE OF SLURRY

Qi *et al.* (2005) utilized slurry as a substitute to chemical fertilizer in an integrated farming system and found an increase in the yield of cucumber and tomato by 18.4 per cent and 17.8 per cent respectively.

Topper *et al.* (2006) reported that the ammonium level in the slurry would be slightly higher than the raw manure. He also pointed out that the total nitrogen content was two folds higher than that of the stored manure as the loss due to the volatilisation was completely minimized. He had also reported that there would be no variation in the levels of P and K because the bacteria cannot utilize them. In some instances the difference in the levels was noticed due to the settlement of solids at the bottom.

A very negligible amount of N would be lost as NH_3 and the majority would be present as organic N and NH_4 in the digestate. The ammonium produced after the microbial digestion would be trapped due to the pressure of the digester. Thus, the N

content of the sludge was more than the raw manure. Anaerobic digestion had a minute effect on the P availability, the P content in the manure would not at all alter even after the microbial digestion (USDA – NRCS, 2007).

Sommer *et al.* (2007) reported that mineralization of N from the animal slurry pits was in positive relation with environmental temperature. Extent of mineralization had increased along with the increase in environmental temperature, especially in the mesophilic range.

Garfi *et al.* (2011) reported an increase in the yield of potato by 27.5 per cent and forage by 1.5 per cent in comparison with no fertilizer applied in the field. While, Raheman and Mondal (2012) observed a 5.9 per cent increase in the N level in the slurry when compared to that of substrate due to the mineralization of organic nitrogen. He also reported no change in the composition of P and K in the slurry when compared to that of substrate.

Anzar (2014) reported that the DM content was highest in swine slurry (9.33 ± 0.11), followed by rabbit and poultry slurries (6.02 ± 0.059). He had also reported a decreased P content in the slurry when compared to that of manure. He observed no significant change in the N content of the slurry when swine and poultry manure were used for biogas production.

There was an increase in the quantity of slurry in monsoon when compared to the summer season and higher DM content of the slurry resulting from AD of goat manure was noticed. A significant increase was observed in N and P content of sludge from digesters when cattle, buffalo and goat excreta were used but there was no significant difference in K content of the substrate and sludge (Shejir, 2014).

Tucho *et al.* (2016) reported a loss of 20 per cent carbon and 20 per cent decrease in the volume of water. He also observed a greater decrease in the quantity of slurry during AcoD when compared to single substrate digestion.

2.7 CARBON SEQUESTRATION THROUGH AD

Pathak *et al.* (2009) opined that promotion of Biogas technology (BT) and integrating the carbon revenues would yield more profits to the farming sector. He reported that existing biogas plants in India had global warming mitigation potential (GMP) of 9.7 t CO₂ equiv. year⁻¹ and could earn US \$ 97 per year. He also reported that if all the cow dung produced in our country could be collected and used, US \$ of 4,968 million could be earned from carbon credits.

Sharma and Agarwal (2011) reported that a Goushala with 250 cows yielding 750 kg of dried cow dung daily had a GMP of 594 t CO₂ equivalent per year. Hence, US \$ 5940 per year can be earned from carbon credits at the existing price of US \$ 10 t⁻¹ CO₂ equiv.

2.8 ECONOMICS OF ANAEROBIC DIGESTION

Gebrezgabher *et al.* (2010) reviewed the economic situation of the biogas plant and has reported that the returns were good with a profit showing a positive NPV (Net Present Value) of € 4 million and an IRR (Internal rate of returns) of 21 per cent.

Cavinato *et al.* (2010) reported that the co-digestion of substrates had favorable economic indicators when biogas was used to generate electricity for a period of three to five years. Quotient of energy input to output was better in co-digestion when compared to the AD of single substrate digestion (Poschl, 2010).

3. MATERIALS AND METHODS

The research project entitled “Enhancing biogas production by co-digestion of livestock manures” was conducted to estimate the biogas production by anaerobic co-digestion of different livestock manures. Effect of season on the quantity and quality of biogas, manurial value of the slurry were also analyzed. The resources and facilities available at College of Veterinary and Animal Sciences, Kerala Veterinary and Animal Sciences University, Mannuthy, were utilized for the study.

3.1 LOCATION OF STUDY

The study was conducted at Ecofarm, Department of Livestock Production Management, College of Veterinary and Animal Sciences, Mannuthy, Thrissur, which is situated 22.25 m above mean sea level at 10° 53’’ N Latitude and 76° 26’’ E Longitude.

3.2 PERIOD OF STUDY

The experiment was conducted in two seasons as classified by Joseph, 2011. Summer (February – May, 2016) and monsoon (June – September, 2016) were considered for the study. The observations were taken for 60 days in each season.

3.3 CLIMATOLOGICAL DATA

Micro-climatic variables were measured inside the experimental shed by a temperature and humidity data logger (HOBO pro v2, Onset) as explained by Prasad (2014). The data was logged at 10 minute interval. THI values were calculated as indicated by Mader *et al.* (2006).

3.4 DESIGN OF EXPERIMENT

3.4.1 Biogas plants

The Portable floating drum biogas plants of 0.5 m³ capacity, designed by Agro Biotechnology Agency for Rural Employment Development (ABARD), Kerala Agricultural University (KAU), Vellanikara were utilized for the study. The schematic sketch of portable floating drum biogas plant is given in plate.1.

3.4.2 Substrates

Fresh manure of farm animals namely cattle, goat, poultry and swine from the farms located in the campus were used as substrates for biogas production.

3.4.3 Treatments

The experiment was conducted in two seasons - summer (S1) and monsoon (S2). There were four treatments T1, T2, T3 and T4 in each season, mainly

Treatment 1: (Control) Two kg of fresh cattle dung was loaded in the digester

Treatment 2: (Cattle + Goat Manure) One kg each of fresh cattle and goat manure was loaded into the digester (1:1 ratio).

Treatment 3: (Cattle+ Poultry manure) One kg each of fresh Cattle and Poultry manure was loaded into the digester (1:1 ratio).

Treatment 4: (Cattle + Pig Manure) One kg each of Cattle and Pig manure was loaded into the digester (1:1 ratio).

3.4.4 Dilution

Water was added in each treatment at 1:1 ratio on whole weight basis (Nijaguna, 2012)

3.5 PHYSICO-CHEMICAL CHARACTERS OF SUBSTRATES

3.5.1 Temperature

The temperature of the substrates was recorded daily in the morning (8 a.m.) by using mercury bulb thermometer (Khoiyangbam *et al.* 2004).

3.5.2 Chemical analysis of substrates

3.5.2.1 pH

The pH of the substrates was recorded in the morning (8 a.m.) daily before loading using Eutech digital PCStestr- 35 (Radhakrishnan, 2013).

Before loading, fresh samples of the substrates from each treatment were collected and analyzed to determine TS. Moisture free samples were analyzed for volatile solids on DM basis and C on fresh basis (Chandra *et al.*, 2012).

3.5.3 Manurial value

Manurial value of the substrates was determined at every week for Nitrogen (AOAC, 2012), Phosphorus (P) and Potassium (K) contents (Davis, 2017). All the samples collected were processed and representative samples were digested using Perkin Elmer Titan MPS model microwave sample preparation system. P and K content were estimated using Inductively Coupled Plasma Optical Emission Spectrometer (ICPOES) Perkin Elmer Model Optima 8000. All the values were estimated on fresh basis.

3.6 BIOGAS PRODUCTION

The biogas production was recorded in the morning (8 a.m.) from the very next day before loading.

3.6.1 Hydraulic Retention Time (HRT)

HRT was recorded as the average time (d) required by the digester to get stabilized in terms of quantity and quality (Shejir, 2014).

3.6.2 Biogas production

The volume of gas produced in each treatment was measured daily in the morning (8 a.m.). The increase in height of gas holder was recorded and volume was calculated (Paudel, 2012) accordingly.

$$\text{Volume of the biogas, } V = \pi r^2 h$$

Where, r denotes radius of gas holder and h denotes the increase in height after gas production.

3.6.3 Composition of biogas

Composition of biogas was determined using Multi Gas Analyser (Chandra *et al.*, 2011). The gas analyzer was standardized with standard gas at the beginning of both the seasons.

3.7 SLURRY

The slurry was collected continuously by placing plastic containers under the slurry outlet. The quantity of slurry collected was recorded daily in the morning (8 a.m.) using digital platform weighing balance.

3.7.1 Physico-chemical characters of slurry

3.7.1.1 Temperature

The temperature of the slurry from each treatment was recorded once in a week in the morning (8 a.m.) using mercury bulb thermometer (Khoiyangbam *et al.*, 2004).

3.7.1.2 Chemical analysis of slurry

The pH of the slurry from each treatment was recorded once in a week in the morning (8 a.m.) using Eutech digital PCStestr 35 (Radhakrishnan, 2013).

Total solid content on fresh basis and VS content on DM basis and C on fresh basis were determined (Chandra *et al.*, 2012) once in a week, throughout the experiment period.

3.7.1.3 Manurial value

Manurial value of the slurry was determined at every week for Nitrogen (AOAC, 2012), Phosphorus (P) and Potassium (K) contents (Davis, 2017). All the samples collected were processed and representative samples were digested using Perkin Elmer Titan MPS model microwave sample preparation system. P and K content were estimated using Inductively Coupled Plasma Optical Emission Spectrometer (ICPOES) Perkin Elmer Model Optima 8000. All the values were estimated on fresh basis.

3.8 CARBON CREDIT POTENTIAL

It was assumed that 60 per cent of the generated biogas would be used for replacing firewood and the remaining 40 per cent can replace the diesel utility in farm application. The calculations were carried out as per Pathak *et al.* (2009) and Sharma and Agrawal (2011).

3.9 ECONOMICS OF BIOGAS PRODUCTION

The cost effectiveness of biogas production from different treatments was compared based on the selling price of the manures from the respective farms and the quantity of biogas obtained (Deshmukh, 2012). It was assumed that only 50 per cent of the substrate was only utilized by the digester as the gas production was recorded only till 60 days.

3.10 STATISTICAL ANALYSIS

The data obtained on various parameters during the course of study were statistically analysed using analysis of variance (ANOVA) as described by Snedecor and Cochran (1994). The correlation of various meteorological parameters with biogas production was analyzed by Pearson's correlation co-efficient method. All the statistical analysis was carried out with SPSS V 24.0.

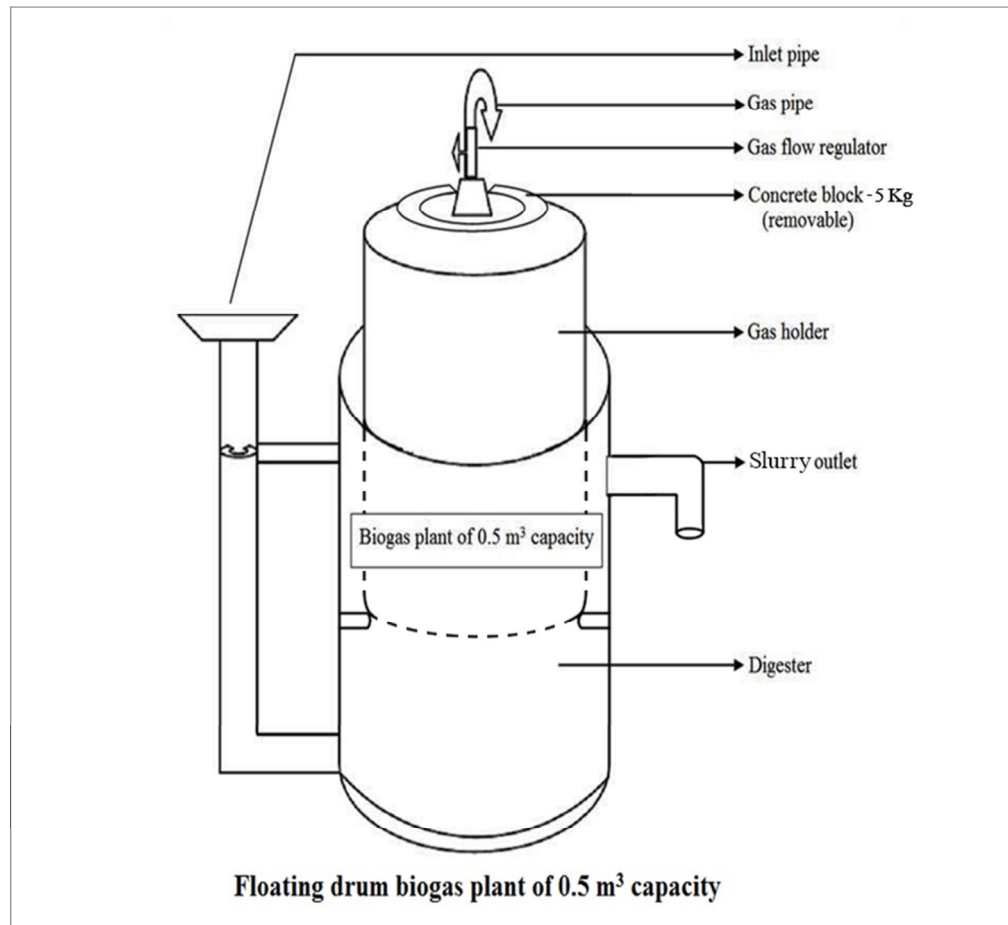


Plate 1. Schematic sketch of portable floating drum biogas plant



Plate 2A. Experimental shed



Plate 2B. HOBO Temperature humidity data logger with its base station and cable for down loading



Plate 3A. Titan MPS Microwave Sample Preparation System



Plate 3B. ICPOES OPTIMA 8000

4. RESULTS

The results obtained in the present study “Enhancing biogas production by co-digestion of livestock manures” were as follows

4.1 CLIMATOLOGICAL DATA

The microclimatic variables considered for the study were atmospheric temperature (°C) and relative humidity (%). Rainfall (mm) received during the observation period was also recorded. The daily average temperature (°C) recorded in season-I (S-I) and season-II (S-II) was 30.7 ± 0.12 and 26.67 ± 0.10 respectively. The R.H was 84.8 ± 0.78 and 93.71 ± 0.34 per cent in S-I and S-II respectively. Rainfall received in S-I and S-II was 719.21 (10 d) and 775.21 mm (40 d) respectively. THI values obtained were 84.88 ± 0.22 in S-I and 79.22 ± 0.12 in S-II.

4.2. PHYSICO-CHEMICAL CHARACTERS OF SUBSTRATES

The details of the physico-chemical characteristics of the substrates are furnished in Table 4.1.

4.2.1 Temperature

The temperature of the substrates (°C) was recorded just before loading into the anaerobic digester in each season. The temperature of substrates was not significantly different between the treatments within a season. Temperature was found to be high in S-I and low in S-II with a significant difference between the seasons. The mean values respectively (°C) for T1, T2, T3 and T4 in S-I were 29.50 ± 0.29 , 29.37 ± 0.29 , 29.25 ± 0.29 and 29.37 ± 0.29 and in S-II the values were 25.25 ± 0.29 , 25.25 ± 0.29 , 25.13 ± 0.29 and 25.38 ± 0.29 respectively for T1, T2, T3 and T4.

4.2.2 Chemical composition

4.2.2.1 pH

The pH of fresh substrate was recorded just before loading and the values for T1, T2, T3 and T4 were 7.32 ± 0.09 , 7.69 ± 0.09 , 6.94 ± 0.09 and 7.50 ± 0.09 respectively in S-I. In S-II it was 7.30 ± 0.09 , 7.40 ± 0.09 , 6.83 ± 0.09 and 7.55 ± 0.09 respectively for T1, T2, T3 and T4. In T1, T2 and T4 pH was slightly alkaline but in T3 it was slightly acidic in nature. There was no significant difference in pH between the seasons and T3 was significantly different from other treatments in both the seasons. However, no significant difference was observed between T1, T2 and T3 in S-II.

4.2.2.2 Total solid

Total solid (TS) content (per cent) of the substrate in different treatments was in the range of seven to ten. T3 was having highest TS content of 10.32 ± 0.69 and 10.14 ± 0.69 per cent in S-I and S-II respectively followed by T2 (9.78 ± 0.69 per cent in S-I and 9.42 ± 0.69 per cent in S-II), T4 (8.77 ± 0.69 per cent in S-I and 8.48 ± 0.69 per cent in S-II) and T1 (7.53 ± 0.69 in S-I and 7.84 ± 0.69 in S-II). There was significant difference between the treatments but no significant difference was noticed within the treatment between the seasons.

