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Chapter 8

Grass Silage for Biogas Production

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Abstract

Renewable energy resources of part of the Asian region are not only able to fight against climate change issues but also could contribute to economic growth, employment, and energy safety. Biogas production and use are generally regarded as a sustainable practice that can guarantee high greenhouse gas savings. Thailand is an agricultural area suitable for growing of many plants, especially annual crops that can be used as an energy crop or raw material for biogas plant. In addition, grassland biomass is suitable in numerous ways for producing energy and is the most common material for producing biogas in the present scenario. There are several types of grasses popularly growing in Thailand. Grasses are converted to silage which will be used as feedstock for anaerobic digestion. Consequently, this chapter addresses the advances in silage preparations and utilization for efficient biogas production with several digestion methods including dry and wet fermentation processes, monodigestions, and co-digestions.

Keywords: silage preparation, thai grasses, fermenters, biogas, renewable energy

1. Introduction

Agriculture is the predominant occupation of Thai people despite the constant industrial growth occurring in many parts of Thailand. In terms of agricultural lands, Thailand is also one of the largest countries in the world, especially in Asia [1]. Thailand is one of the fastest growing and energy-intensive economies in South-East Asia. Fifty percent of the total energy demand required to meet the present growth is met only through import [2]. Being a country with plenty of agricultural and energy crops, Thailand has the potential to fulfill the energy needs through biogas production [3]. Anaerobic digestion technology has emerged as one of

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the best technologies for the production of biogas [4]. Because of the concerns regarding energy security and environmental impact of fossil fuels, utilization of renewable energy is significantly increasing which will leads to the upgradation of living standards of people [5].

Energy crops are the type of plants cultivated as raw materials for biogas production. Agricultural lands in Thailand are well suitable for growing annual crops. Usually, temperature is warm to hot weather year-round in Thailand. The highest temperature recorded is generally during summer in the months of March till May. Most of the region receives an average rainfall of around 1100 mm. The annual crops can be used as an energy crop or raw material for biogas plant [1]. Among energy crops, grasses which belong to perennial crops are suitable due to their fastest growing rates even in infertile land, low cultivation costs, higher accessibility, consumption of whole plants, and lower environmental impacts when compared to other plants [6]. Some grass species are reported to have large amount of fibers and carbohydrates from which biogas can be produced. Many such types of grasses are popularly growing in Thailand [3, 7]. Grass substrates are converted to silage to be used as feedstock for anaerobic digestion. Energy production from silage has also attracted much interest in recent years. In the United States, perennial grasses have been stored as biomass to produce biofuels. This chapter illustrates the basic concepts of anaerobic digestion and addresses the overview of potential of grass as raw material for biogas production advance silage preparations and utilization for efficient biogas production with several digestion methods including dry and wet fermentation processes, monodigestions, and co-digestions, along with environmental impact assessment. Consequently, the aim of this chapter was to provide an overview of how to efficiently utilize the grass silage for biogas production and helpful to reduce greenhouse gas effect with environmental benefits.

2. Anaerobic digestion (AD) process

Biogas is generated from a digestion process under anaerobic conditions whose application is rapidly emerging as a viable means for providing continuous gaseous fuel and power generation. Recently, there are many countries having move towards to utilize the renewable energy especially biogas production through AD. Basically in AD, the organic materials are biologically treated in the absence of oxygen. These processes were naturally occurring through bacteria to produce "biogas." Generally biogas component is a mixture of CH_4 (40–70%), CO_2 (30–60%), and other trace gases, for example, hydrogen, hydrogen sulfide, and ammonia. The co-product from the biogas fermenter is potentially useful fertilizer in the form of a liquid or solid "digestate" [8]. For biogas production, a variety of methods are applied which can be classified in wet and dry fermentation systems.

The AD cycle represents an integrated system of a physiological process of microbial and energy metabolism, as well as the processing of raw materials under specific conditions (**Figure 1**) [4]. However, the microbial community is sensitive to variations in the operating conditions applied. AD process can be possibly integrated with other conversion processes. It could be applicable to improve their sustainability and energy balance. On the other hand, biogas system is different from other biofuels like biohydrogen, bioethanol, and biodiesel which uses only carbohydrates and lipids. Biogas is produced from all the convertible biomass macromolecules under anaerobic conditions [8, 9].

