GAS GENERATION FROM ANAEROBIC FERMENTATION OF ANIMAL MANURES AND THEIR RESIDUE APPLICATIONS ON ORGANIC CROPS

Li Yurong

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การผลิตแก๊สชีวภาพจากการหมักมูลสัตว์ในสภาวะไร้อากาศ และการใช้ของเหลือในการผลิตพืชอินทรีย์

นายหลี ยูหรง

วิทยานิพนธ์นี้สำหรับการศึกษาตามหลักสูตรปริญญาวิทยาศาสตรดุษฎีบัณฑิต
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Suranaree University of Technology has approved this thesis submitted in fulfillment of the requirements for the Degree of Doctor of Philosophy.

Thesis Examining Committee

____

(Asst. Prof. Dr. Hatsachai Boonjung)

Chairperson

____

(Asst. Prof. Dr. Sodchol Wonprasaid)

Member (Thesis Advisor)

____

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เทคโนโลยีไบโอแก๊สมีการพัฒนาอย่างรวดเร็ว ดังนั้นของเหลือจากบ่อไบโอแก๊สอาจก่อให้เกิดมลภาวะต่อสิ่งแวดล้อมได้ ถ้าไม่มีการจัดการอย่างถูกต้อง การพัฒนาระบบการผลิตไบโอแก๊สให้มีความสมบูรณ์สำหรับการผลิตแก๊สและการใช้ของเหลือจากบ่อแก๊สนับเป็นสิ่งจำเป็นในระบบการผลิตพืช งานวิจัยในครั้งนี้ ศึกษาการหมักมูลวัว มูลสุกรและมูลไก่ในถังหมักแบบ Chinese fixed dome digester และการนำเศษเหลือจากการหมักมาใช้เป็นปุ๋ยสำหรับผลิตพืชในระบบอินทรีย์ โดยมีวัตถุประสงค์ คือ 1) เปรียบเทียบปริมาณและความบริสุทธ์ของแก๊สที่ได้จากการหมักมูลสัตว์ชนิดต่าง ๆ 2) ประเมินความเป็นประโยชน์ของธาตุอาหารในของเหลวที่เหลือจากการหมักไบโอแก๊สในระบบไฮโดรโพนิกส์ 3) เปรียบเทียบของเหลือจากบ่อไบโอแก๊สกับปุ๋ยหมักในการใช้เป็นปุ๋ยสำหรับการผลิตผักและข้าวอินทรีย์ 4) ศึกษาอิทธิพลร่วมกันระหว่างการใช้แหนแดงกับของเหลือจากบ่อไบโอแก๊สต่อการผลิตข้าวอินทรีย์ ในการทดลองที่ 1 นำมูลสัตว์ทั้ง 3 ชนิด มาหมักในถังแก๊ส เพื่อประเมินการผลิตแก๊สและปริมาณธาตุอาหารในของเหลือ การทดลองที่ 2 ทดสอบความเข้มข้นระดับต่างๆ ของของเหลือจากบ่อแก๊สของมูลสัตว์ทั้ง 3 ชนิด ในระบบไฮโดรโพนิกส์สำหรับการผลิตผักบุ้งและผักกาดหอม การทดลองที่ 3 นำของเหลวและกากตะกอนจากบ่อไบโอแก๊สจากมูลสัตว์ทั้ง 3 ชนิด และปุ๋ยหมักมาทดสอบในผักบุ้ง การทดลองที่ 4 นำปุ๋ยจากมูลสุกร 3 รูปแบบ มาทดสอบในการผลิตข้าว และการทดลองที่ 5 ทดลองการใช้ของเหลือจากบ่อแก๊สร่วมกับการใช้แหนแดงในการผลิตข้าว จากการศึกษาพบว่า การผลิตไบโอแก๊สมีบทบาทสำคัญต่อการผลิตพืชในระบบเกษตรอินทรีย์ มูลสุกรเป็นวัตถุดิบที่ผลิตแก๊สได้ดีที่สุด โดยมีระยะเวลาในการผลิตแก๊สจากมูลสุกร ไก่ และวัว ได้ 150, 90 และ 90 วัน ปริมาณแก๊สที่ได้ 250, 150 และ 70 ลูกบาศก์เมตร และมีแก๊สมีเทนสูงสุด 76.1, 79.9 และ 62.0% ตามลำดับ ส่วนในของเหลือจากบ่อแก๊ส ส่วนมากไนโตรเจนที่อยู่ในของเหลวที่ได้จากการหมักจะอยู่ในรูปแอมโมเนียม ในช่วงของการย่อยของเหลวที่ได้จากการหมักไบโอแก๊สพบว่ามีแอมโมเนียมเพิ่มขึ้น ในขณะที่ไนเตรทลดลงหลังจากระยะ hydrolysis ซึ่งเป็นช่วงที่มีแก๊สออกซิเจนลดลงต่ำมาก ในขณะที่ไนโตรเจนและโพแทสเซียมที่เป็นประโยชน์ในของเหลวอยู่ในระดับที่สูง แต่ฟอสฟอรัสที่เป็นประโยชน์อยู่ในระดับต่ำ (250, 80 และ 110 ppm ในมูลสุกร มูลไก่และมูลวัว ตามลำดับ) จากการศึกษาการใช้ของเหลวกับไฮโดรโพนิกส์ในระบบเกษตรอินทรีย์ พบว่าผักทั้ง 2 ชนิด สามารถเจริญเติบโตได้ดี เมื่อใช้ของเหลวที่ได้จาก