4.2.2.3 Volatile solid

Volatile solid (VS) content (per cent) was estimated on DMB and it was varying significantly between the treatments. T1 was having highest and T3 was having least volatile solid content. In S-I, VS content was 84.23 ± 0.34 , 81.66 ± 0.34 , 61.52 ± 0.34 and 72.84 ± 0.34 per cent in T1, T2, T3 and T4 respectively. There was no significant difference within the treatment between the seasons. In S-II VS content was 82.28 ± 0.34 , 79.98 ± 0.34 , 60.86 ± 0.34 and 73.42 ± 0.34 per cent in T1, T2, T3 and T4 respectively.

Table 4.1. Physico-Chemical properties of substrate

PARAMETER	SEASON	TREATMENT				Pooled SE
		T1	T2	T3	T4	
Temperature (°C)	S-I	29.50 ^{aA}	29.37 ^{aA}	29.25 ^{aA}	29.37 ^{aA}	0.29
	S-II	25.25 ^{aB}	25.25 ^{aB}	25.13 ^{aB}	25.38 ^{aB}	0.29
Ph	S-I	7.32 ^{bdA}	7.69 ^{aA}	6.94 ^{cA}	7.50 ^{adA}	0.09
	S-II	7.30 ^{aA}	7.40 ^{aB}	6.83 ^{bA}	7.55 ^{Aa}	0.09
Total solid (TS) %	S-I	7.53 ^{dA}	9.78 ^{bA}	10.32 ^{aA}	8.77 ^{cA}	0.69
	S-II	7.84 ^{dA}	9.42 ^{bA}	10.14 ^{aA}	8.48 ^{cA}	0.69
Volatile Solid* (VS) %	S-I	84.23 ^{aA}	81.66 ^{bA}	61.52 ^{dA}	72.84 ^{cA}	0.34
	S-II	82.28 ^{aA}	79.98 ^{bA}	60.86 ^{dA}	73.42 ^{cA}	0.34
C/N ratio	S-I	18.42 ^{cA}	27.62 ^{aA}	16.66 ^{dA}	25.48 ^{bA}	0.66
	S-II	19.10 ^{cA}	28.64 ^{aA}	17.41 ^{dA}	24.92 ^{bA}	0.66
Nitrogen %	S-I	1.68 ^{dA}	2.22 ^{cA}	3.12 ^{aA}	2.75 ^{bA}	0.02
	S-II	1.48 ^{dB}	1.91 ^{cB}	2.81 ^{aB}	2.41 ^{bB}	0.02
Phosphorous %	S-I	1.25 ^{dA}	1.47 ^{cA}	1.84 ^{bA}	2.25 ^{aA}	0.03
	S-II	1.23 ^{dA}	1.43 ^{cA}	1.82 ^{bA}	2.32 ^{aA}	0.03
Potassium %	S-I	0.96 ^{cA}	1.33 ^{aA}	1.16 ^{bA}	0.82 ^{dA}	0.02
	S-II	0.85 ^{cA}	1.28 ^{aA}	1.17 ^{bA}	0.84 ^{dA}	0.02

For each parameter, means with different superscript (a-d in rows, A-B in columns) differ significantly ($p < 0.05$), * - values on DM basis

4.2.2.4 C/N ratio

Carbon to Nitrogen ratio was highest in T2 (27.62 ± 0.66 in S-I and 28.64 ± 0.66 in S-II) and least in T3 (16.66 ± 0.66 in S-I and 17.41 in S-II). While, C/N ratio of T1 was 18.42 ± 0.66 (S-I) and 19.10 ± 0.66 (S-II). T4 was having 25.48 ± 0.66 (S-I) and 24.92 ± 0.66 (S-II). C/N ratio was significantly different in all the treatments but there was no significant difference within the treatments between the seasons. A

slight increase in the C/N values of T1, T2 and T3 was noticed from summer to monsoon but in T4 it was vice versa.

4.2.2.5 Nitrogen content

Nitrogen content was estimated on fresh basis (per cent) and T3 was found to be highest in both the seasons (3.12 ± 0.02 in S-I and 2.81 ± 0.02 in S-II) followed by T4 (2.75 ± 0.02 in S-I and 2.41 ± 0.02 in S-II), T2 (2.22 ± 0.02 in S-I and 1.91 ± 0.02 in S-II) and T1 (1.68 ± 0.02 in S-I and 1.48 ± 0.02 in S-II). Significant difference was observed between the treatments in both the seasons and it was more in summer with a significant difference between the seasons within a treatment.

4.2.2.6 Phosphorous content

Phosphorous content (per cent) of the substrate was significantly different between all the treatments and T4 was having highest. In S-I P content of T1, T2, T3 and T4 was 1.25 ± 0.03 , 1.47 ± 0.03 , 1.84 ± 0.03 and 2.25 ± 0.03 per cent respectively. In S-II P content was 1.23 ± 0.03 , 1.43 ± 0.03 , 1.82 ± 0.03 and 2.32 ± 0.03 per cent for T1, T2, T3 and T4 respectively. A significant difference was noticed between the treatments but there was no significant difference between the seasons.

4.2.2.7 Potassium content

Potassium content was highest in T2 (1.33 ± 0.02 per cent in S-I and 1.28 ± 0.02 per cent in S-II) followed by T3 (1.16 ± 0.02 per cent in S-I and 1.17 ± 0.02 per cent in S-II), T1 (0.96 ± 0.02 per cent in S-I and 0.85 ± 0.02 per cent in S-II) and T4 (0.82 ± 0.02 per cent in S-I and 0.84 ± 0.02 per cent in S-II). A significant difference was noticed between the treatments but there was no significant difference between the seasons.

4.3 BIOGAS YIELD

Biogas yield in both the seasons was furnished in table 4.2

4.3.1 Hydraulic retention time (HRT)

The observed average HRT was less during S-I (22 d) when compared to S-II (28 d). In all the treatments HRT was nearly uniform and the gas yield was stabilized after reaching HRT.

4.3.2 Trend in Biogas production

Trend in gas production was depicted in fig.1 (S-I) and fig. 2 (S-II). Gas yield was observed from third day but the combustible biogas was obtained from eighth day onwards. Initially, T1 and T2 production was more rapid and gas production ceased at around 12th day. Gas yield restarted from 16th day, reached maximum and got stabilized by around 20-24 d (S-I), 27 – 29 d (S-II) in all treatments

4.3.3 Average daily yield

In S-I, average daily yield (L) was highest in T4 (16.41 ± 0.10) followed by T2 (15.39 ± 0.86), T3 (13.73 ± 0.64) and T1 (10.24 ± 0.11). A significant difference was observed between the treatments. Similar trend was observed in the average yield even in S-II with T4 having highest yield (14.24 ± 0.10) followed by T2 (13.32 ± 0.86), T3 (11.53 ± 0.64) and T1 (9.29 ± 0.11). Significant difference was noticed between the seasons within the treatment.

4.3.3.1 Per kg TS

Average daily biogas yield (L) was calculated in terms of per kg TS loaded in each treatment. There was a significant difference between the treatments within a season. Yield was significantly different between the seasons within a treatment and highest yield was observed during summer season. It was highest in T4 in S-I (46.77

± 0.24) and S-II (41.98 ± 0.24) followed by T2 (39.34 ± 0.24 in S-I and 35.35 ± 0.24 in S-II), T1 (33.99 ± 0.24 in S-I and 29.62 ± 0.24 in S-II) and T3 (33.26 ± 0.24 in S-I and 28.42 ± 0.24 in S-II).

4.3.3.2 Per kg VS

Average daily biogas yield (L) was calculated in terms of per kg VS loaded in each treatment. Yield was highest in T4 in S-I (64.22 ± 0.86) and S-II (57.18 ± 0.86) followed by T3 (54.06 ± 0.86 in S-I and 46.71 ± 0.86 in S-II), T2 (48.17 ± 0.86 in S-I and 44.20 ± 0.86 in S-II) and T1 (40.36 ± 0.86 in S-I and 36.01 ± 0.86 in S-II).

Table 4.2. Biogas yield from different substrates

PARAMETER	SEASON	TREATMENT				Pooled SE
		T 1	T 2	T3	T 4	
Daily yield (L)	S-I	10.24 ^{dA}	15.39 ^{bA}	13.73 ^{cA}	16.41 ^{aA}	0.11
	S-II	9.29 ^{dB}	13.32 ^{bb}	11.53 ^{cb}	14.24 ^{ab}	0.11
Daily yield/kg TS (L)	S-I	33.99 ^{cA}	39.34 ^{bA}	33.26 ^{dA}	46.77 ^{aA}	0.24
	S-II	29.62 ^{cb}	35.35 ^{bb}	28.42 ^{db}	41.98 ^{ab}	0.24
Daily yield/kg VS (L)	S-I	40.36 ^{dA}	48.17 ^{cA}	54.06 ^{bA}	64.22 ^{aA}	0.86
	S-II	36.01 ^{dB}	44.20 ^{cb}	46.71 ^{bb}	57.18 ^{ab}	0.86
Cumulative yield (L)	S-I	485.22	650.57	567.65	667.74	-
	S-II	418.50	545.08	467.56	571.08	-
Cumulative yield/kg TS (L)	S-I	26.84	27.72	22.92	31.72	-
	S-II	22.24	24.11	19.21	28.06	-
Cumulative yield/kg VS (L)	S-I	31.87	33.94	37.25	43.55	-
	S-II	27.03	30.14	31.57	38.21	-

For each parameter, means with different superscript (a-d in rows, A-B in columns) differ significantly ($p < 0.05$)

4.3.4 Cumulative biogas yield

Cumulative yield (L) obtained throughout the experiment in S-I was highest in T4 with a total yield of 667.78 followed by T2 (650.57), T3 (567.65) and T1 (485.22). All the treatments were significantly different from each other. Similar trend was observed even in S-II, with a total yield of 418.50 in T1, 545.08 in T2, 467.56 in T3 and 571.08 in T4. Cumulative yield differed significantly between the seasons within a treatment.

4.3.4.1 Per kg TS

Cumulative yield per kg TS (L) was calculated and highest yield was obtained in T4 (31.72 in S-I and 28.06 in S-II) followed by T2 (27.72 in S-I and 24.11 in S-II), T1 (26.84 in S-I and 22.24 in S-II) and T3 (22.92 in S-I and 19.21 in S-II). All the treatments were significantly different from each other and the yield was less in monsoon season when compared to summer season.

4.3.4.2 Per kg VS

Cumulative yield per kg VS (L) was calculated in terms of per kg VS loaded in each treatment. There was a significant difference between the treatments within a season. Yield was highest in T4 (43.55 in S-I and S-II 38.21) followed by T3 (37.25 in S-I and 31.57 in S-II), T2 (33.94 in S-I and 30.14 in S-II) and T1 (31.87 in S-I and 27.03 in S-II). There was significant difference between the seasons within a treatment and maximum yield was observed during summer season.

4.4 COMPOSITION OF BIOGAS

Physico - chemical parameters of the biogas were furnished in table 4.3. Methane and carbon dioxide were found to be the major constituents of biogas. CH₄, CO₂ and O₂ were recorded on per cent of total gas. While other gases like H₂S, NH₃, NO and SO₂ were detected in ppm.

4.4.1 Temperature

Temperature of biogas (°C) was high in S-I (32.42 ± 1.28) and low in S-II (27.60 ± 1.54). There was significant difference between the seasons, however there was no significant difference between the treatments.

4.4.2 R.H

Relative humidity of the biogas produced (per cent) was almost similar in both the seasons. In S-I (76.50 ± 1.12) and in S-II (76.67 ± 0.53). There was no significant difference between the seasons and no significant difference was noticed between the treatments.

4.4.3 CH₄ and CO₂

Methane and carbon dioxide composition was depicted in fig.7. Methane content (per cent) was highest in T4 (62.42 ± 0.26 in S-I and 60.30 ± 0.26 in S-II) followed by T3 (60.42 ± 0.26 in S-I and 56.80 ± 0.26 in S-II), T2 (57.87 ± 0.26 in S-I and 54.45 ± 0.26 in S-II) and T1 (54.05 ± 0.26 in S-I and 51.57 ± 0.26 in S-II). There was significant difference between the treatments and a significant difference was noticed between the seasons with high concentration during summer.

Carbon dioxide concentration (per cent) was high in T1 (43.45 ± 0.25 in S-I) and 44.82 ± 0.25 in S-II) followed by T2 (41.00 ± 0.25 in S-I and 44.12 ± 0.25 in S-II), T3 (38.55 ± 0.25 in S-I and 40.12 ± 0.25 in S-II) and T4 (36.65 ± 0.25 in S-I and 38.55 ± 0.25 in S-II). There was significant difference between the treatments and a significant difference was noticed between the seasons with highest concentration during monsoon.

Concentration of oxygen was very less (< one per cent) ranging from 0.20 to 0.32 per cent in S-I and S-II. T3 had the highest concentration in both the seasons.

Table 4.3. Composition of biogas

PARAMETER	SEASON	TREATMENT				Pooled SE
		T 1	T 2	T3	T 4	
Temperature (°C)	S-I	32.42 ^{aA}	32.42 ^{aA}	32.42 ^{aA}	32.42 ^{aA}	1.28
	S-II	27.60 ^{aB}	27.60 ^{aB}	27.60 ^{aB}	27.60 ^{aB}	1.54
R.H	S-I	76.50 ^{aA}	76.50 ^{aA}	76.50 ^{aA}	76.50 ^{aA}	1.12
	S-II	76.67 ^{aA}	76.67 ^{aA}	76.67 ^{aA}	76.67 ^{aA}	0.53
CH ₄ (%)	S-I	54.05 ^{dA}	57.87 ^{cA}	60.42 ^{bA}	62.42 ^{aA}	0.26
	S-II	51.57 ^{dB}	54.45 ^{cB}	56.80 ^{bB}	60.30 ^{aB}	0.26
CO ₂ (%)	S-I	43.45 ^{aA}	41.00 ^{bA}	38.55 ^{cA}	36.65 ^{dA}	0.25
	S-II	44.82 ^{aB}	44.12 ^{bB}	40.12 ^{cB}	38.55 ^{dB}	0.25
O ₂ (%)	S-I	0.25 ^{abA}	0.20 ^{bA}	0.32 ^{aA}	0.20 ^{bA}	0.04
	S-II	0.30 ^{aA}	0.20 ^{bA}	0.32 ^{aA}	0.30 ^{aB}	0.04
H ₂ S (ppm)	S-I	156.00 ^{dA}	315.50 ^{bA}	717.50 ^{aA}	206.00 ^{cA}	4.83
	S-II	102.00 ^{dB}	335.50 ^{bA}	758.65 ^{aA}	238.00 ^{cA}	4.83
NH ₃ (ppm)	S-I	22.85 ^{dA}	46.25 ^{bA}	61.90 ^{aA}	32.00 ^{cA}	1.24
	S-II	11.50 ^{bB}	15.12 ^{cB}	34.95 ^{aB}	19.55 ^{bB}	1.24
NO (ppm)	S-I	85.10 ^{bA}	113.0 ^{aA}	114.51 ^{aA}	111.70 ^{aA}	1.36
	S-II	77.85 ^{dB}	89.05 ^{bB}	100.27 ^{aB}	78.40 ^{cB}	1.35
SO ₂ (ppm)	S-I	0.20 ^{aA}	0.20 ^{aA}	0.22 ^{aA}	0.10 ^{bA}	0.04
	S-II	0.10 ^{aA}	0.15 ^{aA}	0.22 ^{aA}	0.10 ^{aA}	0.04

For each parameter, means with different superscript (a-d in rows, A-B in columns) differ significantly ($p < 0.05$)

4.4.4 Other gases

Levels of H₂S, NO and NH₃ were found to be higher in T3 in both the seasons. T3 differed significantly from all the treatments and significant difference was also observed between the seasons. Concentration of SO₂ varied between 0.10 to 0.20 ppm in both seasons.

4.5. PHYSICO-CHEMICAL CHARACTERS OF SLURRY

Details of the physico-chemical characteristics of the substrates are furnished in Table 4.4.

4.5.1 Quantity

Quantity of slurry (kg) produced was high from T2 in both the seasons (3.04 ± 0.04 in S-I and 3.18 ± 0.04 in S-II). It was followed by T4 (2.72 ± 0.04 in S-I and 2.81 ± 0.04 in S-II), T3 (2.54 ± 0.04 in S-I and 2.68 ± 0.04 in S-II) and T1 (2.42 ± 0.04 in S-I and 2.61 ± 0.04 in S-II). Significant difference was observed between treatments in both the seasons and it was significantly high in monsoon season in all the treatments.