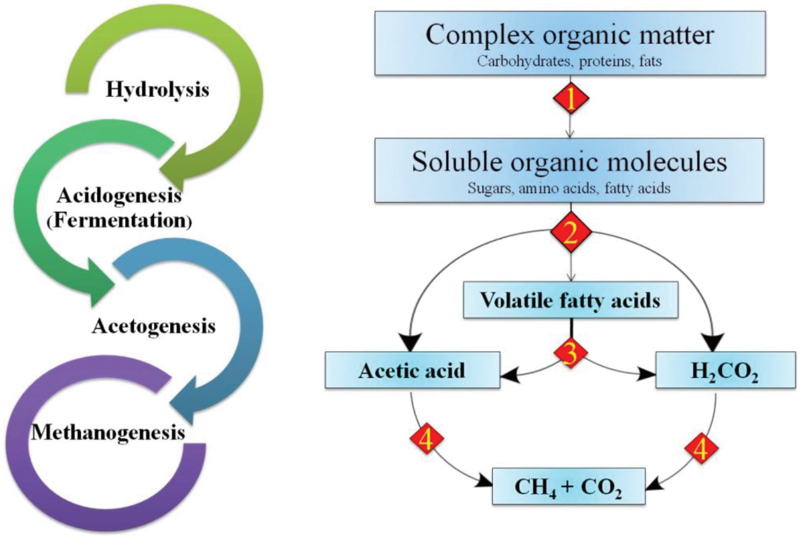

Figure 1. Flow diagram of the anaerobic digestion process.

AD is a collection of process achieved through bacteria that convert organic materials into biogas through four different stages (**Figure 1**) including hydrolysis, acidogenesis, acetogenesis, and methanogenesis [8, 9]. Organic matters are broken down step by step through these four stages towards methane production path. The complex macromolecules and components (carbohydrates, lipids, and proteins) available in organic matter are converted into simple sugars, long-chain fatty acids, and amino acids through first stage so-called hydrolysis. And second stage (acidogenesis) in turn converts these soluble micromolecules into volatile fatty acids, acetic acid, CO_2, and H_2. Third stage of acetogenesis converts the volatile fatty acids into more acetic acid, CO_2, and H_2S gas. The final stage of methanogenesis has the capability to generate methane by using the CO_2 and H_2S gas otherwise the acetic acid produced from either second or third stages [8, 9]. Thus, the AD process, if improperly managed, would become unstable and result in reduced biogas production. An overall review and assessment of AD techniques for biogas production and relevant research progress are necessary and imperative for further biogas development.

3. Grass: energy crop

Compared with other feedstocks, grass has suitable and promising characteristics as energy crop for biogas production. Because of its assurance on availability of throughout year and conservation, ensilage or haylage are indisputable. Typically, compacting to extrude sheltered air and a plastic coverage is enough for conservation of fresh grass [10]. In general, the usage of grassland as a renewable source of energy during biogas production will provide considerable quantity of environment protection, owing to the capability of grass to sequester carbon into the soil matrix. Furthermore, various socioeconomic profits are possible to achieve without harming the food industry [11].

Perennial grasses, especially C_4 grasses, are excellent candidate feedstocks for renewable energy production in support of several rationales such as high potential of dry matter yields, fast growth, and additional potential use of inputs compared to annual crops [12]. Furthermore, perennial grasses offer highest biomass yield which can be available for many harvests per year and give vital role in ecosystem services, for example, carbon sequestration in roots and soil, and to contribute the reduction of soil erosion due to massive perennial root systems that stabilize the soil. Lignin content which is negatively correlated with sugar release is lower in perennial grasses (161–192 mg g^{-1}) when compared to woody plants (157–279 mg g^{-1}) [13].

In Thailand, most of dairy cattle are grown by small-scale farmers and the grasses are used for cattle feeding. In common practice, para (*Brachiaria mutica*), ruzi (*Brachiaria ruziziensis*), guinea (*Panicum maximum*), and Napier grass (*Pennisetum purpureum*) are used in cattle feeding. Much of the prior research on candidate perennial grass biomass crops in Thailand has focused on *Brachiaria ruziziensis, Cynodon* sp., *Digitaria decumbens, Miscanthus sinensis, Panicum maximum, Paspalum atratum, Pennisetum polystachyon, Pennisetum purpureum, Pennisetum purpureum* × *Pennisetum americanum*, and *Vetiveria zizanioides*.

4. Thai grasses

There are many grasses already grown in Thailand that have the potential to be used as lignocellulosic feedstock for biofuel production. Several studies were suggested that wild grasses have lignocellulosic matter as new sustainable substitute raw materials for the establishment of biofuels. Many types and varieties of wild grasses are available in Thailand (**Table 1**). These grasses were potentially possible to use as a raw materials for biogas production.