การหมักมูลสุกรและมูลไก่ ที่ EC 2.5 และ 1.5 mS/cm ตามลำดับ แต่สำหรับของเหลวที่ได้จากการหมักจากมูลวัว ไม่สามารถปลูกผักทั้ง 2 ชนิดได้เนื่องจากมีปริมาณไนโตรเจนต่ำ ของเหลวที่ได้จากการหมักมีความเข้มข้นของอินทรียวัตถุสูง จึงจำเป็นต้องกรองเศษอินทรีย์วัตถุออกก่อนการนำมาใช้ เพื่อลดการเจริญเติบโตของสาหร่ายและเชื้อโรคต่าง ๆ การศึกษาการเจริญเติบโตของผักบุ้ง พบว่าของเหลือจากบ่อแก๊สทั้งส่วนที่เป็นของแข็งและของเหลวมีผลดีต่อการผลิตผักบุ้ง โดยสามารถให้ผลผลิตระหว่าง 20.0-21.6 ตัน/แฮกแตร์ จากการเปรียบเทียบชนิดของมูลสัตว์ที่ใช้ทั้งหมด พบว่าการใช้มูลสุกรและมูลไก่ในรูปของของเหลวจากบ่อแก๊สให้ผลดีที่สุด รองลงมาคือมูลสุกรและมูลไก่ในรูปของของแข็งจากบ่อแก๊สและปุ๋ยหมัก ส่วนในระบบการผลิตข้าว พบว่าการใช้ของเหลือจากบ่อแก๊สทั้งของแข็งและของเหลวให้ผลผลิตและการดูดใช้ธาตุอาหารพืชใกล้เคียงกับการใช้ปุ๋ยหมัก และจากการศึกษาอิทธิพลร่วมระหว่างการใช้แหนแดงกับของเหลือจากบ่อแก๊ส พบว่ามีอิทธิพลร่วมกัน โดยพบว่าของเหลือจากบ่อแก๊สเป็นแหล่งของธาตุอาหารให้แหนแดง ในขณะที่แหนแดงสามารถตรึงไนโตรเจนในบรรยากาศ ซึ่งผลสุดท้ายทำให้ได้ผลผลิตของข้าวที่สูงขึ้น จากการศึกษานี้สามารถสรุปได้ว่า การผลิตไบโอแก๊สในถังหมักแบบ Chinese fixed dome biogas digester ใช้ได้ผลดีกับการผลิตแก๊สในระดับครัวเรือน ในสภาพแวดล้อมของภาคตะวันออกเฉียงเหนือของประเทศไทย มูลสุกรเป็นวัตถุดิบที่ดีที่สุดในการผลิตแก๊ส ของเหลือจากบ่อแก๊สทั้งส่วนที่เป็นของเหลวและของแข็งจากมูลสุกรและมูลไก่ มีปริมาณของธาตุอาหารที่สมดุลกว่ามูลโค ดังนั้นของเหลือจากบ่อแก๊สชีวภาพ จากมูลสัตว์ทั้ง 2 ชนิด สามารถนำมาใช้ได้ดีกับการผลิตพืชในระบบเกษตรอินทรีย์

