[宮崎大学農学部研究報告 58 (69−77) (2012)
Bulletin of the Faculty of Agriculture, University of Miyazaki 58 (69−77) (2012)]

Original Articles

Dry Matter Production and Energy Efficiency of Dwarf Napiergrass (*Pennisetum purpureum* Schumach) under Supply of Animal Manures, Legume Clippings and Chemical Fertilizer

Kannika RENGSIRIKUL[1), 2)], Sayan TUDSRI[2)], Yasuhiro SUGIMOTO[3)], Sachiko IDOTA[4)], Yasuyuki ISHII[4)]

[1)] Interdisciplinary Graduate School of Agriculture and Engineering, University of Miyazaki
[2)] Faculty of Agriculture, Kasetsart University, Bangkok, Thailand
[3)] Department of Agricultural and Environmental Science, Faculty of Agriculture, University of Miyazaki
[4)] Department of Animal and Grassland Sciences, Faculty of Agriculture, University of Miyazaki

(Accepted on December 22, 2011)

Summary : Dwarf napiergrass (*Pennisetum purpureum* Schumach) is a promising C_4 species as a bio-energy crop. This study investigated the effects of nitrogen (N) fertilizer sources on the dry matter production and energy efficiency of pot-cultured napiergrass from May to September 2010. The treatments were three types of organic sources (Manure, Solid-DEM and Legume), chemical fertilizer (Chemical) and the control (No-fertilizer). Manure, Solid-DEM and Legume treatments applied a single dosage (10 g N pot^{-1}) of commercial cattle manure, solid-digested effluent of swine manure and dried ground clippings of greenleaf desmodium (*Desmodium intortum*, Legume), respectively. Chemical treatments applied the same N rate in four equally split amounts at monthly intervals. Energy input as labor for cultivation plus fertilizer was highest in Chemical (222 MJ m^{-2}), followed by the three organic fertilizer treatments (207 MJ m^{-2}) and No-fertilizer (184 MJ m^{-2}). Annual dry matter yield and energy output were highest in Chemical (623 g m^{-2} and 9.6 MJ m^{-2}) and Legume (612 g m^{-2} and 9.4 MJ m^{-2}), followed by Manure (552 g m^{-2} and 8.5 MJ m^{-2}), Solid-DEM (540 g m^{-2} and 8.3 MJ m^{-2}) and No-fertilizer (20 g m^{-2} and 0.3 MJ m^{-2}). As a result, the energy efficiency was highest in Legume (4.6%), followed by Chemical (4.3%), Manure (4.1%), Solid-DEM (4.0%) and No-fertilizer (0.2%). The results suggest that using self-supplied legume clippings as an N source is advantageous in the cultivation of dwarf napiergrass, because it requires less input in energy and is as productive as chemical fertilizer supply.

Key words : Dry matter production, Energy efficiency, Napiergrass, Nitrogen fertilizer.

Introduction

Napiergrass (*Pennisetum purpureum* Schumach) is a promising C_4 species as a bio-energy crop. One of the central challenges in the cultivation of energy crops is to explore how biomass yield (energy output) can be maximized with minimal energy input. Although biomass production in napiergrass can be enhanced by fertilizer application (Sunusi *et al.* 1997 ; Wadi *et al.* 2003), use of chemical fertilizers is not favorable as it increases energy input and production cost (Mandal *et al.* 2002 ; Ozkan *et al.* 2004). Organic fertilizers are thus considered to play a key role in establishing a low-input, productive system of napiergrass as a bio-energy crop.

Organic fertilizers originate from plants and animals. Green manure, as clippings of plants (particularly nitrogen (N)-fixing legumes), has been reported to improve crop yields and soil fertility with reduced use of chemical fertilizer (Biederbeck *et al.* 1998 ; Rochester *et al.* 2001 ; Njiru *et al.* 2006 ; Park *et al.* 2010). Animal manure is used as a fertilizer in varying forms ; e.g. fresh or fermented manure, slurry and di-

責任著者：石井　康之
宮崎大学農学部畜産草地科学科
〒889-2192　宮崎市学園木花台西1-1

Corresponding author : Yasuyuki Ishii
Department of Animal and Grassland Sciences,
Faculty of Agriculture, University of Miyzaki
1-1 Gakuen Kibana-dai Nishi Miyazaki, 889-2192, Japan

gested effluent. These animal manures have also been known to maintain or improve crop yields, soil fertility and/or carbon sequestration in the soil (Lithourgidis *et al.* 2007 ; Mandel *et al.* 2009 ; Thelen *et al.* 2010). Hasyim *et al.* (2010) reported that dwarf napiergrass fertilized with digested effluent of swine manure (DEM) showed similar production efficiency (energy output/input) to that with chemical fertilizer. However, to our knowledge, no studies have compared biomass production and energy efficiency of napiergrass under a range of fertilizers covering different types of organic fertilizers as well as chemical fertilizer.