4.5.2 Temperature

The temperature of slurry was not significantly different between the treatments within a season but a significant difference was found between the seasons. Temperature was found to be high in S-I and low in S-II. The mean values respectively (°C) for T1, T2, T3 and T4 in S-I were 32.37 ± 0.26 , 32.50 ± 0.26 , 32.45 ± 0.26 and 32.38 ± 0.26 . In S-II temperature of the substrate was 27.62 ± 0.26 , 28.12 ± 0.26 , 27.50 ± 0.26 and 27.75 ± 0.26 respectively for T1, T2, T3 and T4.

4.5.3 Chemical composition

4.5.3.1 pH

The pH of fresh slurry for T1, T2, T3 and T4 was 7.40 ± 0.05 , 7.36 ± 0.05 , 8.12 ± 0.05 and 7.38 ± 0.05 respectively in S-I. In S-II it was 7.31 ± 0.09 , 7.38 ± 0.09 , 8.16 ± 0.09 and 7.37 ± 0.09 respectively for T1, T2, T3 and T4. pH was slightly alkaline in T1, T2 and T4 but in T3 it was alkaline in nature. There was no significant difference in pH between the seasons but in T3 it was significantly higher from other treatments in both the seasons.

4.5.3.2 Total solid

Total solid (TS) content of the slurry in different treatments was in the range of four to five per cent and the values were slightly higher in S-II. T2 was having highest TS content of 5.29 ± 0.03 and 5.39 ± 0.69 per cent in S-I and S-II respectively. It was followed by T4 (4.46 ± 0.03 per cent in S-I and 4.61 ± 0.03 per cent in S-II), T3 (4.18 ± 0.03 per cent in S-I and 4.28 ± 0.03 per cent in S-II) and T1 (7.53 ± 0.03 in S-I and 7.84 ± 0.03 in S-II). There was significant difference between the treatments and a significant difference within the treatment between the seasons was also noticed

4.5.3.3 Volatile solid

Volatile solid (VS) content of the slurry (per cent) was varying significantly between the treatments. T1 was having highest and T4 was having least volatile solid content. In S-I VS content was 24.64 ± 0.71 , 20.81 ± 0.71 , 18.25 ± 0.71 and 15.33 ± 0.71 per cent in T1, T2, T3 and T4 respectively. There was significant difference within the treatment between the seasons. In S-II VS content was 26.48 ± 0.34 , 21.92 ± 0.34 , 20.02 ± 0.34 and 17.24 ± 0.34 per cent in T1, T2, T3 and T4 respectively.

Table 4.4. Physico-Chemical properties of slurry

PARAMETER	SEASON	TREATMENT				Pooled SE
		T 1	T 2	T 3	T 4	
Quantity (kg)	S-I	2.42 ^{dA}	3.04 ^{aA}	2.54 ^{cA}	2.72 ^{dA}	0.04
	S-II	2.61 ^{dB}	3.18 ^{aB}	2.68 ^{cB}	2.81 ^{aB}	0.04
Temperature (°C)	S-I	32.37 ^{aA}	32.50 ^{aA}	32.45 ^{aA}	32.38 ^{aA}	0.26
	S-II	27.62 ^{aB}	28.12 ^{aB}	27.50 ^{aB}	27.75 ^{aB}	0.26
pH	S-I	7.40 ^{bA}	7.36 ^{bA}	8.12 ^{aA}	7.38 ^{bA}	0.05
	S-II	7.31 ^{bA}	7.38 ^{bA}	8.16 ^{aA}	7.37 ^{bA}	0.05
Total solid (TS) %	S-I	4.04 ^{dA}	5.29 ^{aA}	4.18 ^{cA}	4.46 ^{bA}	0.03
	S-II	4.14 ^{dB}	5.38 ^{aB}	4.28 ^{bB}	4.61 ^{aB}	0.03
Volatile Solid* (VS) %	S-I	24.64 ^{aA}	20.81 ^{bA}	18.25 ^{cA}	15.33 ^{dA}	0.71
	S-II	26.48 ^{aB}	21.92 ^{bB}	20.02 ^{cB}	17.24 ^{dB}	0.71
C/N ratio	S-I	7.33 ^{cA}	8.56 ^{aA}	7.84 ^{bA}	5.84 ^{dA}	0.06
	S-II	7.51 ^{cB}	8.92 ^{aB}	8.36 ^{bB}	6.24 ^{dB}	0.06
Nitrogen (%)	S-I	1.86 ^{dA}	2.55 ^{cA}	3.48 ^{aA}	3.09 ^{bA}	0.03
	S-II	1.66 ^{dB}	2.19 ^{cB}	3.17 ^{aB}	2.72 ^{bB}	0.03
Phosphorous (%)	S-I	1.22 ^{dA}	1.47 ^{cA}	1.83 ^{bA}	2.28 ^{aA}	0.02
	S-II	1.21 ^{dA}	1.41 ^{cA}	1.84 ^{bA}	2.32 ^{aA}	0.02
Potassium (%)	S-I	0.97 ^{cA}	1.33 ^{aA}	1.14 ^{bA}	0.82 ^{dA}	0.01
	S-II	0.83 ^{cB}	1.30 ^{aA}	1.17 ^{bA}	0.85 ^{cA}	0.01

For each parameter, means with different superscript (a-d in rows, A-B in columns) differ significantly ($p < 0.05$), * - values on DM basis

4.5.3.4 C/N ratio

Carbon Nitrogen ratio of slurry was highest in T2 (8.56 ± 0.06 in S-I and 8.92 ± 0.06) and least in T4 (5.84 ± 0.06 in S-I and 6.24 ± 0.06 in S-II). While, C/N ratio

of T1 was 7.33 ± 0.06 (S-I) and 7.51 ± 0.06 (S-II). T3 was having ratio of 7.84 ± 0.06 (S-I) and 8.36 ± 0.06 (S-II). C/N ratio was significantly different in all the treatments and there was also significant difference within the treatments between the seasons.

4.5.3.5 Nitrogen content

Nitrogen content (per cent) of slurry was estimated on fresh basis and T3 was found to be highest in both the seasons (3.48 ± 0.03 in S-I and 3.17 ± 0.03 in S-II) followed by T4 (3.09 ± 0.03 in S-I and 2.72 ± 0.03 in S-II), T2 (2.55 ± 0.03 in S-I and 2.19 ± 0.03 in S-II) and T1 (1.68 ± 0.03 in S-I and 1.48 ± 0.03 in S-II). Significant difference was observed between the treatments in both the seasons and it was more in summer with a significant difference between the seasons within a treatment.

4.5.3.6 Phosphorous content

Phosphorous content (per cent) of the slurry was significantly different between the treatments within a season and T4 was having highest. In S-I P content of T1, T2, T3 and T4 was 1.22 ± 0.02 , 1.47 ± 0.02 , 1.83 ± 0.02 and 2.28 ± 0.02 per cent respectively. While, in S-II P content was 1.21 ± 0.02 , 1.41 ± 0.02 , 1.84 ± 0.02 and 2.33 ± 0.02 per cent for T1, T2, T3 and T4 respectively. There was no significant difference between the seasons.

4.5.3.7 Potassium content

Potassium content (per cent) was highest in T2 (1.33 ± 0.01 per cent in S-I and 1.30 ± 0.01 per cent in S-II) followed by T3 (1.14 ± 0.02 per cent in S-I and 1.17 ± 0.01 per cent in S-II), T1 (0.97 ± 0.02 per cent in S-I and 0.83 ± 0.02 per cent in S-II) and T4 (0.82 ± 0.02 per cent in S-I and 0.85 ± 0.02 per cent in S-II). There was no significant difference between the seasons except for T1.

4.6 CORRELATION OF CLIMATOLOGICAL PARAMETERS ON BIOGAS YIELD

The correlation of micro-climatic variables with gas production is given in Table 4.5. There was a positive correlation ($P < 0.01$) between mean daily temperature and gas production of all the substrates (as in fig. 3 and 4) and no correlation ($P > 0.01$) was observed between relative humidity and gas production. A positive correlation ($P < 0.01$) between THI and gas production was witnessed in all the substrates (as in fig. 5 and 6).

Table 4.5. Correlation of climatological factors on biogas production

S.No.	Parameter	T I	T II	T III	T IV
1	Temperature	0.526**	0.747**	0.856**	0.488**
2	R.H	0.197	0.142	0.113	0.148
3	THI	0.543**	0.376**	0.845**	0.493**

** Significant at 0.01 level, ($P < 0.01$)

4.7 MANURIAL VALUE OF SUBSTRATE AND SLURRY

Manurial value (N, P, K content) of substrate and slurry was compared and provided in table 4.8 for season-I and table 4.9 for season-II. There was significant change in N content of the slurry when compared to that of substrate. There was no significant change in the concentration of P and K. Similar results were obtained in both the seasons.

4.8 CARBON CREDIT POTENTIAL OF ANAEROBIC DIGESTION

Carbon credit potential was calculated based on the amount of firewood and diesel that can be substituted by the biogas produced in the experiment. It was expressed as global warming mitigation potential (GWMP) in CO₂ equivalents (kg). Obtained results were tabulated in table 4.6

Table 4.6. Carbon credit potential of biogas yield

TREATMENT	BIOGAS YIELD	GWMP (CO ₂ EQUIV.)
T1	903.7313	3.93
T2	1195.653	5.24
T3	1035.219	4.51
T4	1238.828	5.39

4.9 ECONOMICS OF BIOGAS PRODUCTION

Cost of production per litre biogas was furnished in table 4.7 and depicted in fig.10. It was least in T4 (0.08 INR) followed by T3 (0.10 INR), T1 (0.11 INR) and T2 (0.34 INR).

Table 4.7. Economics of biogas production

Treatment	Total biogas yield (L)	Cost Of Manure (INR)	Cost of production per liter (INR)
T 1	903.7313	96	0.11
T 2	1195.653	408	0.34
T 3	1035.219	108	0.10
T 4	1238.828	93	0.08

Table 4.8. Manurial value of substrate and slurry (Season-I)

Sl. No.	Substrate	Parameter	Treatment	Mean	P value
1	T I	N	Substrate	1.68 ± 0.02	0.000*
			Slurry	1.86 ± 0.03	
		P	Substrate	1.28 ± 0.03	0.890
			Slurry	1.22 ± 0.02	
		K	Substrate	0.96 ± 0.02	0.125
			Slurry	0.94 ± 0.02	
2	T II	N	Substrate	2.21 ± 0.02	0.001*
			Slurry	2.55 ± 0.03	
		P	Substrate	1.46 ± 0.03	0.077
			Slurry	1.44 ± 0.02	
		K	Substrate	1.33 ± 0.02	0.758
			Slurry	1.32 ± 0.01	
3	T III	N	Substrate	3.12 ± 0.02	0.000*
			Slurry	3.48 ± 0.03	
		P	Substrate	1.84 ± 0.03	0.791
			Slurry	1.83 ± 0.02	
		K	Substrate	1.16 ± 0.02	0.632
			Slurry	1.14 ± 0.01	
4	T IV	N	Substrate	2.75 ± 0.02	0.000*
			Slurry	3.09 ± 0.03	
		P	Substrate	2.26 ± 0.03	0.231
			Slurry	2.25 ± 0.02	
		K	Substrate	0.82 ± 0.02	0.908
			Slurry	0.82 ± 0.01	

* Significant at 1% level

Table 4.9. Manurial value of substrate and slurry (Season-II)

Sl. No.	Substrate	Parameter	Treatment	Mean	P value
1	T I	N	Substrate	1.48 ± 0.02	0.000*
			Slurry	1.66 ± 0.03	
		P	Substrate	1.23 ± 0.03	0.222
			Slurry	1.20 ± 0.02	
		K	Substrate	0.85 ± 0.02	0.071
			Slurry	0.83 ± 0.01	
2	T II	N	Substrate	1.90 ± 0.02	0.002*
			Slurry	2.18 ± 0.03	
		P	Substrate	1.43 ± 0.03	0.367
			Slurry	1.40 ± 0.02	
		K	Substrate	1.33 ± 0.02	0.500
			Slurry	1.31 ± 0.01	
3	T III	N	Substrate	2.81 ± 0.02	0.001*
			Slurry	3.16 ± 0.03	
		P	Substrate	1.82 ± 0.03	0.608
			Slurry	1.84 ± 0.02	
		K	Substrate	1.17 ± 0.02	0.012
			Slurry	1.18 ± 0.01	
4	T IV	N	Substrate	2.41 ± 0.02	0.000*
			Slurry	2.73 ± 0.03	
		P	Substrate	2.32 ± 0.03	0.013
			Slurry	2.31 ± 0.02	
		K	Substrate	0.83 ± 0.02	0.040
			Slurry	0.86 ± 0.01	