Common name	**Scientific name**	**Cultivation province**	**Dry matter yield (ton/ha/year)**[a]
Atratum grass	*Paspalum atratum*	Chiang Mai, Lampang, Ratchaburi, or Phetchaburi	18.8
Bana grass	*Pennisetum purpureum* (Napier grass) × *Pennisetum americanum* (pearl millet)	Chiang Mai, Lampang, Ratchaburi, or Phetchaburi	7.7
	Pennisetum purpureum (Napier grass) × *Pennisetum americanum* (pearl millet)	Nakhon Ratchasima	49.1
Miscanthus grass	*Miscanthus sinensis*	Chachoengsao	N/A[b]
Mission grass	*Pennisetum polystachyon*	Nakhon Ratchasima	N/A[b]
	Pennisetum polystachyon	Phitsanulok, Phichit, Nakornsawan, Tak, Uttaradit, or Sukhothai	N/A[b]

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Common name	Scientific name	Cultivation province	Dry matter yield (ton/ha/year)[a]
Napier grass (elephant grass)	*Pennisetum purpureum* Schum. (common)	Chiang Mai, Lampang, Ratchaburi, or Phetchaburi	7.7
	Pennisetum purpureum Schum. (common)	Nakhon Ratchasima	51.4
	Pennisetum purpureum Schum cv. Mott (Dwarf)	Chiang Mai, Lampang, Ratchaburi, or Phetchaburi	17.5
	Pennisetum purpureum Schum cv. Mott (Dwarf)	Nakhon Ratchasima	27.1
	Pennisetum purpureum Schum. cv. Kamphaeng Saen	Nakhon Ratchasima	46.3
	Pennisetum purpureum Schum. cv. King	Chiang Mai, Lampang, Ratchaburi	7.7
	Pennisetum purpureum Schum. cv. Muaklek	Nakhon Ratchasima	35.1
	Pennisetum purpureum Schum. cv. Taiwan A148	Nakhon Ratchasima	51.5
	Pennisetum purpureum Schum. cv. WrukWona		52.1
Pangola grass	*Digitaria decumbens*	Chiang Mai, Lampang, Ratchaburi	37.5
Purple guinea grass	*Panicum maximum* cv. TD 58	Chiang Mai, Lampang, Ratchaburi	18.8
	Panicum maximum cv. TD53	Nakhon Ratchasima	N/A[b]
Ruzi grass	*Brachiaria ruziziensis*	Chiang Mai, Lampang, Ratchaburi	14.1
Tifton Bermuda grass	*Cynodon nlemfuensis* cv. Tifton	Nakhon Ratchasima	58.4
Vetiver grass	*Vetiveria zizanioides* cv. Kamphaeng Phet 1	Chiang Mai, Lampang, Ratchaburi	6.5
	Vetiveria zizanioides cv. Kamphaeng Phet 2		6.0
	Vetiveria zizanioides cv. Loei		4.9
	Vetiveria zizanioides cv. Nakhon Sawan		4.2
	Vetiveria zizanioides cv. Prachuap Khiri Khan		8.5
	Vetiveria zizanioides cv. Ratchaburi		7.6
	Vetiveria zizanioides cv. Roi Et		3.5
	Vetiveria zizanioides cv. Songkhla		5.8
	Vetiveria zizanioides cv. Sri Lanka		6.4
	Vetiveria zizanioides cv. Surat Thani		5.5

[a]Banka et al. [14].
[b]Information is not available in the literature.

Table 1. Types of grasses grown in Thailand.

Brachiaria ruziziensis: Ruzi grass *(B. ruziziensis)* used mainly for domestic animals grazing. Initially, ruzi grass was native to southern African continent. It came to Thailand in 1968 from Australia. Subsequently, the grass has become popular as cattle silage because of the large production of seeds, easy to grow nature, and status as a feedstock. There are few draw backs like sensitivity to the dry climate and requirement of fertilizers [15].

Cynodon sp.: *Cynodon sp*. includes perennial grasses referred to as Bermuda grass or star grass, which are commonly grown in the topics and subtropics of the Americas, Africa, and South-East Asia [16]. Generally, they have been used for forage or as fodder for bioenergy [17]. Though Rengsirikul et al. [18] refer to Tifton grass as a type of Napier grass [18], Tifton grass is a specific breed of Bermuda grass (*Cynodon dactylon* L.) from Tifton, Georgia, USA, that was bred for its improved digestibility as a potential biofuel feedstock [17].

Digitaria decumbens: Pangola grass, scientific name *Digitaria decumbens* or *Digitaria eriantha*, is a forage grass originating from South Africa that is currently grown worldwide in the Americas, Africa, Oceania, Australia, and Asia [19]. It has been grown in Thailand since 1983 due to its success as fodder for grazing animals and its ability to grow on lands that previously cultivated rice [19].

Miscanthus sinensis: Miscanthus grass was generally called as Chinese silvergrass. Its scientific name is *Miscanthus sinensis*. Chinese silvergrass is native to eastern Asia, including Thailand. It is a perennial and clumping grass and also grown in some parts of the Americas and Europe. The grass can grow up to 2–3 meters tall [20]. Nowadays, this grass is used as cattle fodder and has been considered as a possible feedstock for biofuels.