In this study, we evaluated three types of organic fertilizers (both plant and animal origin) and chemical fertilizer for dry matter production, energy input (as labor for cultivation + fertilizer) and energy efficiency in pot-cultured dwarf napiergrass. The objective of the study was to obtain some basic information for developing a low-input, productive system of napiergrass as a bio-energy crop.

Materials and methods

Environmental conditions and planting procedures

This study was carried out in a vinyl house in Faculty of Agriculture, University of Miyazaki, Miyazaki, from May to September 2010. Single nodal stem-cuttings of dwarf-late variety (DL) of napiergrass were transplanted into cell-tray filled with nursery soil on 4 May 2010 under natural conditions. Thirty healthy plants were selected and transplanted at a density of 1 plant pot^{-1} in sandy soil of 1/2000 a Wagner pot, 25-cm of diameter and 30-cm of depth, on 3 June 2010. The pot was covered by plastic dome with 35-cm of diameter and 25-cm of height and set on a bowl to block nutrient loss from the pot. Pots were arranged at a density of 4 plants m^{-2} and surrounded by two rows of bordering plants.

The treatments were three types of organic sources (Manure, Solid-DEM and Legume), chemical fertilizer (Chemical) and the control (No-fertilizer). Manure, Solid-DEM and Legume treatments applied a single dosage (10 g N pot^{-1}) of commercial cattle manure, solid-digested effluent of swine manure and dried ground clippings of greenleaf desmodium (*Desmodium intortum*, Legume), respectively. Chemical treatments applied the same rate of N with P_2O_5 and K_2O in four equally split amounts at monthly intervals. Irrigation was conducted every day, depending on growth conditions of each plant. Air temperature inside the vinyl house was recorded by air temperature sensor and logger (Theromoleaf TL-T1, Taisei E and L Ltd., Tokyo, Japan). Photosynthetic photon flux density (PPFD) was measured by quantum light meter (Spectrum Technologies, Inc., Plainfield, IL, USA) diurnally on 4 and 11 June 2011, to estimate the percentage of solar radiation transmission.

Fresh legume was sun-dried and ground to analyze N content. Nitrogen contents in Manure, Solid-DEM and Legume were analyzed by an N/C analyzer (SUMIGRAPH NC-220F, Sumika Chemical Analysis Service Ltd., Osaka, Japan) to calculate fertilizer application rate in this experiment. Nitrogen contents in the examined fertilizer were 2.32, 2.11 and 2.72 % DM for Manure, Solid-DEM and Legume, respectively (Table 1).

Treatments and experimental design

Plants were arranged in a completely randomized design with 6 replications each contained 5 randomly allocated treatments, to have totally 30 plants. Treatments were 5 levels of fertilization, comprised of 4 different fertilizers (Manure, Solid-DEM, Legume and Chemical) and No-fertilizer (control). Napiergrasses were harvested on week 8, 12 and 16 after transplanting (on 2, 30 August and 27 September 2010, respectively).

Plant measurements and chemical analysis

Plant height, plant length, leaf and tiller numbers were measured every week from one week after transplanting to the end of September 2010. At each harvest, grasses were cut at 10 cm above ground level. Grass samples were weighed for fresh weight, sepa-

Table 1. Source and amount of fertilizers used in the present experiment.

Treatment	N (%)	Rate of N (g N pot^{-1})	Amount of fertilizer (g pot^{-1})	Application method
1. Commercial cattle manure (Manure)	2.32	10	71.4	Basal, once
2. Solid type of digested effluent of swine manure (Solid-DEM)	2.11	10	526.1	Basal, once
3. Dried legume (Legume)	2.72	10	363.5	Basal, once
4. Chemical fertilizer (Chemical)	14.0	10	71.4	Split 4 times (17.85 g pot^{-1} time^{-1})
5. No-fertilizer	–	–	–	–

rated into leaf blade, stem inclusive leaf sheath and dead leaf and dried at 70°C for 72 hr in a hot ventilating oven to determine dry matter weight.

At the first harvest, chlorophyll value was measured on the uppermost-expanded leaf by handheld chlorophyll meter, SPAD-502 (Minolta, Co. Ltd., Japan) as SPAD value and as chlorophyll concentration by the Arnon's method (Arnon 1949) on 31 July 2010. The total chlorophyll content was determined by the optical density at 663 and 645 nm (D_{663} and D_{645}, respectively) in a spectrophotometer SFP-3 (FHK Fujihira Industry Co. Ltd., Japan) to calculate from Arnon's equation (Arnon 1949) :

Total chlorophyll content (mg dm^{-2}) =

$$8.02\ D_{663} + 20.2\ D_{645} \cdots [1]$$

From this equation [1], the data of chlorophyll content were used to make a relationship to SPAD value by regression [2], to predict the total chlorophyll content in the following harvests.

$$y = 0.101\ x - 0.580,\ r = 0.963,\ P < 0.001 \cdots [2]$$

where ; y = Total chlorophyll content (mg dm^{-2}),
x = SPAD value.