* Significant at 1 % level

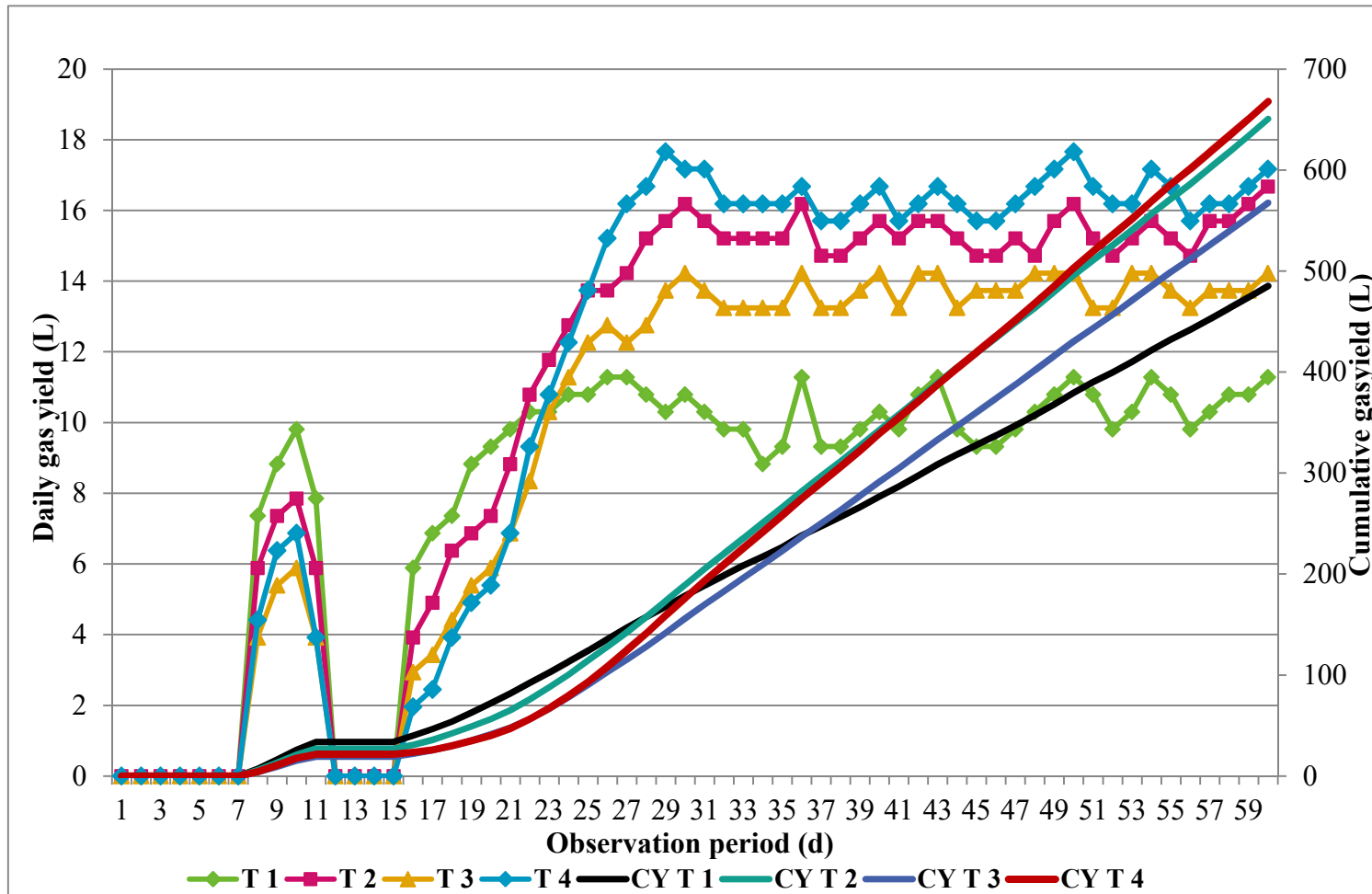


Fig. 1. Biogas yield from different treatments in season - I

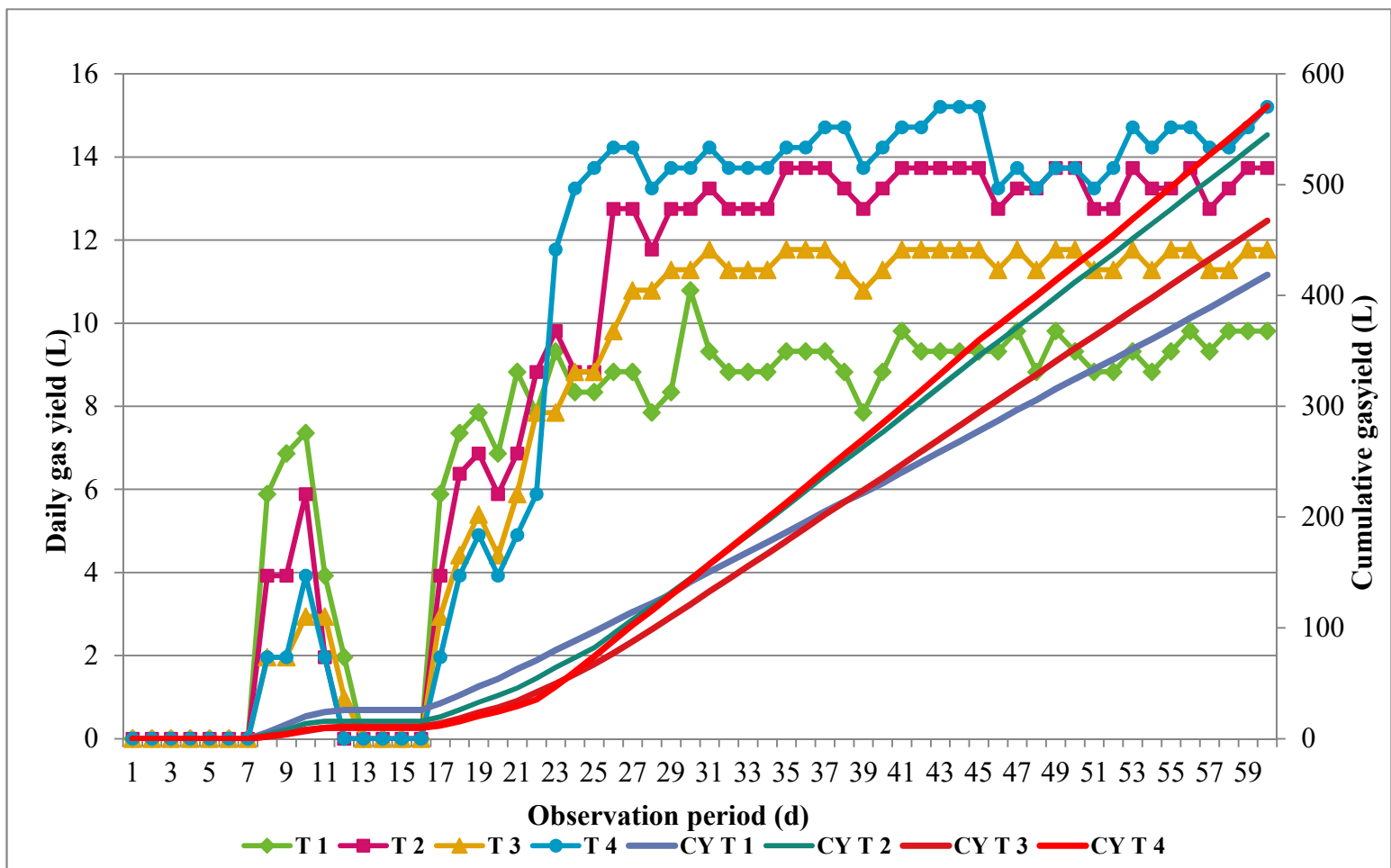


Fig. 2. Biogas yield from different treatments in season - II

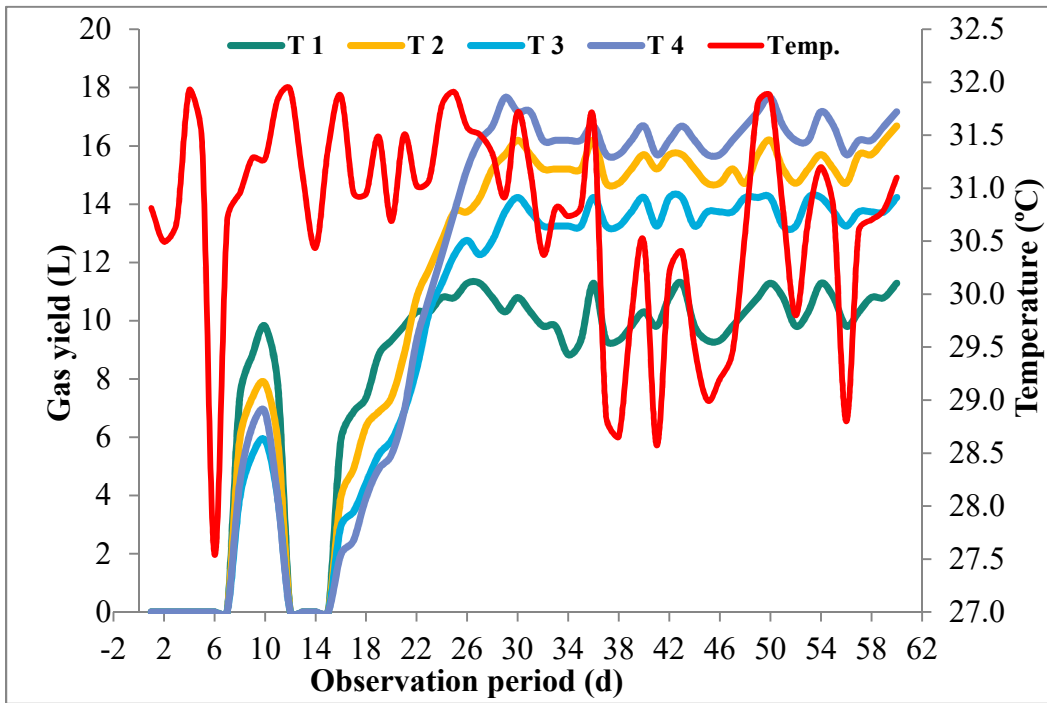


Fig. 3. Correlation between temperature and biogas yield during season - I

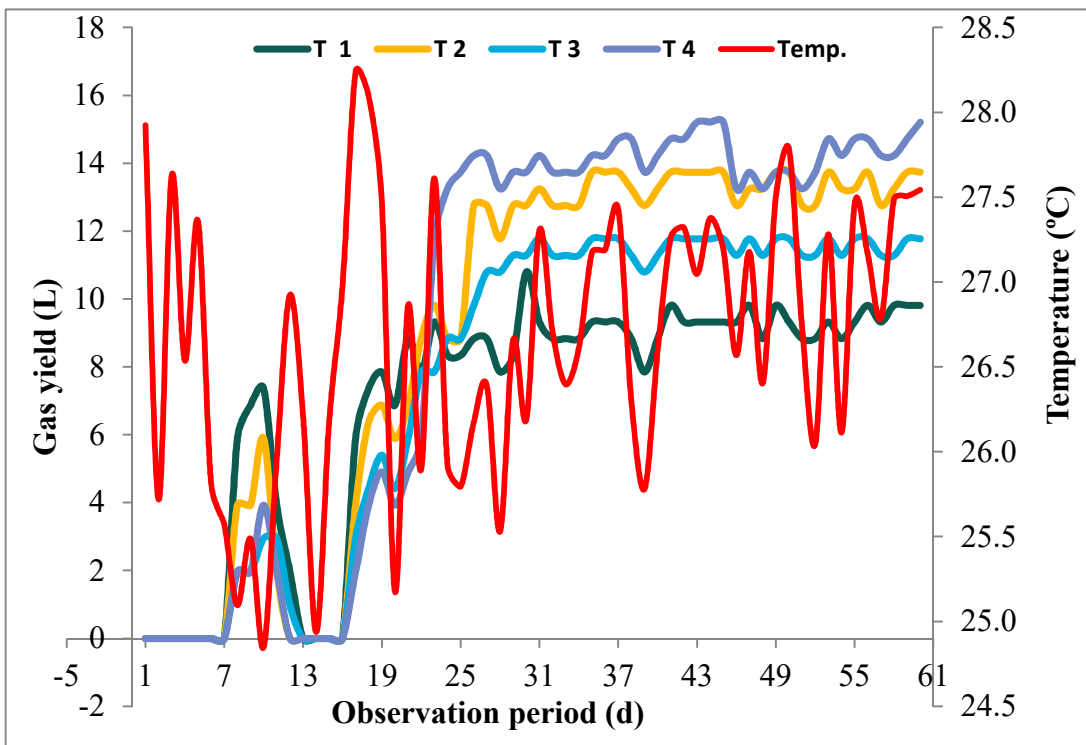


Fig. 4. Correlation between temperature and biogas yield during season - II

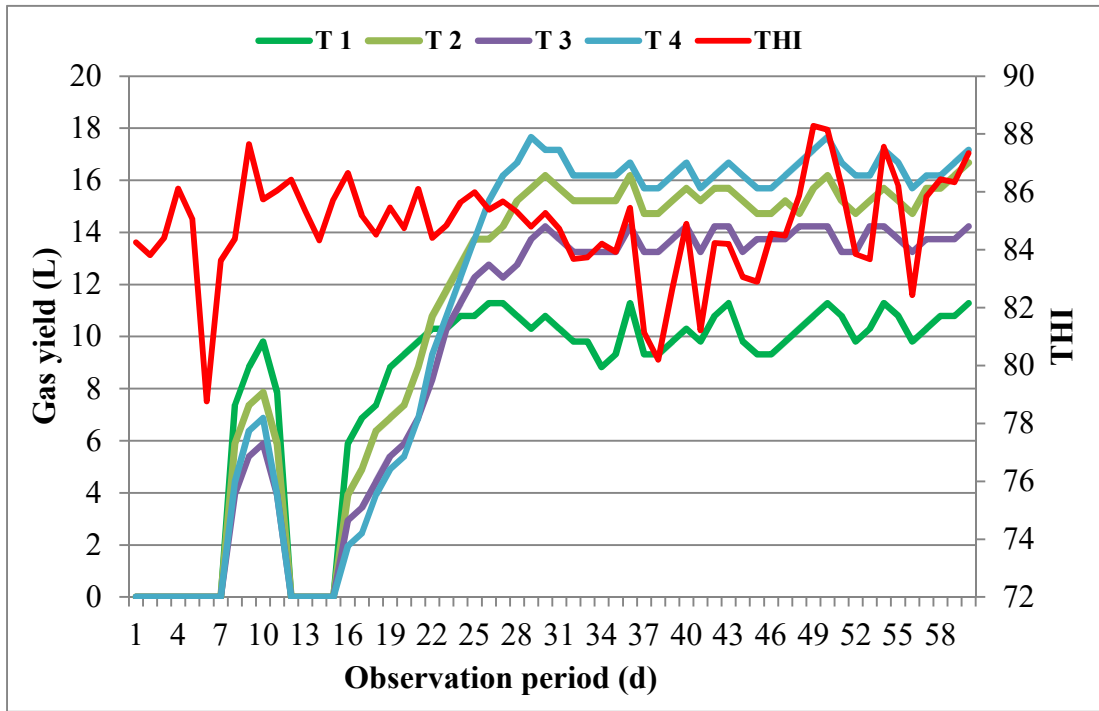


Fig. 5. Correlation between THI and biogas yield during season - I

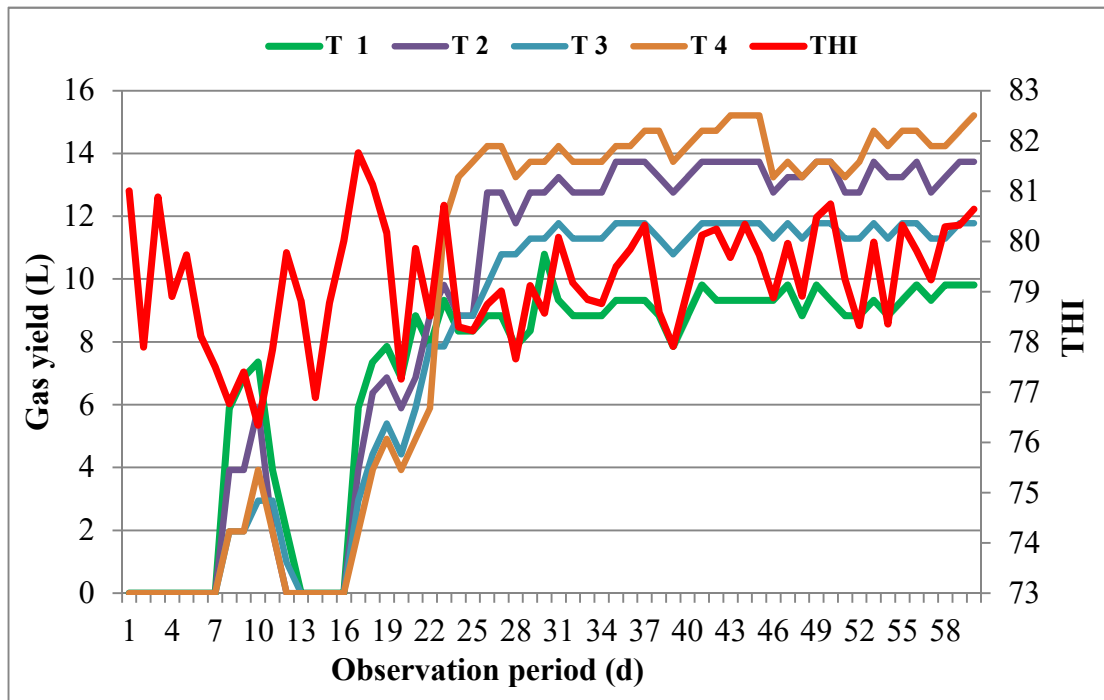


Fig. 6. Correlation between THI and biogas yield during season -II

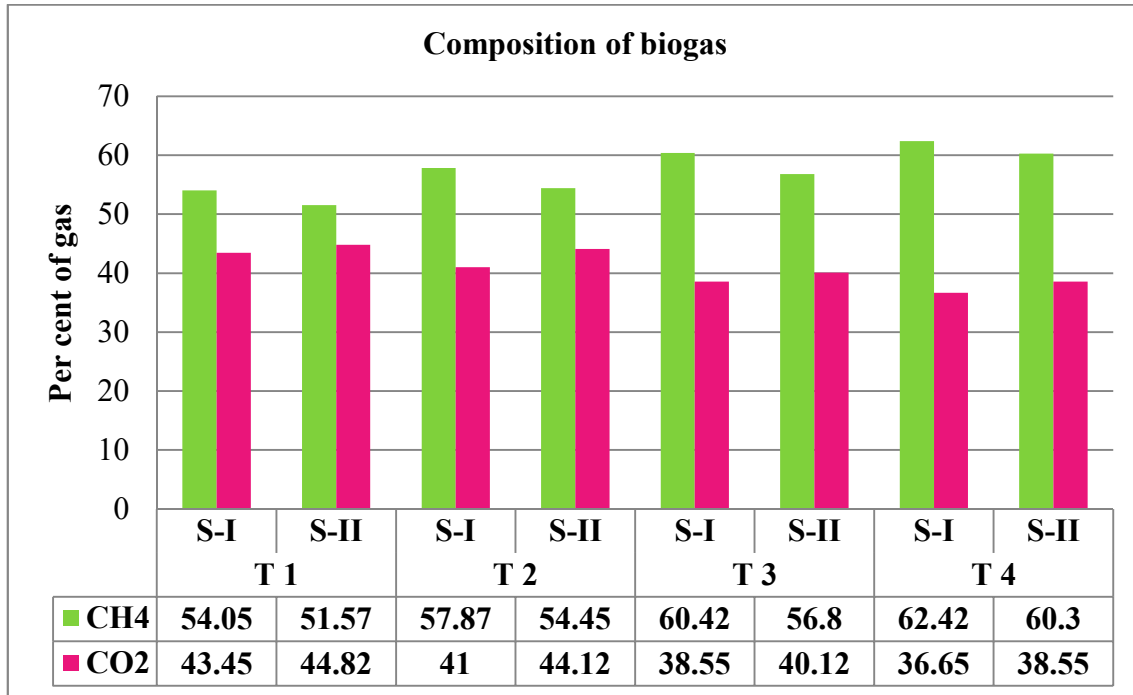


Fig. 7. Composition of biogas between seasons

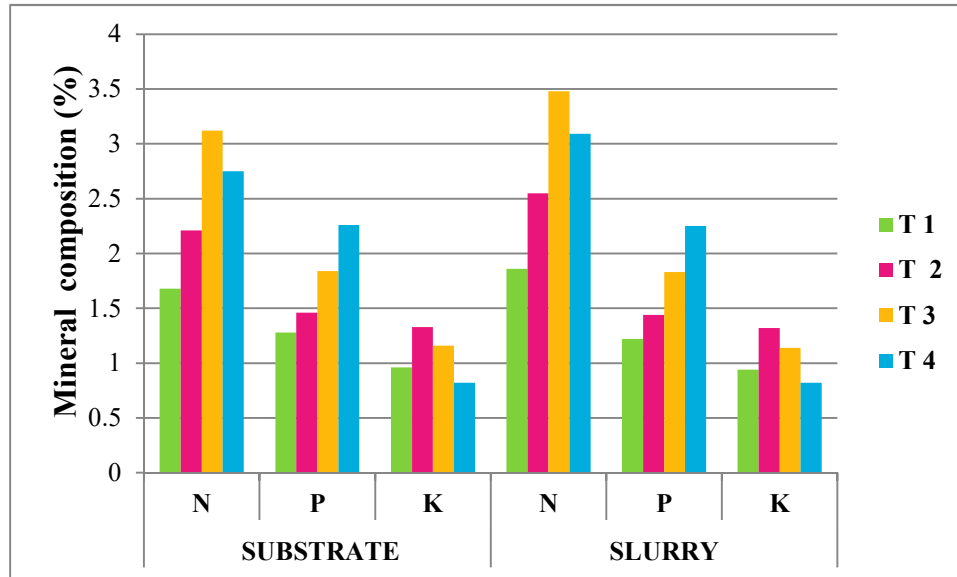


Fig. 8. Manurial value of Substrate and Slurry in S-I

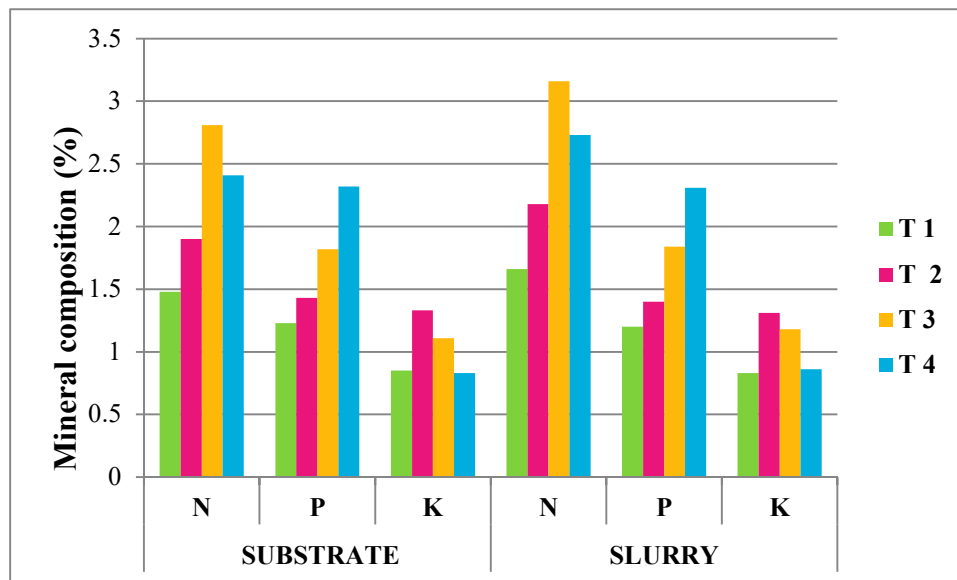


Fig. 9. Manurial value of Substrate and Slurry in S-II

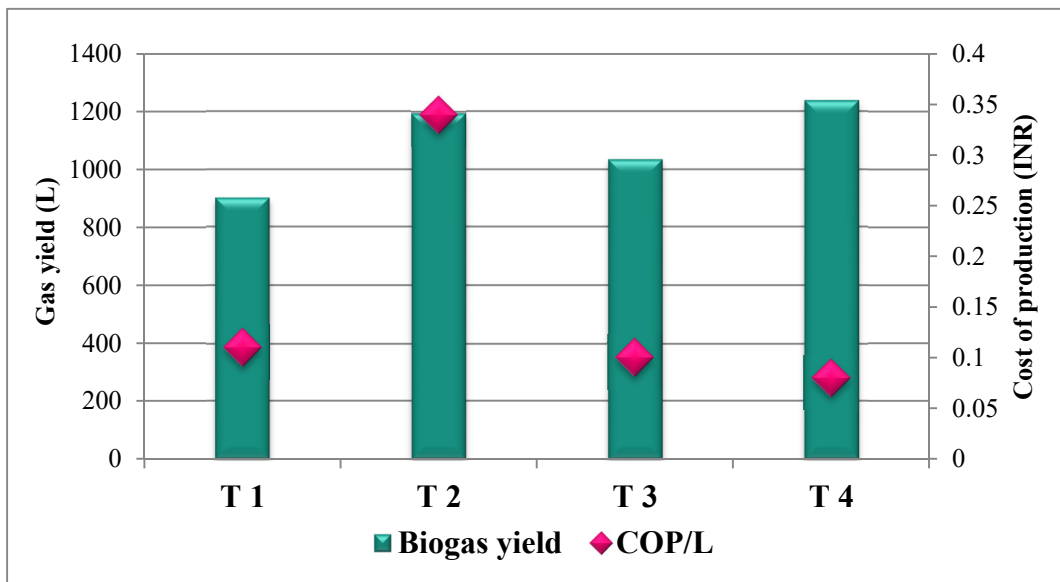


Fig. 10. Economics of biogas production from different treatments

5. DISCUSSION

5.1 CLIMATOLOGICAL DATA

The average daily ambient temperature ($^{\circ}\text{C}$) respectively during S-I and S-II was 30.7 ± 0.12 and 26.67 ± 0.10 . The results obtained in S-I are in agreement with the observations of Joseph (2011) who reported that ambient temperature ($^{\circ}\text{C}$) in Mannuthy during April, May, June, July and August months was 32.97, 31.52, 27.95, 26.74 and 28.04 respectively. Similarly, Shejir (2014) reported that the average daily ambient temperature ($^{\circ}\text{C}$) in University Livestock Farm (ULF), Mannuthy ranged from 25.4 to 27.8 during monsoon and 25.2 to 31.9 during summer.

The R.H (per cent) was 84.8 ± 0.78 and 93.71 ± 0.34 in S-I and S-II respectively. In S-I, Nishant (2009) reported a similar range of 55.7 to 85.16 per cent. In S-II the findings were in accordance with that of Shejir (2014) who reported that relative humidity ranged from 90 to 98 per cent during monsoon but reported 37 to 72 per cent during summer. Rainfall received during S-I and S-II was 719.21 (10 d) and 775.21 mm (40 d) respectively. THI values obtained were 84.88 ± 0.22 in S-I and 79.22 ± 0.12 in S-II. In the present study, higher R.H during S-I (compared to earlier studies) and S-II was due to the rainfall received in respective seasons.

5.2 PHYSICO - CHEMICAL CHARECTERISTICS OF SUBSTRATE

Physico-chemical characters of the substrates were analyzed and furnished in table 4.1. The temperature of substrates was not significantly different ($P > 0.05$) between the treatments within a season but a significant difference was noticed between the seasons ($P < 0.05$). It was found to be high in S-I (29°C) and low (25°C) in S-II. The findings were similar to Anzar (2014) who found that the mean temperature of the substrates was higher in summer season and lower in monsoon and reported that the seasonal variation of substrate temperature was due to the influence of atmospheric temperature. Pham *et al.* (2014) reported that air temperature

indirectly influences the temperature of substrate. In the present study, higher temperature in summer was due to the high air temperature and the substrate temperature was lesser than the average temperature recorded because loading was carried out at eight a.m. when it was comparatively cooler than day time.

In T1, T2 and T4 pH of the substrate was slightly alkaline but in T3 it was slightly acidic. There was no significant difference in pH of the substrate between the seasons ($P > 0.05$) and T3 was significantly different from other treatments in both the seasons ($P < 0.05$). The obtained results were within the range as suggested by Barik and Murugan (2015), who reported that no adverse effects on AD were noticed when the substrates having pH of 6.3 - 7.0 were utilized for the study. Suryawanshi *et al.* (2013) opined that alkalis should be added to the digester to maintain the pH within an array of 6.8 – 7.2. Hence, the pH of the substrate added in the present study was within the range of pre-requisites for efficient fermentation. Slightly acidic nature of T3 substrate might be due to the presence of poultry manure which is rich in uric acid.

Total solid (TS) content of the substrate in different treatments was in the range of 7 - 10 per cent. Treatments differed significantly ($P < 0.05$) but, within the treatment no significant difference was observed between the seasons ($P > 0.05$). T3 was having highest TS content of 10.32 ± 0.69 and 10.14 ± 0.69 per cent in S-I and S-II respectively. The results are in accordance with Rajendran *et al.* (2012) who had reported TS content of seven to ten per cent should be maintained and the substrate should undergo slow degradation to avoid a sudden drop in pH. Divya *et al.* (2015) has opined that the process of AD would be affected if the loading rate was more. They had classified the loading rate into three categories i.e., high (22-40 per cent), medium (15-20 per cent) and lower solids (< 10 per cent). However, Raheman and Mondal (2012) had reported that TS content of substrate should be maintained between 15 and 20 per cent for enhanced biogas yields. In the present study, the

substrate was having lower solid content (< 10 per cent) and it was considered to be optimum because manure undergoes rapid degradation and loading at higher rates might cause a great drop in pH of the digester resulting in failure of biogas production.

Volatile solid (VS) content of the substrate varied significantly between the treatments ($P < 0.05$) with highest values for T1 and least for T2. There was no significant difference within the treatment between the seasons. The findings were similar to that reported by Andrade *et al.* (2016) for the individual manures. In the present study, it was noticed that the substrates with ruminant manures had more VS content than the substrates with monogastric animal manure as co-substrate due to the differences in anatomical, physiological and feeding regime.