Panicum maximum: Purple guinea grass, or *Panicum maximum* cv. Tanzania, is originally from the Ivory Coast of Africa. It is another perennial grass with a high protein content that is currently used as a feedstock for grazing animals in Thailand, having been introduced to the country in the 1980s [21].

Paspalum atratum: Atratum grass, known by its scientific name *Paspalum atratum*, is a perennial grass that can grow 1–2 meters tall. It originated in South America and is now cultivated in the Americas, South-East Asia, and Australia, generally near the equator. Though atratum grass has low drought tolerance, it is popularly grown in Thailand due to its ability to flourish during the rainy seasons and in wet soils [15].

Pennisetum polystachyon: Mission grass (*P. polystachyon*) is originally grown in tropical Africa. But for the past few decades, the grass has been spread throughout Africa, Asia, Australia, and Oceania. It can grow roughly 3 meters tall and is commonly known as a weed. The grass is a perennial and clumping grass. Mission grass is considered as an established weed that is currently not used for any specific purpose in Thailand [22].

Pennisetum purpureum: Pennisetum purpureum Schumacher, more often referred to as Napier grass or elephant grass, is a perennial grass native to Africa that has since been cultivated in tropical areas in Asia, Oceania, and the Americas. Napier grass is a hardy grass that can grow up in clumps up to seven meters in height and is particularly important as a forage and pasture grass, erosion inhibitor, mulch, and as a windbreak for other crops. Due to Napier grass's attractive qualities, such as good productivity, high yields, and drought tolerance, several types of Napier grass have already been investigated in Thailand for their potential in bioethanol conversion to bioethanol. The types of Napier grass which were already investigated include common, dwarf, Kamphaeng Saen, king, Muaklek, Taiwan, and WrukWona [6, 18].

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Pennisetum purpureum × *Pennisetum americanum*: Due to the success of both Napier grass (*P. purpureum*) and pearl millet (*Pennisetum americanum*) as potential lignocellulosic feedstocks, they have been bred to create hybrids, such as bana grass [23]. Bana grass was first produced in South Africa in the 1950s and is now widely grown throughout the tropical and subtropical areas of the world [24]. Bana grass's high yield, hardiness (even when grown in harsh conditions), and its ease of harvesting have made it one of the most popular hybrids [23].

Vetiveria zizanioides: Generally, *V. zizanioides* called as vetiver grass. It is also perennial grass native to South Indian peninsula. It is used as a source of food and aromatic oils in worldwide. Furthermore, the grass has potential to apply in remediating contaminated soils, treating waste water, and reducing soil erosion [25]. Like Napier grass, vetiver grass has been examined already in Thailand as a potential source of lignocellulosic biomass for bioethanol conversion, partly due to its robustness and potential height of two meters [6, 25].

5. Napier grass

Soil fertility is generally rich in Thailand. Genus Pennisetum (including Napier grass) has been reported as the most productive tropical grasses in Thailand. Eight cultivars of Napier grass, namely Dwarf, Muaklek, Bana, Taiwan A148, Common, WrukWona, Tifton and Kamphaeng Saen, are grown in Thailand. There are several cultivars regularly grown from this genus for domestic animal feed. King Napier, Bana, WrukWona, Merkerson, and the short type (Mott dwarf) are called as common Napier. It can produce highest biomass yields more than 25 t/ha/yr dry matter when cut at 30-day intervals. In central Thailand (at Pak Chong), biomass yield was achieved at 75 t/ha/yr when cut at 60-day intervals. The scales of biomass yields demonstrated that Napier grass as a hopeful species for methane generation [18].

There is a huge awareness in the prospective utilization of Napier grass to produce ethanol in Thailand. Recently, these cultivars were selected for utilization as animal feeds, because of high leaf percentage, high nitrogen concentration, and low fiber levels. Because of its high dry matter yield, it was considered mainly as animal feed. On the contrary, for biofuels production, there is a need to get highest yield of biomass with suitability to be used either for direct combustion or for ethanol conversion. Therefore, the objectives of this paper were to quantify the yield and quality of biomass produced in different seasons by a range of Napier grass cultivars when cut at three monthly intervals throughout the year and to assess their potential as a source of energy for biofuel production in central Thailand.

In general, Rengsirikul et al. [18] confirmed that tall cultivars reach a greater length (2–4 m) than Dwarf (<1 m) with Muaklek intermediate. Furthermore, annual biomass yield was differed significantly among cultivars (**Table 2**). The tall cultivars yielded 46.3–58.4 t/ha/yr compared with 27.1 and 35.1 t/ha/yr for Dwarf and Muaklek, respectively. **Table 2** indicates that the potential of tall Napier grass cultivars to produce high biomass in Thailand to satisfy the increasing need for energy. Napier grass is tropical forage; thus, these findings can be applicable to other countries in the tropical region as well.