Grass samples were determined for neutral detergent fiber (NDF), acid detergent fiber (ADF) and acid detergent lignin (ADL) by filter bag technique (ANKOM Technology, USA). Cellulose and hemicelluloses contents were derived from ADF−ADL and NDF−ADF content, respectively (Moran 2005).

Energy input and output were estimated based on the energy equivalents suggested by Singh *et al.* (1997), Fadare *et al.* (2010) and Rengsirikul *et al.* (2011) as presented in Table 2. Energy efficiency (%) was derived from dividing the energy output by the energy input (Mandal *et al.* 2009).

Statistical analysis

The entire data were analyzed with the Sirichai Statistic program (Unsrisong 2003) by using the ANOVA procedure. Duncan's multiple range test (DMRT) was used to compare means between treatments at a probability level of 5%.

Results

Climatic conditions

Seasons in the experimental periods are spring (May) and summer (June, July and August). In summer, the climate is hot and humid together with rainy season in June. The highest air temperature recorded in a vinyl house exceeded 42.0°C and the highest record was 45.5°C in August. Daily lowest temperatures ranged in 14.5-23.0°C and average temperatures were around 27.7-30.6°C. Percentage of solar radiation transmission in a vinyl house, measured by PPFD, ranged in 78.7-83.4% on 4 and 11 June 2010.

Growth characteristics

Plant height (Fig. 1) and length (data not shown), expanded leaf number (Fig. 2), tiller density (Fig. 3), leaf area index (LAI, Fig. 4) and total chlorophyll content (Fig. 5) of napiergrass were highly responded to fertilizer applications ($P < 0.05$). Fertilized grasses had similar heights averaged at 104 and 65 cm in the first and second cutting, respectively, compared with the lowest height in No-fertilizer at 57, 27 and 29 cm in the first, second and third cutting, respectively. The difference in plant height between fertilized treatments was observed in the last harvest, when Chemical had the highest height (65 cm), followed by Legume (62 cm), Manure (56 cm) and the lowest in Solid-DEM (46 cm, $P < 0.05$). Fully expanded leaf number differed significantly between treatments in the first and last cutting ($P < 0.05$). As expected, inorganic Chemical made grass to emerge new leaf per tiller at higher rate (5.4 leaves per tiller) than organic Legume, Ma-

Table 2. Energy equivalents in different sources of input and output.

Particulars	Unit	Energy equivalent (MJ unit^{-1})	Reference
1. Input			
1.1 Human labor			
i) Adult man	Man-hour	1.96	Singh *et al.* (1997)
ii) Adult woman	Woman-hour	1.57	Singh *et al.* (1997)
1.2 Chemical fertilizer			
i) Nitrogen	kg	60.6	Singh *et al.* (1997)
ii) Phosphate (P_2O_5)	kg	11.1	Singh *et al.* (1997)
iii) Potash (K_2O)	kg	6.7	Singh *et al.* (1997)
1.3 Farm yard manure	kg (dry mass)	0.3	Singh *et al.* (1997)
1.4 Organic fertilizer	kg (dry mass)	0.3	Fadare *et al.* (2010)
2. Output			
2.1 Biomass yield (2 month-interval)	kg (dry mass)	15.4	Rengsirikul *et al.* (2011)

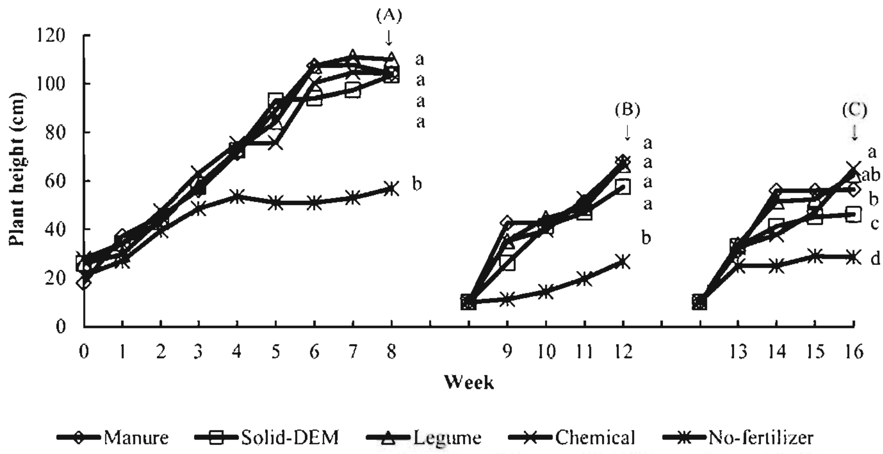

Fig. 1. Changes in plant height of napiergrass. Means with different letters (a-d) are significantly different among fertilizer treatments in each harvest (P < 0.05). Arrows indicate time for the first (A), second (B) and third (C) harvest.