Carbon-Nitrogen ratio was highest in T2 (27.62 ± 0.66 in S-I and 28.64 ± 0.66) and least in T3 (16.66 ± 0.66 in S-I and 17.41 in S-II). The treatments differed significantly ($P < 0.05$) within each season but no significant difference was noticed within the treatments between the seasons ($P > 0.05$). A slight decrease in the C/N values of T1, T2 and T3 was noticed from summer to monsoon. The results obtained were in accordance with Rajendran *et al.* (2012) who reported that C/N ratio should be between 16:1 to 25:1 and an increase or decrease would ultimately affect the biogas production. But, the results were in contrary to the findings of Divya *et al.* (2015) who had reported the C/N ratio for individual manures. In the present study, it was clearly evident that there was nutrient adjustment and almost optimum C/N ratio was obtained due to co-digestion when compared to mono-digestion. Lowest C/N ratio in T3 could be endorsed to the presence of poultry manure which is rich in N and poor in C when compared to other manures. The substrate in T2 comprised of ruminant manure alone which is rich in carbonaceous material, hence the value was towards higher end. Increased C/N ratio during monsoon was because of the decreased N content of animal manure in monsoon.

The manurial value was estimated on fresh basis and N content was highest for T3 in both the seasons (3.12 ± 0.02 in S-I and 2.81 ± 0.02 in S-II). Between the treatments a significant difference was noticed in both the seasons ($P < 0.05$) and it was more in summer with a significant difference between the seasons within a treatment ($P > 0.05$). Phosphorous content of the substrate was significantly different between all the treatments and T4 was having highest. There was no significant difference between the seasons. Potassium content was highest in T2 (1.33 ± 0.02 per cent in S-I and 1.28 ± 0.02 per cent in S-II). A significant difference was noticed between the treatments but there was no significant difference between the seasons. The results for N were in accordance with findings of Anzar (2014) and Shejir (2014) who had studied manurial value of individual manure and reported poultry manure had highest N content when compared to other manures. The high N content in T3 of present study was due to the presence of poultry which is rich in N due to the anatomical and physiological idiosyncrasies. The P values as listed by Li *et al.* (2014) show numerical differences with the result obtained in the present study, but the order of comparison of swine and poultry manure was almost similar which were co-substrates in T4 and T3 respectively. The results of K concentration were almost similar to K values reported by Anzar (2014) and Shejir (2014) for individual manures. It was highest in T1 and T2 due to the presence of ruminant manure in the substrates.

5.3 BIOGAS YIELD

The observed average HRT was less during S-I (22 d) when compared to S-II (28 d). In all the treatments HRT was nearly uniform and the gas yield was stabilized after reaching HRT. The findings were in accordance with Olowoyeyey (2013) who had reported that HRT decreases with increase in temperature and vice versa. But, Adelekan and Bamgboye (2009) reviewed that at a given organic loading rate, HRT was lower for substrates having higher water content than those having lower water content. In the present study, near uniform HRT in all the treatments might be due to

the uniform loading rate and the presence of cattle manure in all the treatments which is having good buffer action.

Trend in gas production was depicted in fig.1 and fig.2. Gas yield was noticed from third day but the combustible biogas was obtained from eighth day onwards. Initially, T1 and T2 production was more rapid and gas production ceased at around 12th day in both the seasons. Gas yield restarted from 16th day, reached maximum and got stabilized at around 20-24 d (S-I), 27 – 29 d (S-II) in all treatments. The findings were in accordance with Liu *et al.* (2009) who observed a cessation in the biogas yield on 10th day due to decrease in the pH value inside the digester and Zhou *et al.* (2011) reported that loading of more fresh dung causes rapid accumulation of acids and drops in pH. Shejir (2014) observed that during initial stage of anaerobic digestion the biogas production was fluctuating and became constant after achieving hydraulic retention time (HRT). Hence in the present day, loading of fresh dung continuously might have caused a drop in pH resulting in cessation of gas yield. In S-II, digesters took longer time to reach stabilization due to the decrease in ambient temperature which had an effect on bacterial growth and efficiency.

Average daily yield (L) of biogas was significantly different in all the treatments and it was highest in T4 (16.41 ± 0.10 in S-I and 14.24 ± 0.10 in S-II) and a significant difference was noticed between the seasons within the treatment with highest yield during S-I. Alike trend was observed when the average yield was calculated in correspondence to per kg TS and VS loaded but T3 was inferior to all the treatments in terms of TS loaded. Cumulative yield also followed the same trend with T4 having highest yield. Similar results were reported by Babatola (2008) who studied the AD of different animal manures and reported higher gas yield from pig manure. Sreekrishnan *et al.* (2004) reported mesophilic (30 – 40 °C) and thermophilic (50–60 °C) supposed to have enhanced gas yield due to the higher activity of methanogens when compared to psychrophilic conditions (< 30 °C). But, findings

were contrary to Olowoyeye (2013) and Anzar (2014) who had reported that poultry manure was more efficient than other manures. In the present study, highest yield of T4 can be attributed to various factors like well-balanced and optimum C/N ratio favoring stable bacterial metabolism, buffering effect on nutrient supply due to co-digestion and avoiding the sedimentation of swine manure had increased its efficiency. Higher activity of methanogens during mesophilic conditions had favored more yield during S-I.