Cultivar	Dry matter yield (t/ha)
Dwarf	27.1
Muaklek	35.1
Bana	49.1
Taiwan A148	51.5
Common	51.4
WrukWona	52.1
Tifton	58.4
Kamphaeng Saen	46.3

Table 2. Annual dry matter (DM) yields of eight Napier grass cultivars.

6. Potential of grass silage

Several studies had been examined via grass/grass silage as feedstocks to produce biogas as a renewable energy; however, if grass is to be used as raw materials for AD for energy production, it should be converted to silage due to the presence of lignocellulosic materials [26]. Lehtomaki et al. [27] showed that AD of grass silage in batch leach bed processes has the highest methane potential when compared with other potential crops. Smyth et al. [26] compared the net energy of the grass in biomethane systems with other energy crops, and they found that grass has higher gross energy than rapeseed biodiesel and wheat ethanol systems [28]. The yields of dry matter in vetiver grass provided the yield of ethanol at 1091.84 L/ha/year, whereas the leaves of dwarf Napier grass given the maximum yield of 2720.55 L/ha/year (0.98 g/L or 0.12 g/g substrate equivalent to 30.60%) [26].

In numerous studies, grass silage has been recommended as an excellent substrate for biomethane production resulting from high-energy yields, low-energy input demand, long time storage, and usage of silage even for a whole year [29]. The higher potential of methane production from grass silage was confirmed both in batch and in semi-continuous experiments and batch leach bed processes [27]. In practice, grass silage is the most important substrate for agricultural biogas production following maize silage in Germany [30]. Though grass silage may be less energetically productive when compared to maize silage, it still offers a good energy balance and environmental advantages [31]. The key purpose of silage preparation is achieved by efficient preservation. It could keep high-energy content of a crop. And this is achieved by the combination of an anaerobic environment as well as the bacterial fermentation of sugar. The lactic acids formed in the latter progression lower the pH and avoid the proliferation of spoilage microorganisms.

Generally, the fermentation under farm conditions was not involved in a controlled process. The silage fermentation characteristics were depending on the nutrients that allow the growth of microorganisms. The fermentation is usually characterized by a low pH, high lactic acid content, and low concentrations of butyric acid and ammonia-N. Additionally, the ensiled

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energy is an entirely recoverable in a closed lactic acid-dominant fermentation. On the contrary, there is negligible loss of energy; the production of ethanol by yeast during fermentation is undesirable because no acidification occurs. Correspondingly, under suboptimal ensiling conditions, secondary clostridial fermentation may lead to considerable total solids and energy losses due to extensive production of CO_2 and H_2 from the fermentation of lactate and hexose sugars. If grass is to be used for energy, it must be harvested and stored, usually as silage. Silage is currently made for feeding livestock, and grass silage is mostly used as co-substrate in biogas plants based on cattle, pig, or chicken manure because of its inappropriate high nitrogen content [32, 33] of about 14% of total solids. The influence of ammonia on anaerobic digestion in terms of process inhibition was found in several literatures [34–36]. However, several authors proved that monodigestion of grass silage is possible, although both applied systems and experimental conditions differ occasionally significant.

7. Biogas from Napier grass silage

Common cultivar of Napier grass was obtained from the agriculture farm which was cultivated at Mae Taeng district, Chiang Mai, Thailand. The grass was a first cut (cut at 45-day-old mature stage). Napier grass was crushed by machine into small particles. Stored grass was pulverized into small particles (1.0 mm) before use. Proximate, ultimate, chemical composition of Napier grass is shown in **Table 3**. The grass collecting and silage preparations are shown in **Figures 2** and **3**. The experiment was carried out in the Energy Research Center, School of Renewable Energy, Maejo University, Thailand. For all experiments, Napier grass (*Pennisetum purpureum*) was used as a monosubstrate.

Property	**Biomass**
pH[a]	4.85
Proximate analysis (wt.%)	
Moisture[a]	77.74
Ash	3.18
Ultimate analysis (wt.%)[b]	
Carbon (C)	44.19
Hydrogen (H)	6.00
Nitrogen (N)	2.00
Oxygen (O)	43.80
Sulfur (S)	0.06

[a]As received at harvest.
[b]Dry basis; unit % by weight.

Table 3. Proximate, ultimate, chemical composition of Napier grass.

Figure 2. Grass collection and silage preparation (A) cultivation, (B) transportation of grass, (C) grass crushing machine, and (D) small particle of grass.

Figure 3. Napier grass silage.