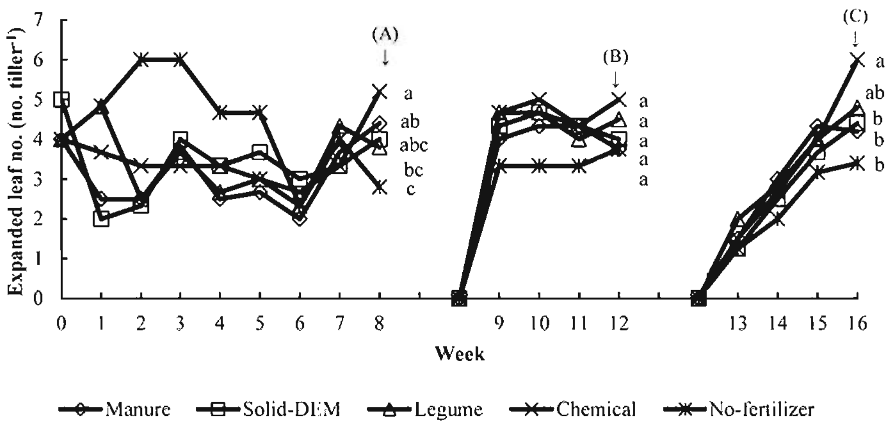

Fig. 2. Changes in number of fully expanded leaf of napiergrass. Means with different letters (a-c) are significantly different among fertilizer treatments in each harvest (P < 0.05). Arrows indicate time for the first (A), second (B) and third (C) harvest.

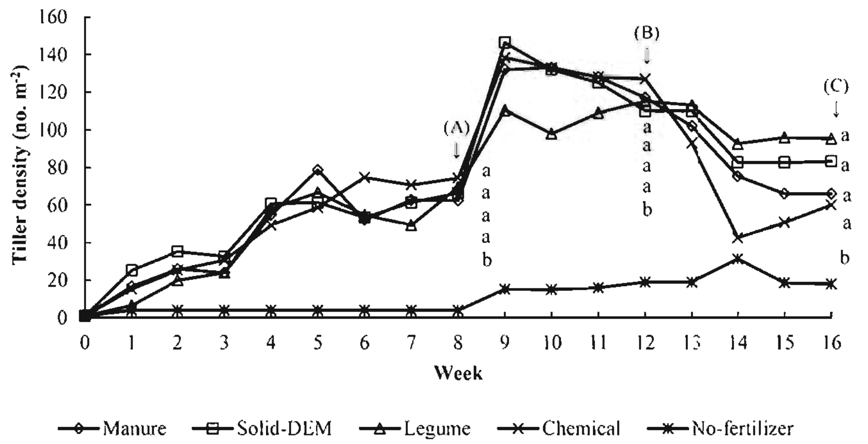

Fig. 3. Changes in tiller density of napiergrass. Means with different letters (a, b) are significantly different among fertilizer treatments in each harvest (P < 0.05). Arrows indicate time for the first (A), second (B) and third (C) harvest.

nure and Solid-DEM at 4.4, 4.1 and 4.1 leaves per tiller, respectively and the lowest in No-fertilizer only at 3.3 leaves per tiller (Fig. 2).

Tiller density revealed that tillering ability of fertilized grasses was significantly higher than those in unfertilized grass in all cuttings ($P < 0.05$), while tiller density of fertilized grasses did not differ significantly in a range of 62-74, 110-127 and 60-95 tillers m^{-2} in the first, second and third harvest, respectively (Fig. 3). Likewise LAI values differed significantly ($P < 0.05$) between fertilized and unfertilized groups in both the first and second cuttings (Fig. 4).

Total chlorophyll content in the first cutting at 2-month old differed significantly among treatments ($P < 0.05$, Fig. 5), where highest content was observed in Chemical at 3.61 mg dm^{-2}, followed by Solid-DEM, Manure and Legume at 2.35, 2.23 and 2.20 mg dm^{-2}, respectively and lowest content in No-fertilizer at 1.81 mg dm^{-2}. This phenomenon also occurred in the second harvest (data not shown).

Biomass yield

Dry matter yield (DMY) of napiergrass was lowest in No-fertilizer among treatments at 13.3, 2.5, and 3.7 g m^{-2} in the first, second and third cutting, respectively, and the annual total was lowest only at 19.0 g m^{-2}. Variation in DMY among fertilized treatments differed depending on the cutting times. In the first cutting, DMY at 8-week old did not differ ($P > 0.05$) among treatments in a range of 428-453 g m^{-2}, and in the second cutting in the end of August for 4-week old plants, Chemical had highest DMY at 107.8 g m^{-2}, and lowest in Solid-DEM at only 52.7 g m^{-2} among fertilized treatments. In the last cutting, performed in late September when air temperature gradually decreased, DMY in all fertilized grasses lowered down to 75.3, 70.8, 55.5, and 37.7 g m^{-2} in Chemical, Legume, Manure, and Solid-DEM, respectively (Fig. 6). Annual total of DMY showed that Chemical as well as Legume had highest yield at 622.5 and 612.3 g m^{-2}, respectively, followed by significantly lower DMY in Manure and Solid-DEM at 551.6 and 540.4 g m^{-2}, respectively (Fig. 6).