สาขาวิชาเทคโนโลยีการผลิตพืช	ลายมือชื่อนักศึกษา__________________________
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	ลายมือชื่ออาจารย์ที่ปรึกษาร่วม________________
	ลายมือชื่ออาจารย์ที่ปรึกษาร่วม________________

LI YURONG : GAS GENERATION FROM ANAEROBIC FERMENTATION OF ANIMAL MANURES AND THEIR RESIDUE APPLICATIONS ON ORGANIC CROPS. THESIS ADVISOR : ASST. PROF. SODCHOL WONPRASAID, Ph.D., 152 PP.

BIOGAS/RESIDUES/ORGANIC HYDROPONICS/ORGANIC CROPS/AZOLLA

Biogas technology has been developed rapidly, but the residues might cause pollution to the environment if not treated properly. Development of a complete biogas system for gas generation and residual recycling might be necessary in the cropping system. In this research, pig, chicken, and cow manures were fermented individually in a Chinese fixed dome digester and their residues were used as fertilizers in organic crops production. The objectives were: 1) to compare the amount and purity of biogas generated from different kinds of animal manures, 2) to evaluate the nutrient availability of the biogas liquid residues (BLRs) in organic hydroponics, 3) to compare the biogas residues (BRs) with composts as organic fertilizers for organic vegetable and rice, 4) to study the interaction effects of BRs and *Azolla cristata* on organic rice. In experiment 1, 3 manures were fermented individually in the digesters to evaluate biogas generation and nutrient dynamics. In experiment 2, different concentration levels of BLRs from all the 3 manures (in experiment 1) were tested in hydroponics for morning glory (*Ipomoea aquatica* Forsk) and lettuce (*Lactuca sativa* L. cv. Duende). In experiment 3, BLRs, biogas solid residues (BSRs), and composts from the 3 manures were tested with morning glory. In experiment 4, 3 forms of pig manure fertilizers were tested with rice. In experiment 5, BSRs combined with *A. cristata* were applied to rice. Overall, the study found that biogas production could

play a central role in organic farming. The digestion of animal manures provided energy and available nutrients, among which, pig manure was the best material. Biogas generation duration of pig, chicken, and cow manures were 150, 90, and 90 days, generating biogases of 250, 150, and 70 m^3 with maximum CH_4 compositions of 76.1, 79.9, and 62.0%, respectively. Most of the N in the BLRs was in NH_4^+ form. In digested BLRs, NH_4^+ increased while NO_3^- decreased after hydrolysis due to O_2 absence. While available N and K were relatively high, available P was relatively low (240, 80, and 110 ppm in pig, chicken and cow BLR, respectively). The organic hydroponic study found that the two vegetables could be successfully grown in pig and chicken BLRs at the EC of 2.5 and 1.5 mS/cm, respectively. Cow BLR was not applicable because of its low N content. Because of high concentration of OM, the BLRs needed to be well filtered to reduce large particle OM and avoid the growth of algae and pathogens. Vegetable growing study indicated the beneficial effects of both BLRs and BSRs application for short-season vegetables. These residues applications could produce 20.0-21.6 t/ha of vegetables. From the comparison of all forms and kinds of manures, pig and chicken BLRs were found to be the best, followed by those of the pig and chicken BSRs, and composts. The study of the residues application on rice found that BSR and BLR had similar effects on rice yield and nutrient uptake as composts. In the study of *A. cristata* and biogas residue application in rice, the interaction effect was found. The BRs could provide nutrients for *A. cristata* biomass, while *A. cristata* harnessed atmospheric N and subsequently improved the organic rice production. In conclusion, the Chinese fixed dome biogas digester could be effectively applied in households in the Northeast Thailand environmental conditions. Pig manure was the best material in term of biogas production. The biogas residues from pig and chicken manures had relatively more balance nutrients than cow manure. Both of them would be the good sources of organic fertilizers for organic crops.