Leachate Recirculation Digester (LBR): A prototype of 100-L dry anaerobic batch digester was employed so-called LBR system, sometimes called percolating anaerobic or dry anaerobic digester [37], and experimental setup is shown in **Figure 4**. Specification of experimental parameters and biogas measurements are listed in **Table 1**. In this design, LBR was sequentially loaded with grass biomass and mixed with residual digested solids and leachate. For all experiments, prepared grass was used as a monosubstrate. Biogas production was received

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through improvements in the fermentation process using with Napier grass and water. Thirty kilograms of grass substrates was used in a leachate recirculation digester. The reactor working volume was 60 L.

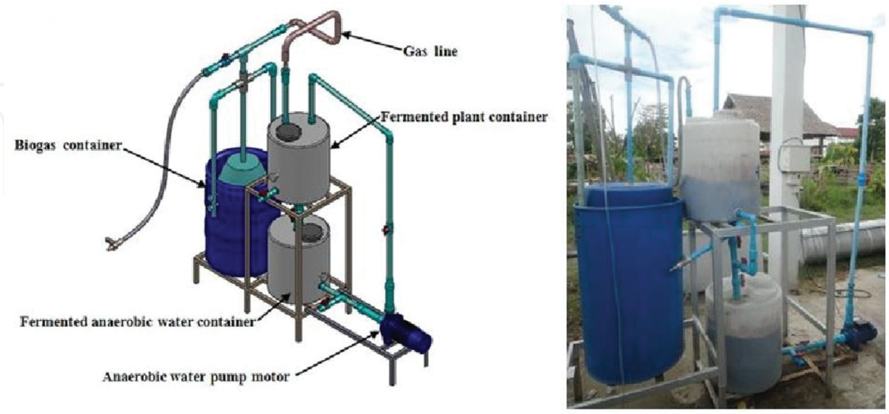

Figure 4. Dry fermentation anaerobic digestion process.

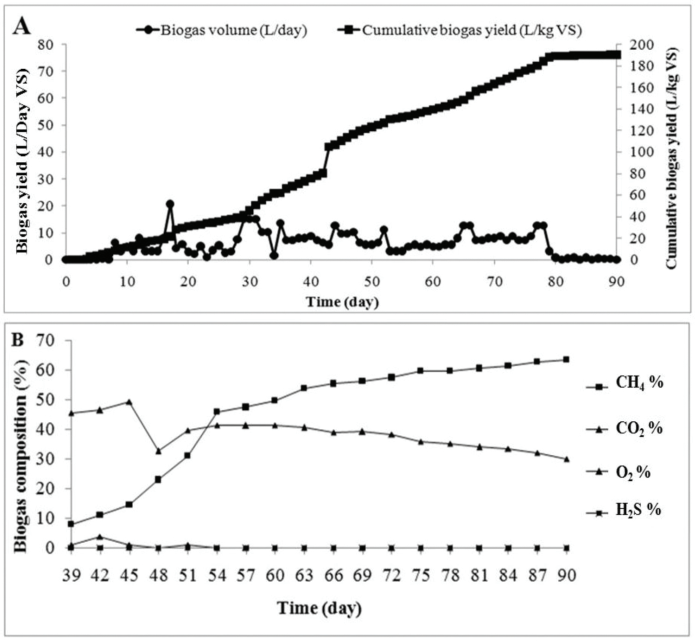

Figure 5. (A) Biogas yield (L/day VS) and cumulative biogas yield (L/kg VS) and (B) biogas compositions produced from Napier grass.

Daily total biogas production of Napier grass as monosubstrate in the reactor is given in **Figure 3**. Energy crops and crop residues can be digested either alone or in co-digestion with other materials, employing either wet or dry processes. And after 85 days, the rate of biogas production was gradually declined. The biogas was accumulated throughout study period 20.62 L/kg fresh grass or 190.25 L/kg VS is the average total amount of gas 6.87 L/day (=6870 ml/day), as shown in **Figure 5**. Bussabong et al. [38] stated the performance of the biogas production of ruzi grass (*Brachiaria ruziziensis*) as the monosubstrate had value of 244 ml/day with CSTR. This study results were demonstrated that biogas yield was 28 times higher than ruzi grass which was performed in CSTR. Batch reactors are often leach bed processes where solids are hydrolyzed by circulating leachate over a bed of organic matter. Recirculation of leachate stimulates the overall degradation owing to more efficient dispersion of inoculums, nutrients, and degradation products [27]. Accordingly, that is, main reason this study result confirmed was much higher than CSTR.

Parameter	Equipment or method
Napier grass particle size	1.00 mm
Grass substrate	30 kg
Reactor type	Leachate recirculation digester
Digesting system	Dry anaerobic digester
Volume of reactor	100 L
Used volume of reactor	60 L
Methane	ASTM D 1945
Carbon dioxide	ASTM D 1945-03
Hydrogen	ASTM D 1945-03
Hydrogen sulfide	ASTM D 5504-01
Oxygen	ASTM D1945
Sulfur	ASTM D 6667-04

Table 4. Specification of experimental parameters and biogas measurements.