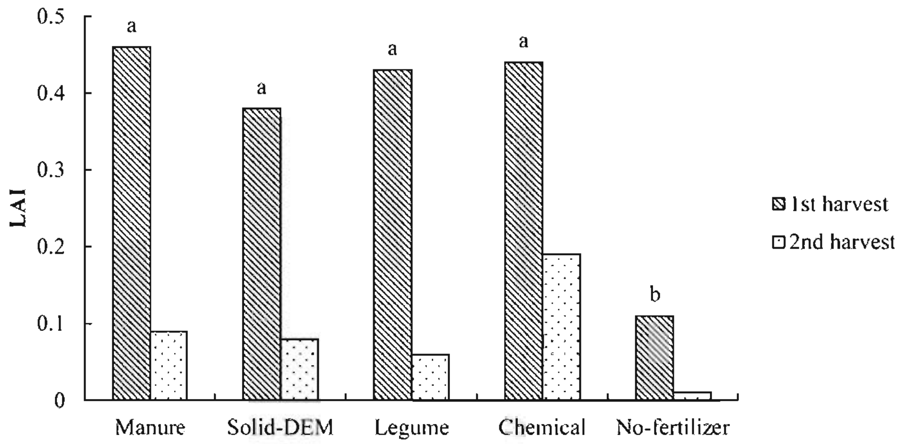

Fig. 4. Leaf area index (LAI) of napiergrass in the first and second harvests. Differences in the first harvest were tested by DMRT. Means with different letters (a, b) in each harvest are significantly different among fertilizer treatments at $P < 0.05$.

Manure	Solid-DEM	Legume	Chemical	No-fertilizer
T-Chl=2.23^b mg dm^{-2}	T-Chl=2.35^b mg dm^{-2}	T-Chl=2.20^b mg dm^{-2}	T-Chl=3.61^a mg dm^{-2}	T-Chl=1.81^c mg dm^{-2}

Fig. 5. Total chlorophyll content (T-Chl) of napiergrass in the first harvest. Means with different letters (a, b) are significantly different among fertilizer treatments at $P < 0.05$.

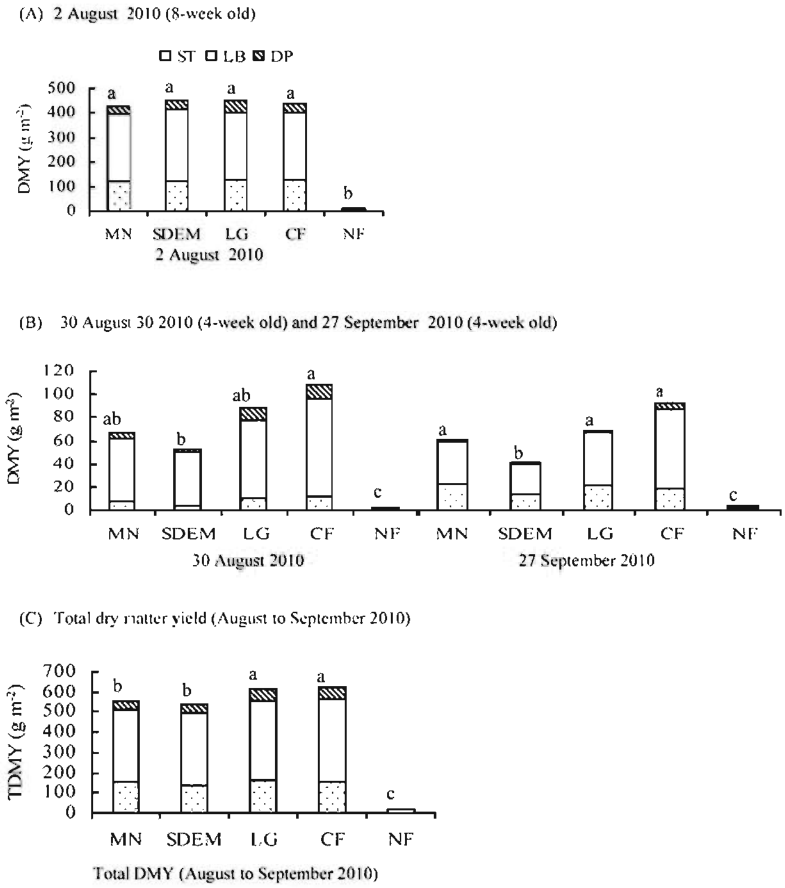

Fig. 6. Dry matter yield of napiergrass fertilized by several fertilizer sources. Means (ST + LB + DP) with different letters (a-c) are significantly different among fertilizer treatments in each harvest at $P < 0.05$. Treatment: Manure (MN), Solid-DEM (SDEM), Legume (LG), Chemical (CF) and No-fertilizer (NF). Plant part: stem inclusive of leaf sheath (ST), leaf blade (LB) and dead parts (DP).

Table 3. Cell wall components in plant parts of napiergrass among fertilizer treatments at 8-week old.