5.4 COMPOSITION OF BIOGAS

Composition of biogas was tabulated in table 4.3. Temperature of biogas (°C) was higher in S-I (32.42 ± 1.28) than in S-II (27.60 ± 1.54). There was significant difference between the seasons and there was no significant difference between the treatments. Relative humidity (%) of the biogas produced was almost similar in both the seasons. Methane content (%) was highest in T4 (62.42 ± 0.26 in S-I and 60.30 ± 0.26 in S-II) and there was significant difference between the treatments. There was also a significant difference between the seasons with highest during summer. But, Carbon dioxide concentration was higher in T1 (43.45 ± 0.25 in S-I and 44.82 ± 0.25 in S-II) with highest concentration during monsoon. There was significant difference between the treatments and a significant difference was noticed between the seasons. Similar results were reported by Moller *et al.* (2004) who had indicated higher theoretical CH₄ yield in pig manure than in cattle manure. Nnabuchi *et al.* (2012) observed that the mixture with 1:1 ratio of cattle and poultry manure had least biogas yield and Sebola *et al.* (2015) found that the treatments with higher proportion of cattle dung had a lower methane yield than other treatments. But, Anzar (2014) and Shejir (2014) had respectively reported that poultry manure and goat manure had produced higher biogas yield. In the present study, methane composition was about 51 – 63 per cent and the obtained biogas is combustible in nature. It was also clearly evident that the co-digestion had a significant role but the adopted 1:1 ratio was not suitable for all the treatments because there was an imbalance in C/N ratio which

directly influences the composition of gas and the varied results might be due to the variation in composition of animal manures.

Levels of H₂S, NO and NH₃ were found to be higher in T3 in both the seasons. T3 differs significantly from all the treatments and also significant difference was observed between the seasons. Concentration of SO₂ varied between 0.10 to 0.20 ppm in both the seasons. In T3 and T2, H₂S (700 – 750 ppm in T3 and 315 - 335 ppm in T2) was found at inhibitory levels as reported by Sebola *et al.* (2015) who testified that H₂S at concentration of 327.7 ppm had adversely affected biogas production, composition and the downstream process of AD. Hence, the decreased efficiency of T3 and T2 in the present study can be attributed to the impurities present and care must be taken to minimize the inhibitory effects by adopting proper mixing proportions.

5.5. PHYSICO-CHEMICAL CHARACTERS OF SLURRY

The details of the physico-chemical characteristics of the substrates are furnished in table 4.4.

Quantity of slurry produced was highest in T2 in both the seasons with higher quantity during S-II. The temperature of slurry was not significantly different between the treatments within a season but a significant difference was found between the seasons. Temperature was found to be high in S-I and low in S-II. The findings are in accordance with Perringault *et al.* (2012), Pham *et al.* (2015) and Tucho *et al.* (2016). Authors had reported that the temperature inside the anaerobic digester had followed a similar trend of ambient temperature. Tucho *et al.* (2016) reported a 20 per cent decrease in the volume of water after AD. But the quantity of slurry produced in different seasons was in contrary to observations of Shejir (2014), who reported an increase in the quantity and temperature of sludge during summer season. In the present study, as the ambient temperature was high during S-I the

temperature of slurry was high and the increased quantity of slurry might be due to the decrease in the activity of methanogens at psychrophilic conditions.

The pH of fresh slurry was recorded and it was slightly alkaline in T1, T2 and T4 but in T3 it was alkaline in nature. There was no significant difference in pH between the seasons and T3 was significantly different from other treatments in both the seasons. Similar results were reported by Babae *et al.* (2013) who found that the pH of the slurry was in the range of 7.75-8.0. In the present study, increased pH of T3 when compared to other treatments might be due to the increased N content in the substrate which in turn increased the pH of digester (Dioha *et al.*, 2013).

Total solid (TS) content of the slurry in different treatments was in the range of 4 - 5 per cent and the values were slightly higher in S-II. T2 had highest TS content of 5.29 ± 0.03 and 5.39 ± 0.69 per cent in S-I and S-II respectively. There was significant difference between the treatments and significant difference was also noticed within the treatment between the seasons. The results obtained were similar to those of Anzar (2014) and Shejir (2014), but numerical difference existed from their observations. In the present study, higher TS content of T2 was due to higher DM content of goat manure and it was less digested when compared to other manures.

Volatile solid (VS) content of the slurry was varying significantly between the treatments and T1 had highest content. There was significant difference within the treatment between the seasons. In S-II, VS content was highest in all the treatments. In the present study, there was a considerable decrease in the VS content of the slurry when compared to substrate indicating the degradation of organic matter during AD. Similar results were reported by Tucho *et al.* (2016). He had reported a loss of 20 per cent carbon and 20 per cent decrease in the volume of water.

C/N ratio of slurry was highest in T2 (8.56 ± 0.06 in S-I and 8.92 ± 0.06) and least in T4 (5.84 ± 0.06 in S-I and 6.24 ± 0.06 in S-II). C/N ratio was significantly

different in all the treatments and there was also significant difference within the treatments between the seasons with slightly higher values in S-II. In the present study, decreased C/N ratio when compared to the substrate was due to the decreased VS content of the slurry. Higher C/N ratio during S-II was due to lesser activity of bacteria during monsoon which had resulted in lower degradation rates.

Manurial value of slurry was assessed on fresh basis and the Nitrogen content (per cent) of T3 was found to be highest in both the seasons (3.48 ± 0.02 in S-I and 3.17 ± 0.02 in S-II). Significant difference was observed between the treatments in both the seasons and it was more in summer with a significant difference between the seasons within a treatment. Phosphorous content (per cent) of the substrate was significantly different between all the treatments ranging from 1.2 to 2.3 and T4 was having highest (2.28 ± 0.02 in S-I and 2.32 ± 0.02 in S-II). There was no significant difference between the seasons. Potassium content (per cent) varied significantly in all the treatments and it was highest in T2 (1.33 ± 0.01 per cent in S-I and 1.30 ± 0.01 per cent in S-II). There was no significant difference between the seasons. The findings were in accordance with Anzar (2014) and Shejir (2014) who had evaluated the manurial value of slurry obtained after the AD of different manures as sole substrate. In the present study higher N content might be due to the presence of poultry manure and high phosphorous content can be attributed to swine manure. Hence, it can be inferred that varied differences in the composition of manures had an influence on the manurial value of slurry.

5.6 CORRELATION OF CLIMATOLOGICAL PARAMETERS ON BIOGAS YIELD

The correlation of micro-climatic variables with gas production is given in table 4.5. There was a positive correlation ($P < 0.01$) between mean daily ambient temperature and gas production of all the substrates (fig. 3 and 4) and no correlation ($P > 0.01$) was observed between relative humidity and gas production. A positive

correlation ($P < 0.01$) between THI and gas production of all the substrates (fig.5 and fig. 6). Similar results were reported by Ghani and Idris (2009), Anzar (2014) and Shejir (2014) for the correlation of ambient temperature on biogas yield. Yin *et al.* (2016) had reported that R.H had no effect on the biogas yield. But, the results reported by Anzar (2014) and Shejir (2014) regarding the effect of R.H were contrary to our findings. In the present study, effect of temperature was clearly evident on the quantity of biogas in both the seasons. The bacteria involved in AD cannot tolerate abrupt changes in the environmental temperature.

5.7 MANURIAL VALUE OF SUBSTRATE AND SLURRY

Manurial value (N, P, K content) of substrate and slurry was compared and provided in table 4.8 for season-I and table 4.9 for season-II. There was a significant change in the N content in slurry when compared to that of substrate. There was no significant change in the concentration of P and K. Similar results were obtained in both the seasons. The results obtained were in accordance with reports of USDA-NRCS (2007) and Topper *et al.* (2006). In the present study, increased concentration of N in the slurry might be due to the trapping of NH_4^+ formed during bacterial metabolism.

5.8 CARBON CREDIT POTENTIAL OF BIOGAS PRODUCED

Global warming mitigation potential (GWMP) was calculated in CO_2 equivalents (kg) and the obtained results were tabulated in table 4.6. Similar methods were adopted by Pathak *et al.* (2009) and Sharma and Agarwal (2011). They had reported that adoption of biogas would mitigate the GHG emission arising from utilization of fossil fuels and during manufacture of synthetic chemical fertilizers. Pathak *et al.* (2009) reported that global warming mitigation potential (GMP) of family size biogas plant was $9.7 \text{ t CO}_2 \text{ equiv. year}^{-1}$. Sharma and Agarwal (2011) reported that a goushala with 250 cows yielding 750 kg of dried cow dung daily had a GMP of $594 \text{ t CO}_2 \text{ equiv. year}^{-1}$. Hence, a carbon credit of US \$ 5940/year can be

earned at a current price of US \$ 10 t⁻¹ CO₂ equiv. In the present study, the trapped C was very less (5.3 to 3.2 kg of CO₂) due to the utilization of very less amount of animal manure and small size of digester adopted. Hence to obtain better carbon sequestration potential, large scale digesters with optimum operational parameters should be adopted.

5.9 ECONOMICS OF BIOGAS PRODUCTION

Cost of production per litre biogas was furnished in table 4.7 and depicted in fig.10. Cost of production was least in T4 (0.08 INR) followed by T3 (0.10 INR), T1 (0.11 INR) and T2 (0.34 INR). Similar method was adopted by Anzar (2014) and indicated that cost of the manure was prime factor determining the cost of production. Therefore, in the present study, even though the substrate T2 was efficient in biogas yield, it was not economical due to the presence of goat manure which is expensive and in turn inflated the cost of production.

From the study, it can be concluded that substrate used in T4 was efficient in biogas production and was also cheaper at the existing tariffs. Limitations of swine manure for employing in AD *viz.*, sediment formation as reported by Anzar, 2014 was triumphed due to the presence of cattle dung. Hence, it can be recommended for the co-digestion of cattle and swine manure in 1:1 proportion for enhanced biogas production. It can also be suggested to carry out further experiments on co-digestion of different manures to identify and standardise the optimum mixing ratio of different manures for better performance of digester and aid in improving the returns of the farm.

6. SUMMARY

The research programme entitled “Enhancing biogas production by co-digestion of livestock manures” was conducted to estimate the biogas production by anaerobic co-digestion of different livestock manures. The study was conducted at Ecofarm, Department of Livestock Production Management, College of Veterinary and Animal Sciences, Mannuthy, Thrissur. The experiment was conducted in two seasons namely, summer (February – May, 2016) and monsoon (June – September, 2016). Portable floating drum biogas plants of 0.5 m³ capacity, designed by agro biotechnology agency for rural employment development (ABARD), Kerala Agricultural University (KAU), Vellanikara were utilized for the study. Micro climatic variables like temperature, humidity were recorded and THI was calculated. Rainfall received was also recorded and the observations were taken for 60 days in each season.

There were four treatments considered for the study mainly, T1 (Two kg of fresh cattle dung), T2 (One kg. each of fresh cattle and goat manure), T3 (One kg each of fresh Cattle and Poultry manure) and T4 (One kg each of Cattle and Pig manure). Water is added in each treatment at 1:1 ratio on whole weight basis. Before loading, fresh samples of the substrate from each treatment were collected and analyzed to determine TS. Moisture free samples were analyzed for volatile solids on DM basis and C on fresh basis. The temperature and pH of the substrates was recorded in the morning (8 a.m.) daily before loading. Manurial value of the substrates was determined at every week for Nitrogen, Phosphorus and Potassium contents. Hydraulic retention time (HRT) was recorded as the average time (d) required by the digester to get stabilized in terms of quantity and quality of gas. The biogas production was recorded in the morning (8 a.m.) from the very next day before loading and the composition of biogas was determined using gas analyzer.

The slurry was collected continuously and the quantity of slurry collected was recorded daily in the morning. The temperature and pH of the substrates was recorded in the morning. Manurial value of the slurry was determined at every week for nitrogen, phosphorus and potassium content. Carbon credit potential and the economics of the biogas production were also worked out.

The average daily ambient temperature ($^{\circ}\text{C}$) was found to be high during S-I (30.7 ± 0.12) when compared to S-II (26.67 ± 0.10). The R.H inside the shed was 84.8 ± 0.78 and 93.71 ± 0.34 per cent in S-I and S-II respectively. Rainfall received during S-I and S-II was 719.21 (10 d) and 775.21 mm (40 d) respectively. THI values obtained were 84.88 ± 0.22 in S-I and 79.22 ± 0.12 in S-II.

The mean temperature of the substrate was higher in summer season (around 29°C) when compared to monsoon (around 25°C). In T1, T2 and T4 pH was slightly alkaline but in T3 it was slightly acidic in nature. Total solid (TS) content of the substrate in different treatments was in the range of 7 -10 per cent. T3 was having highest TS content of 10.32 ± 0.69 and 10.14 ± 0.69 per cent in S-I and S-II respectively. Volatile solid (VS) content was varying significantly between treatments with T1 having highest (84.23 ± 0.34 per cent in S-I and 82.28 ± 0.34 in S-II). C/N ratio was highest in T2 (27.62 ± 0.66 in S-I and 28.64 ± 0.66) and least in T3 (16.66 ± 0.66 in S-I and 17.41 in S-II). A slight increase in the C/N values of T1, T2 and T3 was noticed from summer to monsoon but in T4 it was vice versa. Manurial value of the substrate was estimated and Nitrogen content was found to be high in T3 (3.12 ± 0.02 in S-I and 2.81 ± 0.02 in S-II) and it was more in summer. Phosphorous content was highest in T4 (2.25 ± 0.03 in S-I and 2.32 ± 0.03 per cent) while, potassium content was highest in T2 (1.33 ± 0.02 per cent in S-I and 1.28 ± 0.02 per cent in S-II).

The observed average HRT was less during S-I (22 d) when compared to S-II (28 d). Gas yield was observed from third day but the combustible biogas was

obtained from eighth day onwards. Initially, T1 and T2 production was more rapid and gas production ceased at around 12th day. Gas yield restarted from 16th day, reached maximum and got stabilized by around 20-24 d (S-I), 27 – 29 d (S-II) in all treatments. Average daily yield (L) was highest in T4 in both the seasons. The trend in average yield was T4 (16.41 ± 0.10) followed by T2 (15.39 ± 0.86), T3 (13.73 ± 0.64) and T1 (10.24 ± 0.11). Likewise, in S-II T4 was having highest yield (14.24 ± 0.10) followed by T2 (13.32 ± 0.86), T3 (11.53 ± 0.64) and T1 (9.29 ± 0.11). Cumulative yield (L) obtained throughout the experiment in S-I was highest in T4 with a total yield of 667.78 followed by T2 (650.57), T3 (567.65) and T1 (485.22). Similar trend was observed even in S-II with a total yield in different treatments was 418.50 in T1, 545.08 in T2, 467.56 in T3 and 571.08 in T4.

Temperature of biogas (°C) was highest in S-I (32.42 ± 1.28) followed by S-II (27.60 ± 1.54). Relative humidity (per cent) of the biogas produced was similar in both the seasons (76.50 ± 1.28 in S-I and 76.67 ± 1.54 in S-II). Methane content (per cent) was highest in T4 (62.42 ± 0.26 in S-I and 60.30 ± 0.26 in S-II). Carbon dioxide concentration (per cent) was higher in T1 (43.45 ± 0.25 in S-I and 44.82 ± 0.25 in S-II). Levels of H₂S, NO and NH₃ were found to be higher in T3 in both the seasons. Concentration of SO₂ varied between 0.10 to 0.20 ppm in both the seasons.

Slurry was collected and weighed every day in the morning. T2 had produced higher quantity of slurry (kg) in both the seasons (3.04 ± 0.04 in S-I and 3.18 ± 0.04 in S-II). Temperature was found to be high in S-I (around 32 °C) and low in S-II (around 28 °C). pH was slightly alkaline in T1, T2 and T4 but in T3 it was more alkaline in nature. Total solid (TS) content of the slurry in different treatments was in the range of four to five per cent and the values were slightly higher in S-II. T2 was having highest TS content of 5.29 ± 0.03 and 5.39 ± 0.69 per cent in S-I and S-II respectively. Volatile solid (VS) content of the slurry was highest for T1 (24.64 ± 0.71 in S-I and 26.48 ± 0.34 per cent in S-II). C/N ratio of slurry was highest in T2 (8.56 ± 0.06 in S-I and 8.92 ± 0.06) and least in T4 (5.84 ± 0.06 in S-I and $6.24 \pm$

0.06 in S-II). Nitrogen content (per cent) of slurry was estimated on fresh basis and T3 was found to be highest in both the seasons (3.48 ± 0.02 in S-I and 3.17 ± 0.02 in S-II) with higher values during summer. Phosphorous content of the substrate was highest in T4 (2.28 ± 0.02 per cent in S-I and 2.33 ± 0.02 per cent in S-II).