School of Crop Production Technology Student's Signature____________________

Academic Year 2010 Advisor's Signature____________________

Co-advisor's Signature__________________

Co-advisor's Signature__________________

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Li Yurong

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LIST OF ABBREVIATIONS

AAS	=	Atomic Absorption Spectrophotometer
BLR	=	Biogas liquid residue
BR	=	Biogas residue
BSR	=	Biogas solid resudue
C/N ratio	=	Carbon nitrogen ratio
Ca	=	Calcium
CEC	=	Cation exchange capacity
CH_4	=	Methane
CLR	=	Cow liquid residue
CHLR	=	Chicken liquid residue
CO_2	=	Carbon dioxide
CRD	=	Complete randomized design
Cu	=	Copper
EC	=	Electric conductivity
FAO	=	Food and Agriculture Organization
Fe	=	Iron
FEC	=	Farmers' electric cooperative
FYM	=	Farm yard manure
GC	=	Gas chromatography

LIST OF ABBREVIATIONS (Continued)

GMOs	=	Genetically modified organisms
$H_2 O_2$	=	Hydrogen peroxide
IFOAM	=	International Federation of Organic Agriculture Movements
K	=	Potassium
k Pa	=	Kilo Paska
Mg	=	Magnesium
Mn	=	Magnesium
N	=	Nitrogen
Na	=	Sodium
NFT	=	Nutrient film technique
NH_4^+	=	Ammonium
NO_3^-	=	Nitrate
NOSB	=	National Organic Standards Board
OFRF	=	Organic Farming Research Foundation
OM	=	Organic matter
P	=	Phosphorus
PLR	=	Pig liquid residue
PGPR	=	Plant growth-promoting rhizobacteria
RCB(D)	=	Randomized complete block (design)
RO	=	Reverse osmosis

LIST OF ABBREVIATIONS (Continued)

SOM	=	Soil organic matter
SPSS	=	Statistical Package for the Social Sciences
SUT	=	Suranaree University of Technology
USDA	=	United States Department of Agriculture
WCED	=	World Commission on Environment and Development
Zn	=	Zinc

CHAPTER I

INTRODUCTION

1.1 Background of the selected topic

1.1.1 Organic farming and biogas production in relation to environment

Nowadays, organic farming is widely known and accepted by people all over the world and organic crops growers are ever increasing. Organic farming reduces the use of chemicals, pesticides, and herbicides to avoid harm to human health. However, organic farming has constraints, of which the most serious is the lack of readily available nutrientscan solve pollution problems for reducing and recycling the carbon release into the atmosphere, hygiene and sanitation problems for waste treatment, and most importantly it can solve the energy supply problems through the waste treatments. Residues as by-products from biogas production could be readily available organic fertilizers in the organic farming.

1.1.2 Importance of organic farming and biogas technology

(1) Organic farming

Organic farming is important for human beings and the environment. It causes less pesticide contamination in food, people and the environment. Soil fertility (physical, chemical and biological fertility) can be maintained by the application of organic matter. Soil physical fertility is improved due to the beneficial effects of increased organic matter inputs on soil organisms, soil structure and soil erosion protected by the organic matter compared to conventional practice (Shepherd *et al*., 2002). Soil chemical fertility improvement depends strongly on the application of organic matter and the transformation of nutrients such as mineralization of organic matter and dissolution of minerals. Soil biological fertility indicates by the number of microorganisms such as root symbiosis bacteria and mycorrhizal fungi. By using organic matter, pesticide and fungicide prohibition, higher levels of soil biological activity and biodiversity can be achieved.