Fertilizer	Cellulose			Hemicelluloses			Lignin		
	LB	ST	DP	LB	ST	DP	LB	ST	DP
Manure	28.7^{b}	30.1^{ab}	33.7^{a}	23.2^{a}	25.6^{a}	9.3^{a}	4.4^{ab}	5.0^{b}	8.8^{b}
Solid-DEM	30.3^{ab}	28.6^{b}	32.9^{b}	21.5^{a}	24.6^{a}	11.0^{a}	4.4^{ab}	5.4^{b}	7.5^{c}
Legume	31.2^{a}	29.9^{ab}	31.2^{b}	21.7^{a}	21.1^{b}	7.3^{a}	3.8^{b}	5.2^{b}	8.3^{bc}
Chemical	30.7^{a}	29.8^{ab}	38.0^{a}	21.6^{a}	19.4^{b}	12.2^{a}	4.5^{ab}	4.8^{ab}	10.2^{a}
No-fertilizer	31.7^{a}	32.1^{a}	33.0^{b}	21.5^{a}	20.5^{b}	9.5^{a}	5.6^{a}	6.6^{a}	7.8^{bc}

^{abc} Different letters indicate significant differences among fertilizer treatments in each parameter at $P < 0.05$.
LB = Leaf blade, ST = Stem inclusive leaf sheath, DP = Dead parts.

Cellulose, hemicelluloses and lignin contents

Contents of cell wall components in leaf blade, stem inclusive leaf sheath and dead parts differed among treatments ($P < 0.05$, Table 3). Cellulose contents in leaf blade, stem and dead parts ranged in 28.7-31.7%, 28.6-32.1% and 31.2-38.0%, respectively. Hemicelluloses contents in leaf blade and dead parts were not as variable in a range of 21.5-23.2% and 7.3-12.2%, respectively, as those in the stem which differed significantly among treatments in a rage of 19.4-25.6%. Lignin contents seem to be higher in dead parts at 7.5-10.2% across all treatments than those in stem and leaf parts at 4.8-6.6% and 3.8-5.6%, respectively. In this experiment, unfertilized grass contained highest level of cellulose and lignin contents uniformly in leaf blade, stem and whole plant (Tables 3

Table 4. Percentage of the cellulose, hemicelluloses, and lignin in whole plant and cellulose yield of napiergrass among fertilizer treatments at 8-week old.

Fertilizer	Cellulose (%)	Hemicelluloses (%)	Lignin (%)	Cellulose yield (g m^{-2})
Manure	29.7^{c}	21.8^{a}	5.2^{b}	127.2^{a}
Solid-DEM	30.0^{bc}	21.5^{a}	4.9^{b}	135.2^{a}
Legume	30.8^{b}	20.0^{ab}	4.7^{b}	139.6^{a}
Chemical	31.2^{ab}	20.2^{ab}	5.0^{b}	137.0^{a}
No-fertilizer	32.0^{a}	18.7^{b}	6.3^{a}	4.3^{b}

^{abc}Different letters indicate significant differences among fertilizer treatments in each parameter at $P<0.05$.

Table 5. Energy input, output and efficiency of napiergrass production fertilized with inorganic and organic sources.

	Treatment				
	Manure	Solid-DEM	Legume	Chemical	No-fertilizer
Input (MJ m^{-2})					
1. Human labor	206.1	206.1	206.1	204.3	183.8
2. Fertilizer	0.9	0.6	0.5	17.3	0.0
Total	207.0	206.7	206.6	221.6	183.8
Output					
1. Energy in grass (MJ m^{-2})	8.49	8.32	9.43	9.59	0.30
2. DMY of grass (g m^{-2})	551.6	540.4	612.3	622.5	19.7
Efficiency					
1. Energy (%)	4.10	4.03	4.56	4.31	0.16
2. Production (g DM MJ^{-1})	2.66	2.61	2.96	2.81	0.11

The energy input and output were estimated based on the energy equivalents in Table 2.

and 4). However, cellulose yield was highest at 140 g m^{-2} in Legume, followed by 127-137 g m^{-2} in Chemical, Solid-DEM, and Manure and lowest at only 4.3 g m^{-2} in No-fertilizer (Table 4).

Energy balance and efficiency

Energy input was consisted of that with human labor, including land preparation, fertilizer application, irrigation and herbage collection, and with fertilizer (Table 5). Labor input tended to be lower in unfertilized grass at 183.8 MJ m^{-2}, compared with the same amount of energy consumed for labor at 204-206 MJ m^{-2} in Manure, Solid-DEM, Legume and Chemical. Chemical fertilizer needs higher energy for the production than organic fertilizers (Table 2). Thus, Chemical needed highest energy input at 17.3 MJ m^{-2}, followed by Manure, Solid-DEM and Legume at 0.9, 0.6 and 0.5 MJ m^{-2}, respectively. In total, Chemical needed higher in energy input (221.6 MJ m^{-2}) than Manure, Solid-DEM and Legume similarly at 207 MJ m^{-2}, and lowest input was observed at 183.8 MJ m^{-2} in No-fertilizer.