There was a positive correlation ($P < 0.01$) between mean daily temperature and gas production from all the treatments and no correlation ($P > 0.01$) was observed between relative humidity and gas production. A positive correlation ($P < 0.01$) between THI and gas production was observed in all the substrates. There was a significant change in the N content in slurry when compared to that of substrate and there was no significant change in the concentration of P and K. Carbon sequestration was calculated in CO₂ equivalents and it was highest for T4 with GWMP of 5.39 CO₂ equiv. Cost of production per litre biogas was least in T4 (0.08 INR) followed by T3 (0.10 INR), T1 (0.11 INR) and T2 (0.34 INR).

Hence, from the present study it can be concluded that co-digestion had a greater influence on the quantity and quality of the biogas produced from livestock manures. Superior biogas yield from T4 substrate with cattle and swine manure might be due to the interaction of various factors at optimum levels *viz.*, pH, TS content of the substrate and C/N ratio. Effect of chemical composition of the individual manures on AD was also clearly evident as in case of T3, where the presence of poultry manure had resulted in decreased efficiency when compared to T4. Greater influence of the microclimate on the performance of the digester is clearly manifested by the increased biogas yield and methane concentration from all the treatments in S-I when compared to S-II. The relative humidity had no influence on the performance of AD but THI values had a positive correlation on the quantity of gas produced. Slurry obtained had good manurial value and it can be used for application in agriculture. Utilisation of biogas on large scale as a substitute for firewood and fossil fuels will help in mitigating GHG emission and aids in carbon sequestration with an additional income to the farm. Cost of production per litre biogas was least in T4 (0.08 INR)

when compared to other treatments. The present study has helped to overcome the limitations of earlier works carried out with monogastric manure for biogas production.

Further, extensive research has to be carried in the development of integrated models of farming system with biogas technology as one integer and widespread awareness on design of digester, optimisation of available substrate combinations, dilution factor, addition of inoculum and scrubbing mechanism have to be structured among the farming community for a sustainable and green economy.

7. REFERENCES

- Abdulsalam, S., Mohammed, J. and Etim, J.O. 2012. Production of biogas from cow and elephant dung. *Global J. Engng. Tech.* **5**: 51-56.
- Adekunle, K.F. and Okolie, J.A. 2015. A review of biochemical process of anaerobic digestion. *Adv. Biosci. Biotech.* **6**: 205-218.
- Adelekan, B.A. and Bamgboye, A.I. 2009. Comparison of biogas productivity of cassava peels mixed in selected ratios with major livestock waste types. *Afr. J. Agric. Res.* **4**: 571-577.
- Agrahari, R.P. and Tiwari, G.N. 2011. Parametric study of portable floating type biogas plant. In: *World Renewable Energy Congress-Sweden*; 8th to 13th May, 2011, Linköping; Sweden. Linköping University Electronic Press. pp. 404-410.
- Ahn, H.K., Smith, M.C., Kondrad, S.L. and White, J.W. 2010. Evaluation of biogas production potential by dry anaerobic digestion of switchgrass – animal manure mixtures. *Appl. Biochem. Biotech.* **160**: 965-975.
- Alvarez, R. and Liden, G., 2008. The effect of temperature variation on biomethanation at high altitude. *Bioresour. Technol.* **99**: 7278-7284.
- An, B.X. and Preston, T.R. 1999. Gas production from pig manure fed at different loading rates to polyethylene tubular bio-digesters. *Livest. Res. Rural Dev.* **11**: 1-9.
- Andrade, W.R., Xavier, C.A.N., Coca, F.O.C.G., Arruda, L.D.O. and Santos, T.M.B. 2016. Biogas production from ruminant and monogastric animal manure co-digested with manipueira. *Arch. Zootec.* **65**:375-380.

- Anzar, M.R. 2014. Assessment of biogas production potential of monogastric farm animal waste. *M.V.Sc thesis*, Kerala Veterinary and Animal Sciences University, Pookode, 57p.
- AOAC 2012. *Official methods of Analysis* (19th Ed.). Association of Official Analytical Chemists, Washington D. C, USA.
- Arreola-Vargas, J., Ojeda-Castillo, V., Snell-Castro, R., Corona-Gonzalez, R.I., Alatraste-Mondragon, F. and Mendez-Acosta, H.O. 2015. Methane production from acid hydrolysates of *Agave tequilana* bagasse: evaluation of hydrolysis conditions and methane yield. *Bioresour. Technol.* **181**:191-199.
- Atandi, E. and Rahman, S. 2012. Prospect of anaerobic co-digestion of dairy manure: a review. *Environ. Technol. Rev.* **1**: 127-135.
- Babae, A., Shayegan, J. and Roshani, A. 2013. Anaerobic slurry co-digestion of poultry manure and straw: effect of organic loading and temperature. *J. Environ. Hlth. Sci. Engng.* **11**: 1-6.
- Babatola, J.O. 2008. Comparative study of biogas yield pattern in some animal and household wastes. *Afr. Res. Rev.* **2**:54-68.
- Barik, D. and Murugan, S. 2015. Assessment of sustainable biogas production from de-oiled seed cake of karanja-an organic industrial waste from biodiesel industries. *Fuel.* **148**: 25-31.
- Bouskova, A., Dohanyos, M., Schmidt, J.E., Angelidaki, I. 2005. Strategies for changing temperature from mesophilic to thermophilic conditions in anaerobic CSTR reactors treating sewage sludge. *Wat. Res.* **39**: 1481–1488.

- Budiyono, T.D., Kusworo, A.F., Ismail, I.N. and Widiassa, S.J. 2010. Synthesis and characterization of polyimide–zeolite mixed matrix membrane for biogas purification. *Int. J. Basic Appl. Sci.* **10**:1-7.
- Cantrell, K.B., Ducey, T., Ro, K.S. and Hunt, P.G. 2008. Livestock waste-to-bioenergy generation opportunities. *Bioresour. Technol.* **99**: 7941-7953.
- Cavinato, C., Fatone, F., Bolzonella, D. and Pavan, P. 2010. Thermophilic anaerobic co-digestion of cattle manure with agro-wastes and energy crops: comparison of pilot and full scale experiences. *Bioresour. Technol.* **101**: 545-550.
- Chandra, R., Vijay, V.K., Subbarao, P.M.V. and Khura, T.K. 2011. Performance evaluation of a constant speed IC engine on CNG, methane enriched biogas and biogas. *Appl. Energy.* **88**: 3969-3977.
- Chandra, R., Vijay, V.K., Subbarao, P.M.V. and Khura, T.K. 2012. Production of methane from anaerobic digestion of jatropha and pongamia oil cakes. *Appl. Energy.* **93**: 148-159.
- Christy, P.M., Gopinath, L.R. and Divya, D. 2014. A review on anaerobic decomposition and enhancement of biogas production through enzymes and microorganisms. *Renewable Sustain. Energy Rev.* **34**: 167-173.
- Clemens, J., Trimborn, M., Weiland, P. and Amon, B. 2006. Mitigation of greenhouse gas emissions by anaerobic digestion of cattle slurry. *Agric., Ecosyst. Environ.* **112**: 171-177.
- Costa, J.C., Barbosa, G., Alves, M.M. and Souza, D.Z. 2012. Thermochemical pre- and biochemical co- treatments to improve hydrolysis and methane production from poultry litter. *Bioresour. Technol.* **111**:141-147.

- Cuellar, A.D. and Webber, M.E. 2008. Cow power: the energy and emissions benefits of converting manure to biogas. *Environ. Res. Lett.* **3**: 1-8.
- Cuili, Z., Gaihe, Y., Guanxin, R., Lili, C., Yongzhong, F. and Dongsheng, B. 2008. Effects of temperature on biogas production efficiency and fermentation time of four manures. *Trans. Chinese Soc. Agric. Engng.* **7**: 1-6.
- Davis, J. 2017. Mineral profile of livestock farm waste and its bio-accumulation effects in crossbred cattle. *Ph.D thesis*, Kerala Veterinary and Animal Sciences University, Pookode, 146p.
- Deshmukh, H.V. 2012. Economic feasibility and pollution abatement study of biogas production process utilizing admixture of *Ipomea carnea* and distillery waste. *J. Environ. Res. Dev.* **7**: 633- 641.
- Dhanalakshmi, S.V. and Ramanujam, R.A. 2012. Biogas generation in a vegetable waste anaerobic digester: An analytical approach. *Res. J. Recent Sci.* **1**: 41-47.
- Dioha, I.J., Ikeme, C.H., Nafiu, T., Soba, N.I. and Yusuf, M.B.S. 2013. Effect of carbon to nitrogen ratio on biogas production. *Int. Res. J. Nat. Sci.* **1**: 1-10.
- Divya, D., Gopinath, L.R. and Christy, P.M. 2014. A Review on Trends issues and Prospects for Biogas Production in Developing Countries. *Int. Res. J. Environ. Stud.* **3**: 62 – 69.
- Divya, D., Gopinath, L.R. and Christy, P.M., 2015. A review on current aspects and diverse prospects for enhancing biogas production in sustainable means. *Renewable Sustain. Energy Rev.* **42**: 690-699.

- Dueblein, D. and Steinhauser, A. 2008. *Biogas from waste and renewable resources*. KGaA: Wiley-VCH Verlag GmbH and Co. 276p.
- Eggleston, H.S., Buendia, L., Miwa, K., Ngara, T. and Tanabe, K. 2006. *IPCC guidelines for national greenhouse gas inventories*. Institute for Global Environmental Strategies, Hayama, Japan, 285p.
- Ekama, G. and Wentzel, M. 2008. *Organic material removal. Biological Wastewater Treatment: Principles, Modelling and Design*. IWA Publishing, London, UK. pp. 53-86.
- El-Mashad, H.M., Zeeman, G., van Loon, W.K.P., Gerard, P.A.B. and Lettinga, G. 2004. Effect of temperature and temperature fluctuation on thermophilic anaerobic digestion of cattle manure. *Bioresour. Technol.* **95**: 191–201.
- Esposito, G., Frunzo, L., Giordano, A., Liotta, F., Panico, A. and Pirozzi, F. 2012. Anaerobic co-digestion of organic wastes. *Rev. Environ. Sci. Biotech.* **11**: 325-341.
- Ferreira, L., Durate, D. and Figueiredo, D. 2012. Utilization of wasted sardine oil as co-substrate with pig slurry for biogas production – A pilot experience of decentralized industrial organic waste management in a Portuguese pig farm. *Bioresour. Technol.* **116**: 285-289.
- Garba, B. 1996. Effect of temperature and retention period on biogas production from lignocellulosic material. *Renewable Energy.* **9**: 938-941.
- Garfi, M., Gelman, P., Comas, J., Carrasco, W. and Ferrer, I. 2011. Agricultural reuse of the digestate from low-cost tubular digesters in rural andean communities. *Waste Manag.* **31**: 2584–2589.

- Gebrezgabher, S.A., Meuwissen, M.P. and Lansink, A.G.O. 2010. Costs of producing biogas at dairy farms in the Netherlands. *Int. J. Food Syst. Dyn.* **1**: 26-35.
- Ghani, W.A.W.A.K. and Idris, A. 2009. Preliminary study on biogas production of biogas from municipal solid waste (MSW) leachate. *J. Engng. Sci. Tech.* **4**: 374-380.
- Hagos, K., Zong, J., Li, D., Liu, C. and Lu, X. 2016. Anaerobic co-digestion process for biogas production: progress, challenges and perspectives. *Renewable Sustain. Energy Rev.* 1485-1496.
- Hansen, K.H., Angelidaki, I. and Ahring, B.K. 1998. Anaerobic digestion of swine manure: inhibition by ammonia. *Water Res.* **32**: 5-12.
- Hassan, M. A. M. 2004. The feasibility of family biogas production from mixed organic wastes in Palestinian rural areas. *M.Sc. thesis*, Faculty of Graduated Studies, An-Najah National University, 163p.
- Iyagba, E.T., Mangibo, I.A. and Mohammad, Y.S. 2009. The study of cow dung as co-substrate with rice husk in biogas production. *Sci. Res. Essays.* **4**: 861-866.
- Joseph, B.A. 2011. Assessment and alleviation of environmental stress on productive performance of rabbits. *Ph.D. thesis*, Kerala Veterinary and Animal Sciences University, Pookode, 158p.
- Kacprzak, A., Krzystek, L. and Ledakowicz, S. 2010. Co-digestion of agricultural and industrial wastes. *Chem. Pap.* **64**: 127-131.

- Kallistova, A.Y., Goel, G. and Nozhevnikova A.N. 2014. Microbial diversity of methanogenic communities in the systems for anaerobic treatment of organic waste. *Microbiol.* **83**: 462–83.
- Kangle, K.M., Kore, S.V., Kore, V.S. and Kulkarni, G.S. 2012. Recent trends in anaerobic codigestion: a review. *Univers. J. Environ. Res. Technol.* **2**: 210-219.
- Kelleher, B.P., Leahy, J.J., Henihan, A.M., O'Dwyer, T.F., Sutton, D. and Leahy, M.J. 2002. Advances in poultry litter disposal technology – a review. *Bioresour. Technol.* **83**: 27-36.
- Khoiyangbam, R.S., Kumar, S., Jain, M.C., Gupta, N., Kumar, A. and Kumar, V. 2004. Methane emission from fixed dome biogas plants in hilly and plain regions of northern India. *Bioresour. Technol.* **95**: 35-39.
- Kiely, G., Tayfur, G., Dolan, C. and Tanji, K. 1997. Physical and mathematical modelling of anaerobic digestion of organic wastes. *Wat. Res.* **31**: 534-540.
- Komemoto, K., Lim, Y.G., Nagao, N., Onoue, Y., Niwa, C. and Toda, T. 2009. Effect of temperature on VFA's and biogas production in anaerobic solubilization of food waste. *Waste Mgmt.* **29**: 2950-2955.
- Lalitha, K., Swaminathan, K.R. and Padma, B.R. 1994. Kinetics of biomethanation of solid tannery waste and the concept of interactive metabolic control. *Appl. Biochem. Biotech.* **47**: 73-87.
- Li, G., Li, H., Leffelaar, P.A., Shen, J. and Zhang, F. 2014. Characterization of phosphorus in animal manures collected from three (dairy, swine, and broiler) farms in China. *PLoS One.* **9**: 1-8

- Li, X., Li, L., Zheng, M., Fu, G. and Lar, J.S. 2009. Anaerobic co-digestion of cattle manure with corn stover pretreated by sodium hydroxide for efficient biogas production. *Energy Fuels*. **23**: 4635-4639.
- Liu, G., Zhang, R., El-Mashad, H.M. and Dong, R. 2009. Effect of feed to inoculum ratios on biogas yields of food and green wastes. *Bioresour. Technol.* **100**: 5103-5108.
- Lo, K.V. and Liao, P.H. 1986. Digestion of cheese whey with anaerobic rotating biological contact reactors. *Biomass*. **10**: 243-252.
- Macias-Corral, M., Samani, Z., Hanson, A., Smith, G., Funk, P., Yu, H. and Longworth, J. 2008. Anaerobic digestion of municipal solid waste and agricultural waste and the effect of co-digestion with dairy cow manure. *Bioresour. Technol.* **99**: 8288-8293.
- Mader, T.L., Davis, M.S. and Brown-Brandl, T. 2006. Environmental factors influencing heat stress in feedlot cattle. *J. Anim. Sci.* **84**: 712-719.
- Mahadevaswamy, M. and Venkataraman, L.V. 1988. Integrated utilization of rabbit droppings for biogas and fish production. *Biol. Wastes*. **25**: 249-256.
- Mahanta, P., Saha, U.K., Dewan, A., Kalita, P. and Buragohain, B. 2005. Biogas digester: a discussion on factors affecting biogas production and field investigation of a novel duplex digester. *SESI J.* **15**: 1-12.
- Malini, T. and Narayanan, D.K. 2015. Evaluation of biogas production potential from elephant dung. *Int. Res. J. Engng. Technol.* **02**: 1780 - 1785

- Mao, C., Feng, Y., Wang, X. and Ren, G. 2015. Review on research achievements of biogas from anaerobic digestion. *Renewable Sustain. Energy Rev.* **45**: 540-555.
- Mata-Alvarez, J., Mace, S. and Llabres, P. 2000. Anaerobic digestion of organic solid wastes: an overview of research achievements and perspectives. *Bioresour. Technol.* **74**: 3-16.
- Mateescu, C. and Constantinescu, I. 2011. Comparative analysis of inoculum biomass for biogas potential in the anaerobic digestion. *UPB Sci. Bull.* **73**: 99-104.
- Mital, K.M. 1996. *Biogas systems – Principles and applications*. (1st Ed.). New age international (p) limited, New Delhi, 412p.
- Moller, H.B., Sommer, S.G. and Ahring, B.K. 2004. Methane productivity of manure, straw and solid fractions of manure. *Biomass Bioenergy.* **26**: 485-495.
- Monou, M., Pafitis, N., Kythreotou, N., Smith, S.R., Mantzavinos, D. and Kassinou, D. 2008. Anaerobic co-digestion of potato processing wastewater with pig slurry and abattoir wastewater. *J. Chem. Technol. Biotechnol.* **83**: 1658–63.
- Monteiro, E., Mantha, V. and Rouboa, A. 2011. Prospective application of farm cattle manure for bioenergy production in Portugal. *Renewable Energy.* **36**: 627-631.
- Muyiyi, N. and Kasisira, L. 2009. Assessment of the effect of mixing pig and cow dung on biogas yield. *Agric. Engng. Int.* **11**: 1-5.
- Nagamani, B. and Ramasamy, K. 1999. Biogas production technology: An Indian perspective. *Curr. Sci.* **77**: 44-55.