Meanwhile, organic agriculture is faced with certain problems and challenges. First of all, yield is a common question asked for organic agriculture (Trewavas, 2004). As the FAO reported, one major criticism on organic agriculture is its lower productivity since synthesized fertilizers are not allowed to apply. Compared with the input-high yielding system, the yield of organic agriculture is much lower. So it is difficult to convince farmers to accept organic farming since they are used to obtain higher productivity with high input of fertilizers. Organic fertilizer cannot provide enough nutrients for short-time growing crops such as vegetables since it needs time for decomposition. Therefore, the nutrients availability of organic fertilizer is lower for vegetables unless a huge amount of fertilizer is applied. Besides, weeds can be a major impact on yield, and specific pests and diseases can be problematic in their host crops.

With all the constraints mentioned above, organic farming in the world is still under development and has limitations in scale. In 2004, 80% of organically managed land was located in only ten countries, with more than 50% in Australia and Argentina (Yussefi, 2004). Currently, 0.61% of the world's reported agriculture land is certified organic agriculture. There are no recent data on the extent of non-certified organic agriculture. However, it is widely known that a large part of global food production systems is non-certified organic agriculture, often at subsistence level (Niggli, *et al*., 2007).

If productivity of crops under organic farming can reach as high as that of industrial fertilizers-based farming, there will be more people practicing organic farming. The solution is to find the mechanisms helping to obtain the amounts of nutrients for crops production under organic agriculture practice as the industrial fertilizers application.

(2) —Biogas technology

_Biogas technique has been developing fast in the world. Most biogas is produced in industrial farms, some of which use biogas to generate electricity. Some European countries such as Germany, Sweden, and the US use biogas to generate power for the engines of vehicles or trains (Dieter, 2008). Biogas technologies for household use have been developing very fast in China in present years. At the end of 2005, there were 17 million biogas tanks which produced 6.5 billion cubic meters of biogas annually, and 50 million people benefited from these technologies. It is estimated that the annual production of biogas will be 25 billion cubic meter in 2020 (Liu, 2009 and Li, 2002). It has been realized by farmers in China that the BLR from biogas production tank can be used as a fertilizer.

(3) Biogas residues

_Anaerobic fermentation residues (BRs, BLR, BSR) are the by-products of biogas digested by the anaerobic bacteria during the animal manure fermentation (digestion), while most organic fertilizers such as compost used in organic agriculture is aerobic digested. Biogas residues have complete nutrients available for plants.

During fermentation, only carbon and a little amount of N gets lost (produced major gases as CH_4 and CO_2, and trace CO, H_2, NH_3, and H_2S), and most of the nutrients are still in the residues. Furthermore, during fermentation, most of the nutrients in organic matter are converted to inorganic nutrients and dissolve in the solution. Therefore, the availability of nutrients in biogas residues is higher, and the nutrients can be taken by the plants as soon as possible. There are also some growth hormones and enzymes produced by the bacteria. Therefore using the biogas residues to solve the nutrient deficiency in organic farming can be a best solution.

The benefits of biogas include the production of energy (heat, light, electricity), the transformation of organic wastes into high quality fertilizers, the improvement of hygienic conditions through reduction of pathogens, worm eggs and flies. The reduction of workload especially for women in firewood collection and cooking, the environmental advantages through protection of forests, soil, water and air, and the global environmental benefits of biogas technology were also the benefits of biogas. However, there is not much information yet on energy generated and the value of fertilizer from the anaerobic fermentation of different manures.

1.2 —Research objectives of this study

(1) —To compare the amount and purity of biogas generated from different kinds of common animal manures (pig, chicken, and cow manure).

(2) —To evaluate the nutrient availability of the biogas liquid residues (BLRs) in organic hydroponics.

(3) To compare the BRs with composts as organic fertilizers for organic vegetable.

(4) To compare the BRs with composts as organic fertilizers for organic rice.

(5) To find the interaction effects of BRs and *Azolla cristata* on organic rice.

1.3 Hypotheses of this study

(1) Different animal manures produce different amounts of biogas and plant nutrients in the BRs. The factors affecting gas generation could be pH, temperature and the chemical composition in the manures.

(2) The nutrients in the BLRs are readily available for the organic hydroponic crops. Different manure BLR has different nutrient ratio, and specific crops need different suitable nutrient ratio.