Energy outputs were estimated based on dry matter yield and energy content in napiergrass. Even though Chemical produced highest energy output at 9.59 MJ m^{-2} due to highest DMY at 622.5 g m^{-2}, it also consumed highest energy input at 221.6 MJ m^{-2} among treatments. Therefore, efficiencies in both energy and dry weight bases were highest in using clippings of leguminous plant as alternative fertilizer at 4.56% and 2.96 g DM MJ^{-1}, respectively, among treatments (Table 5).

Discussion

Napiergrass performed well when received all 4 fertilizers and yielding ability can be clearly divided into higher yielding groups in Legume and Chemical and slightly lower ones in Solid-DEM and Manure (Fig. 6). Highest efficiency in Legume was derived from containing readily available N source (Valus and Jones 1973) and easily mineralized compounds absorbed by plants and microorganisms (Astier *et al.* 2006).

Digested effluent of animal manure from biogas plant or cattle dung also enhanced biomass yield and tended to increase quality of napiergrass forages, such as crude protein content and digestibility (Sunusi *et al.* 1997 ; Hasyim *et al.* 2010). In this aspect, cell wall components differed slightly among the examined treatments. This may be brought about by the effects of other growth essential elements, such as phosphorus and potassium in animal manure. Growth components, such as plant height, tiller number, leaf area index and total chlorophyll content, were uniformly increased in all of organic and inorganic fertilizer applications from No-fertilizer.

An advantage of using chemical compound fertilizer to enhance crop productivity (Wadi *et al.* 2003) was achieved in the present study, while some weak points have been disclosed in term of energy input and adverse effect on long-term soil fertilities (Mandal *et al.* 2009). Chemical fertilizer needs high level of energy to produce at 60.6 MJ kg^{-1} of N fertilizer, such as urea containing 46% N, while only 0.3 MJ kg^{-1} energy was needed to produce farm yard manure or organic fertilizers (Singh *et al.* 1997 ; Fadare *et al.* 2010). The present study revealed that energy input from Chemical represented 7.8% of total energy used while those from other N sources, *i.e.* Legume, solid-DEM and Manure, represented 0.2, 0.3 and 0.4%, respectively.

Leguminous plants are used as a fallow crop and green manure so as to reduce N fertilizer application, confirmed by Rochester *et al.* (2001) and Park *et al.* (2010), that asserted that soil chemical and physical properties were considerably improved by using leguminous crops, which substituted chemical fertilizers.

Conclusion

The results suggest that using self-supplied legume clippings as an N source is advantageous in the cultivation of dwarf napiergrass for bio-energy production, because it requires less energy input and is as productive as chemical fertilizer supply.

Acknowledgements

Kannika RENGSIRIKUL received the Golden Jubilee scholarship (TRF, Thailand) and was also supported by the Office of the Higher Education Commission, Thailand. A part of this study was supported by the research fund (organized by Yasuhiro SUGIMOTO) of the Ministry of Education, Culture, Sports, Science and Technology in Japan.

References

Arnon, D. I. (1949) Copper enzymes in isolated chloroplasts polyphenoloxidase in *Beta vulgaris*. *Plant Physiol.* **24**, 1-15.

Astier, M., J. M. Maass, J. D. Etchevers-Barra, J. J. Peña, F. de León González (2006) Short-term green manure and tillage management effects on maize yield and soil quality in an Andisol. *Soil Till. Res.* **88**, 153-159.

Biederbeck, V. O., C. A. Campbell, V. Rasiah, R. P. Zentner, G. Wen (1998) Soil quality attributes as influenced by annual legumes used as green manure. *Soil Biol. Biochem.* **30**, 1177-1185.

Fadare, D. A., O. A. Bamiro, A. O. Oni (2010) Energy and cost analysis of organic fertilizer production in Nigeria. *Energy* **35**, 332-340.

Hasyim, H., Y. Ishii, A. Wadi, S. Idota, Y. Sugimoto (2010) Growth response of dwarf napiergrass to manure application originated from digested effluent. *J. Warm Region. Anim. Sci., Japan* **53**, 115-126.

Lithourgidis, A. S., T. Matsi, N. Barbayiannis, C. A. Dordas (2007) Effect of liquid cattle manure on corn yield, composition, and soil properties. *Agron J.* **99**, 1041-1047.

Mandal, K. G., K. P. Saha, P. K. Ghosh, K. M. Hati, K. K. Bandyopadhyay (2002) Bioenergy and economic analysis of soybean-based crop production systems in central India. *Biomass Bioenerg.* **23**, 337-345.

Mandal, K. G., K. M. Hati, A. K. Misra (2009) Biomass yield and energy analysis of soybean production in relation to fertilizer-NPK and organic manure. *Biomass Bioenerg.* **33**, 1670-1679.

Moran, J. (2005) *What is in feed?*, pp. 27-39. (*In*) J. Moran. *Tropical dairy farming : feeding management for smallholder dairy farmers in the humid tropics*. Landlinks Press, Australia.