Biogas composition results are presented in **Figure 5**. Biogas composition from experimental measurements starting from 39 days of the experiment showed that the initial composition of the gas as possible. This term microbial methane was generated. (Methanogenic bacteria are not in the right conditions for growth.) The pH less than 6.5 was inhibit the growth of methanogenic bacteria are composed of methane, 7.9 after 54 days, the methane production increased due to the microbial production of methane. Theoretical and measured composition of methane and biogas production is presented in **Table 4**. The biogas composition of carbon dioxide (30.10%), methane (63.50%), and 5 ppm of hydrogen sulfide was estimated from the biogas.

H_2S is commonly found in natural gas, biogas, and LPG. It is corrosive, toxic, and odorous; it can significantly damage mechanical and electrical equipment used for process control, energy generation, and heat recovery. Moreover, the combustion of H_2S results in the release of sulfur dioxide, which is a problematic environmental gas emission [39]. The usages of biogas with H_2S standard are as follows: steam and fired boilers (<1000 ppmv), steam and fired boilers (<1000 ppmv), fuel engines (<500 ppmv), motor fuels (i.e., CNG and CBG <23 ppmv), and pipe

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line gas (i.e., gas grid <1 ppmv) [39]. This study which verified H_2S was extremely lower (i.e., 5 ppm). Therefore, the study approach is certainly applicable for CBG (compressed biomethane gas) engine. Consequently, this study investigated the potential of Napier grass biomass as a feedstock for biogas production. This suggested that it is possible to achieve stable operation using Napier grass, as a substrate for biogas production in pilot or large-scale biogas plant in the future. It was concluded that Napier grass as energy crop can be an alternative energy resource.

7.1. Co-digestion

Recently, most of the agricultural biogas plants digest manure with the addition co-substrates to increase the content of organic material for achieving a higher gas yield [40]. For these reasons, co-digestion is commonly practiced and most recommended co-substrate was manure.

Figure 6. Wet fermentation (continuums type).

Co-digestion has been defined as the anaerobic treatment of a mixture of at least two different substrates with the aim of improving the efficiency of the anaerobic digestion process. At present, there are an increasing number of full-scale co-digestion plants treating manure and industrial organic wastes. Co-digestion of mixed substrates offers many advantages, including ecological, technological, and economic benefits, compared to digesting a single substrate. However, combining two or more different types of feed stocks requires careful selection to improve the efficiency of anaerobic digestion [40]. The main resource is represented by animal manure and slurries from cattle and pig production units as well as from poultry, fish, etc. And agricultural substrate suitable for anaerobic digestion is represented by energy crops, of which most common are grain crops, grass crops, and maize. Grass crops are among the most promising energy crops for biogas production [41].

Day	Cumulative biogas (cb-m)	Biogas component				Temp (°C)	pH
		CH_4	CO_2	O_2	H_2S (ppm)		
14	0.2618	4.9	29.6	0.9	823	31.8	5.43
15	0.6952	6.0	33.0	0.5	3877	30.5	5.65
16	1.0864	5.8	32.6	0.6	3562	29.5	5.61
17	1.4983	6.3	33.2	0.0	2325	29.2	5.45
18	2.0725	6.3	32.0	0.5	5	29.6	5.56
19	2.6462	6.9	32.0	0.1	38	30.4	5.64
20	3.2223	7.8	32.0	0.0	310	31.1	5.39
21	3.8514	8.6	32.1	0.0	423	31.7	5.48
22	4.4955	8.6	32.0	0.0	1073	31.5	5.54
23	5.1493	10.5	32.0	0.0	1458	31.9	5.42
24	5.8107	11.3	32.3	0.0	1693	30.7	5.66
25	6.8659	13.1	31.9	0.0	3715	28.5	5.68
26	7.8239	14.1	33.8	0.0	4143	29.6	5.71
27	8.4877	16.6	33.6	0.0	3972	29.9	5.74
28	9.1979	20.2	33.5	0.0	4067	28.9	5.64
29	9.7640	22.8	34.3	0.2	5345	29.7	6.08
30	10.2390	29.4	33.2	0.0	4117	28.4	6.25
31	10.8979	35.6	34.4	0.0	3623	30.1	6.08
32	11.3843	42.4	33.3	0.0	3713	30.6	6.76
33	11.8339	53.4	29.4	0.0	2522	30.6	6.78
34	12.1919	58.8	27.1	0.0	1996	27.5	6.51
35	12.7557	64.9	23.8	0.0	1592	25.1	6.85
36	13.2300	68.9	22.3	0.0	1700	24.6	6.89
37	13.5053	**70.2**	21.9	0.0	1205	25.4	6.51
38	14.1023	66.9	23.0	0.0	775	26.5	6.92
39	14.7192	62.9	26.9	0.0	1200	27.8	6.84
40	15.2051	56.9	30.4	0.0	1223	29.0	6.72

Table 5. Biogas composition and fermenter characteristic of co-digestion of Napier grass and microalgae.