(3) The nutrients in fermented manure BLRs and BSRs are soluble and readily available for the crops, while the nutrients in dry compost are not readily available. For the short-season crops such as vegetables, the use of BLRs and BSRs will be better than the use of compost as fertilizer.

(4) Not only do the fermented BRs have available nutrients for short-season crops, but the organic form nutrients are also available for long-season crops such as rice.

(5) The available nutrients in BRs can stimulate the growth of *Azolla*, and there could be interaction between the BRs and *Azolla* which improves the growth of rice by the combination of nutrient supply and nitrogen fixation.

1.4 Significance and design routes of this study

1.4.1 Significance of this study

Environmental and health problems are the big concerns in the future. Organic farming avoids contamination of chemical fertilizers, pesticides, herbicides, etc. Organic farming is gaining acceptance by the public. However, so far, organic farming is still an expensive agriculture form with high cost of investment and management. A major constraint of organic farming is the lack of readily available fertilizer for the organic crops. Biogas production solves pollution problems for reducing and recycling the carbon release to the atmosphere, hygiene and sanitation problems for waste treatments, and most importantly solves the energy supply problems from the waste treatments.

Thus this study combined organic farming and biogas production together to improve organic farming and approach self sufficiency.

First of all, the study identified the important role of biogas in organic farming. The treatment of residues from animal production and crop production, provided energy for self sufficiency, and provided nutrients readily available organic fertilizers for organic growers by converting most residues through anaerobic fermentation. Biogas production should be emphasized for its central role in the organic system.

The study also monitored the nutrient dynamics in both BLRs and BSRs in all the pig, chicken, and cow manures.

Secondly, the study explored the possibility of BLR application in organic hydroponics through a nutrient availability evaluation experiment. It was found that pig BLR with EC 2.5 and chicken BLR with EC 1.5 were applicable for both a resistant crop morning glory (*I. aquatic* Forsk) and a sensitive crop lettuce (*L. sativa* L. cv. Duende),while cow BLR was not applicable.

Thirdly, the study established the importance of both BLRs and BSRs application for short-season vegetables.

Apart from the short-season organic vegetable, the study also tested the nutrient availability of BRs in organic rice production: BLR, BSR, and compost of pig manure were tested in organic rice planting as long-season crop.

The study also investigated the interaction effect between green manure (*Azolla*) and BRs (BLR and BSR) on organic rice production: *Azolla* was used as green manure, and BRs (BLR and BSR) were tested in organic rice planting as a long-season crop in a close-system so as to study the interaction between green manure and BRs.

1.4.2 —The design routes of this study

In this study, common animal manures including pig, chicken, and cow manure were compared with each other as the study object for biogas generation.

The study was divided according to 2 digestion methods (6 continuous experimental studies) into the following procedures.

(1) —Aerobic digestion : Pig, chicken, and cow manures were fermented individually without adding any other materials in the normal condition in order to prepare composts of each individual manure, and the manures were turned over regularly.

(2) —Anaerobic digestion : Pig, chicken, and cow manures were digested in the Chinese fixed dome digester for the comparison among the biogas generation, gas purity, and nutrient dynamics in both BLR and BSR during the digestion from individual manure.

(3) —Hydroponic system : Digested BLRs from pig, chicken, and cow manures were used in an organic hydroponics system to evaluate the nutrient availability. Morning glory (*I. aquatica* Forsk) and lettuce (*L. sativa* L. cv. Duende) were used as a resistant and a sensitive crop in this study.

(4) —Organic vegetable : All forms of residues (compost from aerobic digestion, BLRs and BSRs from anaerobic digestion of pig, chicken, and cow manures) were tested in organic morning glory (*I. aquatica* Forsk) as the representative of short duration crop.

(5) —Organic rice plating in field as an open-system: BLR, BSR, and compost of pig manure were tested in organic rice as the representative of long duration crop.

(6) —Organic rice plating in cement tank as a close-system : *Azolla cristata* was used as a green manure, pig BLR and BSR were tested in organic rice planting in close-system to study the interaction between green manure and BRs.