Njiru, N. E. N., M. G. Njarui, S. A. Abdulrazak, J. G. Murethi (2006) Effect of intercropping herbaceous legumes with napier grass on dry matter yield and nutritive value of the feedstuffs in semi-arid region of eastern Kenya. *Agricultura Tropica Et Subtropica* **39**, 255-267.

Ozkan, B., H. Akcaoz, F. Karadeniz (2004) Energy requirement and economic analysis of citrus production in Turkey. *Energ. Convers. Manage.* **45**, 1821-1830.

Park, S. E., T. J. Webster, H. L. Horan, A. T. James, P. J. Thorburn (2010) A legume rotation crop lessens the need for nitrogen fertilizer throughout the sugarcane cropping cycle. *Field Crop Res.* **119**, 331-341.

Rengsirikul, K., Y. Ishii, K. Kangvansaichol, P. Sripichitt, V. Punsuvon, P. Vaithanomsat, G. Nakamanee, S. Tudsri (2011) Effects of inter-cutting interval on biomass yield, growth components and chemical composition of napiergrass (*Pennisetum purpureum*) cultivars as bioenergy crops in Thailand. *Grassl. Sci.* **57**, 135-141.

Rochester, I. I., M. B. Peoples, N. R. Hulugalle, R. R. Gault, G. A. Constable (2001) Using legumes to enhance nitrogen fertility and improve soil condition in cotton cropping system. *Field Crop Res.* **70**, 27-41.

Singh, M. K., S. K. Pal, R. Thakur, U. N. Verma (1997) Energy input-output relationship of cropping systems. *Indian J. Agr. Sci.* **67,** 262-264.

Sunusi, A. A., K. Ito, S. Tanaka, Y. Ishii, M. Ueno, E. Miyaki (1997) Yield and digestibility of Napiergrass (*Pennisetum purpureum* Schumach) as affected by the level of manure input and the cutting interval. *Grassl. Sci.* **43**, 209-217.

Thelen, K. D., B. E. Fronning, A. Kravchenko, D. H. Min, G. P. Robertson (2010) Integrating livestock manure with a corn-soybean bioenergy cropping system improves short-term carbon sequestration rates and net global warming potential. *Biomass Bioenerg.* **34**, 960-966.

Unsrisong, S. (2003) Sirichai Statistics 6.00. (Computer Program). Maejo University, Chiangmai.

Valus, I., R. J. Jones (1973) Net mineralization of nitrogen in leaves and leaf litter of *Desmodium intortum* and *Phaseolus atropurpureum* mixed with soil. *Soil boil. Biochem.* **5,** 391-398.

Wadi, A., Y. Ishii, S. Idota (2003) Effects of the level of fertilizer input on dry matter productivity of napiergrass and kinggrass. *Grassl. Sci.* **48**, 490-503.

家畜堆肥，マメ科乾草および化成肥料を施用した矮性ネピアグラスにおける乾物生産とエネルギー効率

カニカ レングシリクル[1),2)]・サヤン タッツィー[2)]・杉本安寛[3)]・井戸田幸子[4)]・石井康之[4)]

[1)] 宮崎大学大学院農学工学総合研究科
[2)] カセサート大学農学部
[3)] 宮崎大学農学部植物生産環境科学科
[4)] 宮崎大学農学部畜産草地科学科

要　約

矮性ネピアグラスはバイオエネルギー作物として有望なC_4植物種である．本研究では窒素肥料源が本草種のポット栽培下での乾物生産とエネルギー効率に及ぼす影響を2010年５～９月に検討した．処理としては，３種の有機質肥料区，すなわち市販家畜堆肥（堆肥），固形有機発酵消化液（固形DEM），乾燥し粉砕したグリーンリーフデスモディウム乾草（マメ科草）を基肥としてポット当たり各々年間10 g N施用した区，慣行法として４回に分施した化成肥料を年間同N量施用した化成区および対照として無施肥区を設けた．栽培に係る労働力と肥料に基づくエネルギー投入量は化成区（222 MJ m^{-2}）で最も高く，次いで３種の有機肥料区（207 MJ m^{-2}），無施肥区（184 MJ m^{-2}）の順となった．ネピアグラスの年間乾物収量およびエネルギー産出量は化成区（623 g m^{-2}，9.6 MJ m^{-2}）とマメ科草（612 g m^{-2}，9.4 MJ m^{-2}）で最も高く，次いで堆肥区（552 g m^{-2}，8.5 MJ m^{-2}），固形DEM区（540 g m^{-2}，8.3 MJ m^{-2}）の順であり，無施肥区（20 g m^{-2}，0.3 MJ m^{-2}）で最も低くなった．したがって，エネルギー効率は，マメ科草区（4.6%）で最も高く，化成区（4.3%），堆肥区（4.1%），固形DEM区（4.0%），無施肥区（0.2%）の順となった．本研究から，自給マメ科乾草をN源として用いることは，矮性ネピアグラス栽培にとってエネルギー投入量を削減し，化成肥料施用と同等の生産性を維持できることから有益であると推察された．

キーワード：エネルギー効率，乾物生産，窒素肥料，ネピアグラス