In this study, we used 40-L inoculums, 1000 L of microalgae and 200 Kg of Napier silage. Microalgae was cultivated in the open pond culture, and the mesophilic anaerobic inoculum was obtained from a working mesophilic anaerobic digester at Energy Research Center, Maejo University. The inocula had a TS concentration around 296.1 ± 0.4 mg/L, with 158.5 ± 1.02 mg/L of VS. Total COD was 1241.6 mg/L, and 291.2 mg/L as $CaCO_3$ of alkalinity, 136.4

mgCH_3COOH/L of VFA along with 6.66 of pH value. Wet fermentation (continuums type) is shown in **Figure 6**.

Gas samples were collected and analyzed, and gas components is presented in **Table 5** and **Figure 7**. The results obtained in this study suggest that co-digestion of microalgae and grass silage is a promising approach for improving biogas production. On 37 days, methane (CH_4) content was reached over 70% and CO_2 (10.05%), O_2 (21%), and H_2S 1205 ppm), which were met the standard of the Department of Energy. Efficiency criteria explained good performance throughout the study.

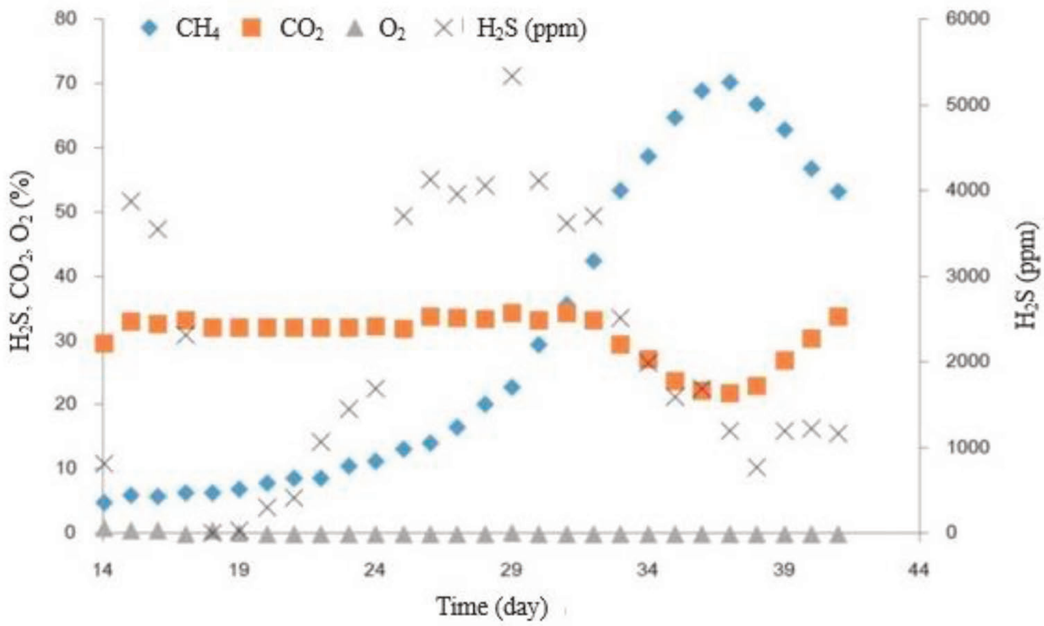

Figure 7. Biogas compositions produced from Napier grass and microalgae.

8. Conclusions

This study investigated the potential of Napier grass biomass as a feedstock for biogas production. Napier grass is fast-growing, high-yielding crops, and highly nutritious especially, so it is suitable for use as energy crops for biogas production. These results indicated that, Napier grass contains rich organic substances and these substances are suitable to use in the anaerobic fermentation process to be used to sustain microbial life and transform nutrients into biogas. Dry anaerobic digestion is a biological method used to convert organic substances into a stable product for land application without adverse environmental effects. The high content of methane (i.e., 63.50%) amount was found in total biogas from dry anaerobic fermentation in 90 days hydraulic detention time. But using with co-digestion of microalgae and Napier grass silage shows good results. In 37 days, methane content was 70%. This suggested that it is possible to achieve stable operation using Napier grass, as a substrate for biogas production with co-digestion method in pilot or large-scale biogas plant in the future. The biogas digested material is excellent source for fertilizer and it is beneficial for environmental safety and management aspects as well. It was concluded that Napier grass as energy crop can be an alternative energy resource.

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