1.5 —Scope and limitation of the study

Various biomass materials can be used as raw materials for the fermentation to generate biogas. This study only focuses on evaluating gas generation by the common manures of pig, chicken, and cow. The anaerobic digested BLRs, dry BSRs, and aerobic compost of 3 kinds of manures were used as fertilizers in the following:

1.5.1 —Only one design of the biogas digester, the efficient Chinese fixed dome digester was used for gas generation in this study.

1.5.2 —Only 3 kinds of common animal manures, namely pig, chicken, and cow manures were tested for gas generation.

1.5.3 —Different EC levels of BLRs from pig, chicken and cow manures were tested in organic hydroponics study.

1.5.4 —Only 2 crops, namely morning glory (*I. aquatica* Forsk) and lettuce (*L. sativa* L. cv. Duende) were tested as a resistant and a sensitive crop in the hydroponics study.

1.5.5 —BLRs, BSRs, and compost from all the 3 manures were used for the multi-factor to study the interaction among the crops.

1.5.6 —Only morning glory (*I. aquatica* Forsk) was used as a short-season crop to test for the 3 forms of residues (BLRs, BSR, and compost) from 3 kinds of animal manures.

1.5.7 —Multi factor experiment would not show the accurate result, 2-3 factors would be limited for the study of interaction when the fertilizers were combined to apply to the crops.

1.5.8— Only pig BLR, BSR and compost were used to test rice as a long-season crop in the open field system.

1.5.9 —Only *Azolla* was tested as a green manure to combine with pig manure BLR and BSR for organic rice in a close-system (cement tank) in the study.

1.5.10 Crop season, pests, mice, and uncontrollable natural disaster would be the limitation which is difficult to control in the study.

1.6 Expected results of the study

1.6.1 Results of biogas generation from pig, chicken, and cow manures, provide useful information and methods on efficient gas generation for the household consumption in the tropical condition.

1.6.2 Gaining suitable EC and other conditions for BLRs used as nutrient resource in organic hydroponics.

1.6.3 Understanding the effects BRs on organic vegetables and organic rice.

1.6.4 Identifying the interaction between green manure *Azolla* and pig manure BRs to improve the nutrient uptake for rice in organic farming.

1.6.5 The results of using biogas residues can widen the organic farming principle and improve the application of organic farming.

By identifying the difference of BRs and compost used in organic farming to assess BRs used as alternative bio-fertilizer in organic practice, the higher nutrient content availability in the BRs compared with the compost should be known and emphasized to be used for crop production in organic farming.

Although BRs and compost have the same effect, BRs can be the best bio-fertilizer in organic farming. The digestion process can not only degrade and digest the organic matter, but also generate gas for household consumption. Its energy value should be equal to or even higher than its value as a bio-fertilizer only.

CHAPTER II

REVIEW OF LITERATURES

2.1 Importance of organic agriculture

2.1.1 Definition and origin of organic agriculture

Organic agriculture is a holistic production management system which promotes and enhances agro-ecosystem health, including biodiversity, biological cycles, and soil biological activities. It is a form of agriculture which avoids or largely excludes the use of synthetic fertilizers and pesticides, plant growth regulators, and livestock feed additives. As far as possible organic farmers rely on crop rotation, crop residues, animal manures and mechanical cultivation to maintain soil productivity and tilth, to supply plant nutrients, and to control weeds, insects and other pests (Kuepper & Gegner, 2004). It emphasizes the use of management practices in preference to the use of off-farm inputs, taking into account that regional conditions require locally adapted systems. This is accomplished by using, where possible, agronomic, biological, and mechanical methods, as opposed to using synthetic materials, to fulfill any specific function within the system (FAO 1999). According to the USDA National Organic Standards Board (NOSB), it is defined as “an ecological production management system that promotes and enhances biodiversity, biological cycles, and soil biological activity. It is based on minimal use of off-farm inputs and on management practices that restore, maintain, or enhance ecological harmony. The primary goal of organic agriculture is to optimize the health and productivity of interdependent communities of soil life, plants, animals and people" (NOSB, 1997).