- Naik, L., Gebreegziabher, Z., Tumwesige, V., Balana, B.B., Mwirigi, J. and Austin, G. 2014. Factors determining the stability and productivity of small scale anaerobic digesters. *Biomass Bioenergy*. **70**: 51-57.
- Neves, L., Oliveira, R. and Alves, M.M. 2009. Co-digestion of cow manure, food waste and intermittent input of fat. *Bioresour. Technol.* **100**: 1957-1962.
- Nijaguna, B.T. 2012. *Biogas Technology*. (2nd Ed.). New Age International Publishers, New Delhi, 287p.
- Nishant, P. 2009. Management protocol for averting drop of milk production in dairy cattle during summer. *M.V.Sc thesis*, Kerala Agricultural University, Thrissur, 65p.
- Nnabuchi, M.N., Akubuko, F.O., Augustine, C. and Ugwu, G.Z. 2012. Assessment of the effect of co-digestion of chicken dropping and cow dung on biogas generation. *Global J. Sci. Front. Res.* **12**: 21-26.
- Ogunwande, G.A., Adeagbo, O.A. and Ojo, S.O. 2015. Enhancing biogas yield from cow dung by co-digesting with chicken and swine manures at different proportions. *J. Solid Waste Technol. Mgmt.* **41**:157-164.
- Olowoyeye, J. 2013. Comparative Studies on Biogas Production using Six Different Animal Dungs. *J. Biol. Agric. Healthcare.* **3**: 7-10.
- Pathak, H., Jain, N., Bhatia, A., Mohanty, S. and Gupta, N. 2009. Global warming mitigation potential of biogas plants in India. *Environ. Monitor. Assess.* **157**: 407-418.
- Paudel, B.P. 2012. Suitability of azolla (*azolla pinnata*) for biogas slurry enhancement. *M.Sc. thesis*, Kerala Agricultural University, Thrissur, 58p.

- Perrigault, T., Weatherford, V., Marti-Herrero, J. and Poggio, D. 2012. Towards thermal design optimization of tubular digesters in cold climates: A heat transfer model. *Bioresour. Technol.* **124**: 259-268.
- Pham, C.H., Triolo, J.M. and Sommer, S.G. 2014. Predicting methane production in simple and unheated biogas digesters at low temperatures. *Appl. Energy.* **136**: 1-6.
- Poliaficio, M. 2007. Anaerobic digestion: decision support software. *Masters Degree Dissertation*. Cork Institute of Technology, Department of Civil, Structural and Environmental Engineering. Cork. Ireland.
- Porras, J.P. and Gebresenbet, G. 2003. *Review of biogas development in developing countries with special emphasis in India*. Sveriges lantbruks university.
- Poschl, M., Ward, S. and Owende, P. 2010. Evaluation of energy efficiency of various biogas production and utilization pathways. *Appl. Energy.* **87**: 3305-3321.
- Prasad, A. 2014. Climatic adaptation and stress evaluation of crossbred cattle of Kerala. *Ph.D thesis*, Kerala Veterinary and Animal Sciences University, Pookode, 160p.
- Qi, X., Zhang, S., Wang, Y. and Wang, R. 2005. Advantages of the integrated pig-biogas-vegetable greenhouse system in North China. *Ecol. Eng.* **24**: 175–183.
- Radhakrishnan, M. 2013. Development and evaluation of a model for wastewater management in Pig farms. *M.V.Sc. thesis*, Kerala Veterinary and Animal Sciences University, Pookode, 98p.

- Raheman, H. and Mondal, S. 2012. Biogas production potential of jatropha seed cake. *Biomass Bioenergy*. **37**: 25-30.
- Rajendran, K., Aslanzadeh, S. and Taherzadeh, M.J. 2012. Household biogas digesters—A review. *Energies*. **5**: 2911-2942.
- Rao, A.G., Prakash, S.S., Joseph, J., Reddy, A.R. and Sarma, P.N. 2011. Multi stage high rate biomethanation of poultry litter with self-mixed anaerobic digester. *Bioresour. Technol.* **102**:729-735.
- Rico, C., Munoz, N., Fernandez, J. and Rico, J.L. 2015. High-load anaerobic co-digestion of cheese whey and liquid fraction of dairy manure in a one-stage UASB process: limits in co-substrates ratio and organic loading rate. *Chem. Engng, J.* **262**: 794-802.
- Rico, J.L., Garcia, H., Rico, C. and Tejero, I. 2007. Characterisation of solid and liquid fractions of dairy manure with regard to their component distribution and methane production. *Bioresour. Technol.* **98**: 971-979.
- Rincoin, B., Borja, R., Martin, M.A. and Martin, A. 2009. Evaluation of the methanogenic step of a two-stage anaerobic digestion process of acidified olive mill solid residue from a previous hydrolytic–acidogenic step. *Waste Mgmt.* **29**: 2566-2573.
- Salminen, E.A. and Rintala, J.A. 2002. Semi-continuous anaerobic digestion of solid poultry slaughterhouse waste: effect of hydraulic retention time and loading. *Water Res.* **36**: 3175-3182.
- Schnurer, A. and Nordberg, A. 2008. Ammonia, a selective agent for methane production by syntrophic acetate oxidation at mesophilic temperature. *Water Sci. Technol.* **57**: 735–40.

- Seadi, T., Rutz, D., Prassl, H., Kottner, M., Finsterwalder, T., Volk, S. and Janssen, R. 2008. *Biogas Handbook*. University of Southern Denmark, Denmark.
- Sebola, M. R., Tesfagiorgis, H. B. and Muzenda, E. Methane production from anaerobic co-digestion of cow dung, chicken manure, pig manure and sewage waste. In: Vol. I WCE 2015, *Proceedings of the World Congress on Engineering*; 1st to 3rd July, 2015. London, U.K. pp.592-598
- Seppala, M. 2013. Biogas production from high-yielding energy crops in boreal conditions. *Jyvaskyla studies in biological and environmental science*. University Library of Jyvaskyla, 266p.
- Shan, M.H. 1991. Biogas production from sheep and goat manure. *Landtechnik*. **46**: 535-538.
- Sharma, D.K, and Agrawal, G.D. 2011. Carbon credit potential of biogas plants at Durgapura Goushala, Jaipur. *Proceedings of the international conference on science and engineering*, RG Education society.
- Shejir, R.M. 2014. Assessment of biogas production potential of ruminant farm animal waste. *M.V.Sc thesis*, Kerala Veterinary and Animal Sciences University, Pookode, 61p.
- Singh, P.S., Vatsa, D.K. and Verma, H.N. 1997. Problems with biogas plants in Himachal Pradesh. *Bioresour. Technol.* **59**: 69 – 71.
- Singh, R. and Mandal, S.K. 2011. The utilization of non-edible oil cake along with cow dung for methane-enriched biogas production using mixed inoculum. *Energy Sources, Part A*: **33**: 449-458.

- Snedecor, G.W. and Cochran, W.G. 1994. *Statistical Methods*. (8th Ed.). The Iowa State University Press, Ames, Iowa, USA, 564 p.
- Sommer, S.G., Petersen, S.O., Sorensen, P., Poulsen, H.D. and Møller, H.B. 2007. Methane and carbon dioxide emissions and nitrogen turnover during liquid manure storage. *Nutr. Cycling Agroecosyst.* **78**: 27-36.
- Song, L., Deng, L., Yong, Y., Xiaodong, P. and Zhiyong, W. 2010. Biogas production potential of manure sheep, duck and rabbit for anaerobic digestion and their characteristics. *Trans CSAE.* **26**: 277-82.
- Sreekrishnan, T.R., Kohli, S. and Rana, V. 2004. Enhancement of biogas production from solid substrates using different techniques - a review. *Bioresour. Technol.* **95**:1-10.
- Suryawanshi, P.C., Chaudhari, B., Bhardwaj, S. and Yeole, T.Y. 2013. Operating procedures for efficient anaerobic digester operation. *Res. J. Anim. Vet. Fish. Sci.* **1**:12-15.
- Thy, S. 2003. Management and utilization of biodigesters in integrated farming systems. *M.Sc. Paper*. University of Tropical Agriculture Foundation, Cambodia, 18p.
- Tippayawong, N. and Thanompongchart, P. 2010. Biogas quality upgrade by simultaneous removal of CO₂ and H₂S in a packed column reactor. *Energy.* **35**: 4531- 4535.
- Tomar, S.S. 1995. *Energy agriculture and environment: with special reference to non-conventional energy sources in development of rural areas.* (1st Ed.). Mittal Publications, New Delhi. 213p.

- Topper, P.A., Graves, R.E. and Richard, T., 2006. The fate of nutrients and pathogens during anaerobic digestion of dairy manure. *Lehman (PA): Penn State University. College of Agricultural Science, Cooperative Extension Bulletin*. 71p.
- Tucho, G.T., Moll, H.C., Schoot Uiterkamp, A.J. and Nonhebel, S. 2016. Problems with biogas implementation in developing countries from the perspective of labor requirements. *Energies*. **9**: 750.
- USDA - NRCS. 2007. [United States Department of Agriculture – Natural Resources Conservation Service]. *Manure chemistry – Nitrogen, Phosphorous and Carbon*. Manure management information sheet No.7. USA. 4p.
- Wang, X., Yang, G., Feng, Y., Ren, G. and Han, X. 2012. Optimizing feeding composition and carbon-nitrogen ratios for improved methane yield during anaerobic co-digestion of dairy, chicken manure and wheat straw. *Bioresour. Technol.* **120**: 78–83.
- Wante, H.P., Ngaram, S.M., Bala, G.A. and Buba, M. 2016. Optimization of biogas production from cow and goat manure. *IDOSR J. Appl. Sci.* **1**: 24-35.
- Weiland, P., 2010. Biogas production: current state and perspectives. *Appl. Microbiol. Biotech.* **85**: 849-860.
- Wijeyamohan, S. 2003. Biogas from elephant dung: a means of mitigating human-elephant conflict. *Gajah*. **22**: 62-64.
- Yangin-Gomec, C. and Ozturk, I. 2013. Effect of maize silage addition on biomethane recovery from mesophilic co-digestion of chicken and cattle manure to suppress ammonia inhibition. *Energy conversion mgmt.* **71**: 92-100.

- Yasin, M. and Wasim, M. 2011. Anaerobic digestion of buffalo dung, sheep waste and poultry litter for biogas production. *J. Agric. Res.* **49**:73-82.
- Ye, J., Li, D., Sun, Y., Wang, G., Yuan, Z., Zhen, F. and Wang, Y. 2013. Improved biogas production from rice straw by co-digestion with kitchen waste and pig manure. *Waste Mgmt.* **33**: 2653-2658.
- Yin, F., Li, Z., Zhou, X., Bai, X. and Lian, J. 2016. Effects of temperature and relative humidity on the methane permeability rate of biogas storage membranes. *Int. J. Green Energy.* **13**: 951-956.
- Zhang, T., Liu, L., Song, Z., Ren, G., Feng, Y., Han, X. and Yang, G. 2013. Biogas production by co-digestion of goat manure with three crop residues. *PloS one.* **8**: 1-7
- Zhou, Y., Zhang, Z., Nakamoto, T., Li, Y., Yang, Y., Utsumi, M. and Sugiura, N. 2011. Influence of substrate-to-inoculum ratio on the batch anaerobic digestion of bean curd refuse-okara under mesophilic conditions. *Biomass Bioenergy.* **35**: 3251-3256.
- Zupanic, G.D. and Grilc, V. 2012. Anaerobic treatment and biogas production from organic waste. *Mgmt. Org. Waste.* 1-28.

**ENHANCING BIOGAS PRODUCTION BY CO-DIGESTION OF
LIVESTOCK MANURES**

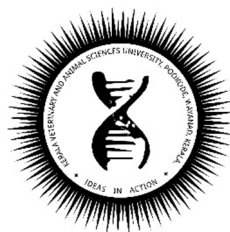
**CHINTALAPATI GOWTHAM VARMA
(15-MVM-15)**

ABSTRACT OF THESIS

Submitted in partial fulfilment of the requirement for the degree of

**MASTER OF VETERINARY SCIENCE
(Livestock Production Management)
2017**

**Faculty of Veterinary and Animal Sciences
Kerala Veterinary and Animal Sciences University**



**DEPARTMENT OF LIVESTOCK PRODUCTION MANAGEMENT
COLLEGE OF VETERINARY AND ANIMAL SCIENCES
MANNUTHY, THRISSUR- 680 651
KERALA, INDIA**

ABSTRACT

The study was conducted to estimate the biogas production by anaerobic co-digestion of different livestock manures and the effect of season on biogas yield. The experiment was conducted in two seasons *viz.*, summer and monsoon for 60 days in each season with biogas plants of 0.5 m³ capacity. Four treatments were considered for the study namely, T1 (Two kg of fresh cattle dung), T2 (One kg each of fresh cattle and goat manure), T3 (One kg each of fresh cattle and poultry manure) and T4 (One kg each of cattle and pig manure). Substrates were diluted with water in 1:1 ratio on whole weight basis and the biogas production was recorded every day. Composition of biogas was determined using gas analyzer at weekly interval. Physico-chemical analysis of substrate and slurry were carried out at weekly intervals

Average daily biogas yield (L) was highest in T4 (16.41 ± 0.10 in S-I and 14.24 ± 0.10 in S-II) followed by T2 (15.39 ± 0.86 in S-I and 13.32 ± 0.86 in S-II), T3 (13.73 ± 0.64 in S-I and 11.53 ± 0.64 in S-II) and T1 (10.24 ± 0.11 in S-I and 9.29 ± 0.11 in S-II). There was a significant difference between the treatments ($P < 0.05$) in both the seasons and the gas yield was highest in summer. Cumulative yield (L) obtained throughout the experiment in S-I was highest in T4 with a total yield of 667.78 followed by T2 (650.57), T3 (567.65) and T1 (485.22) in S-I. While, in S-II it was 418.50 in T1, 545.08 in T2, 467.56 in T3 and 571.08 in T4. A significant positive correlation of ambient temperature and THI on biogas yield was noticed. Average methane yield also differed significantly ($P < 0.05$) ranging from 52-62 per cent with highest yield from T4 (62.42 ± 0.26 in S-I and 60.30 ± 0.26 in S-II). The biogas slurry was observed to have good nutritive value and CO₂ equivalent (kg) mitigated in the experiment by T1, T2, T3 and T4 was 3.93, 5.24, 4.31 and 5.39 respectively. The cost of production per liter of biogas was least in T4 (0.08 INR) followed by T3 (0.10 INR), T1 (0.11 INR) and T2 (0.34 INR).

CURRICULUM VITAE

1. **Name of the candidate** : C. GOWTHAM VARMA
2. **Date of birth** : 07-05-1992
3. **Place of birth** : Visakhapatnam, A.P
4. **Marital status** : Unmarried
5. **Permanent address** : 4-40/1, Thatithuru, Bheemunipatnam,
Visakhapatnam, AndhraPradesh, 531162
Mobile : 7893323532
E mail : varma200911@gmail.com
6. **Major field of specialization** : Livestock Production Management
7. **Educational status** : B.V.Sc & A.H
8. **Professional experience** : Nil
9. **Publications made** :

Varma, C.G., Kannan, A., Anil, K.S., Geetha, N., Shyama, K. and Gleeja, V.L.
2017. Co-digestion of livestock manures for enhanced biogas production. *Int. J. Sci. Environ. Technol.* **6**: 2005-2010.
10. **Membership of professional societies** : A.P. State Veterinary council