It is defined by Organic Farming Research Foundation (OFRF) in the USA as "a modern, sustainable farming system which maintains the long-term fertility of the soil and use less of the earth's finite resources to produce high quality, nutritious foods" (OFRF, 2004). The International Federation of Organic Agriculture Movements (IFOAM) goes further in defining it as "an agriculture production system that promotes environmentally, socially and economically sound production of food and fibers, and excludes the use of synthetically compounds fertilizers, pesticides, growth regulators, livestock feed and additive and genetically modified organisms " (IFOAM, 2004). According to the international organic farming organization IFOAM, the role of organic agriculture, whether in farming, processing, distribution, or consumption, is to sustain and enhance the health of ecosystems and organisms from the smallest in the soil to human beings.

Organic farming excludes the use of synthetic inputs, such as synthetic fertilizers, pesticides, herbicides and genetically modified organisms (GMOs). In addition to the exclusion of synthetic agrichemicals, organic farming includes protection of the soil, promotion of biodiversity and outdoor grazing for livestock and poultry. Within this framework, individual farmers develop their own organic production systems, determined by factors such as climate, market conditions, and local agricultural regulations. There are some regulation practices of organic farming, that is to say, not allowing chemical fertilizers, chemical pesticides and things allowed in terms of fertilizers. Compost becomes the major fertilizer used in organic farming.

2.1.2 Sustainability of organic farming

Sustainability is defined in Bru ntland Report (WCED, 1987) as "meet the needs and aspirations of the present without compromising the ability of future generations to meet their own needs". Sustainable agriculture refers to the ability of a farm to produce food indefinitely, without causing severe or irreversible damage to ecosystem health. Biophysical (the long-term effects of various practices on soil properties and processes essential for crop productivity) and socio-economic e.g. long-term ability of farmers to obtain inputs are the two key issues. Ikerd (1993) defines a sustainable agriculture as "capable of maintaining its productivity and usefulness to society over the long run, it must be environmentally-sound, resource-conserving, economically viable and socially supportive, commercially competitive, and environmentally sound".

The sustainability of organic farming mainly refers the soil fertility sustainability and productivity sustainability. To achieve and maintain the sustainability, proper nutrient management is basically needed, which means the use of compost, green manure, and input in rotations including plant residue, animal manures, rock dust and biological activators (IFOAM, 2002)

2.1.3 Soil quality concern in organic farming

Soil quality is an important indicator to evaluate the sustainability of organic farming. It is commonly defined as "the capacity of a special kind of soil to function within natural or managed ecosystem boundaries, to sustain plant and animal productivity, to maintain or enhance water and air quality, and to support human health and habitation" (Doran *et al*., 1996). Soil fertility includes soil physical fertility, soil chemical fertility and soil biological fertility. Soil physical fertility involves soil structure and erosion control. Soil chemical fertility depends strongly on the application of organic matter, the process that governs transformations from fixed to soluble forms of nutrients, namely mineralization of organic matter and dissolution of minerals. Organic farms rely on organic matter to a great extent (Stockdale *et al.,* 2002; Watson *et al*, 2002). Soil biological fertility refers to soil process involving organisms that improve plant growth directly and indirectly e.g. root symbiosis bacteria and mycorrhizal fungi. Biological indicator can be quantified by measuring the size, activity, diversity and function of communities of microorganisms.

The interaction among soil chemical, physical, and biological properties defines a particular soil quality and determines how effectively the soil performs ecosystem functions :

1) retain and release nutrients and other chemical constituents

2) partition rainfall at the soil surface into runoff and infiltration

3) hold and release soil water to plants, streams, and groundwater

4) resist wind and water erosion

5) buffer against the concentration of potentially toxic materials (Larson and Pierce, 1991; Karlen *et al*., 1997)

Soil quality indicators include soil organic matter (OM), soil nutrient content (macro nutrients and micro nutrients), soil microorganisms and their activities, soil pH value, soil electric conductivity (EC), soil structure etc. Monitoring the indicators is an important technique for sustainability evaluation of an organic farming system.

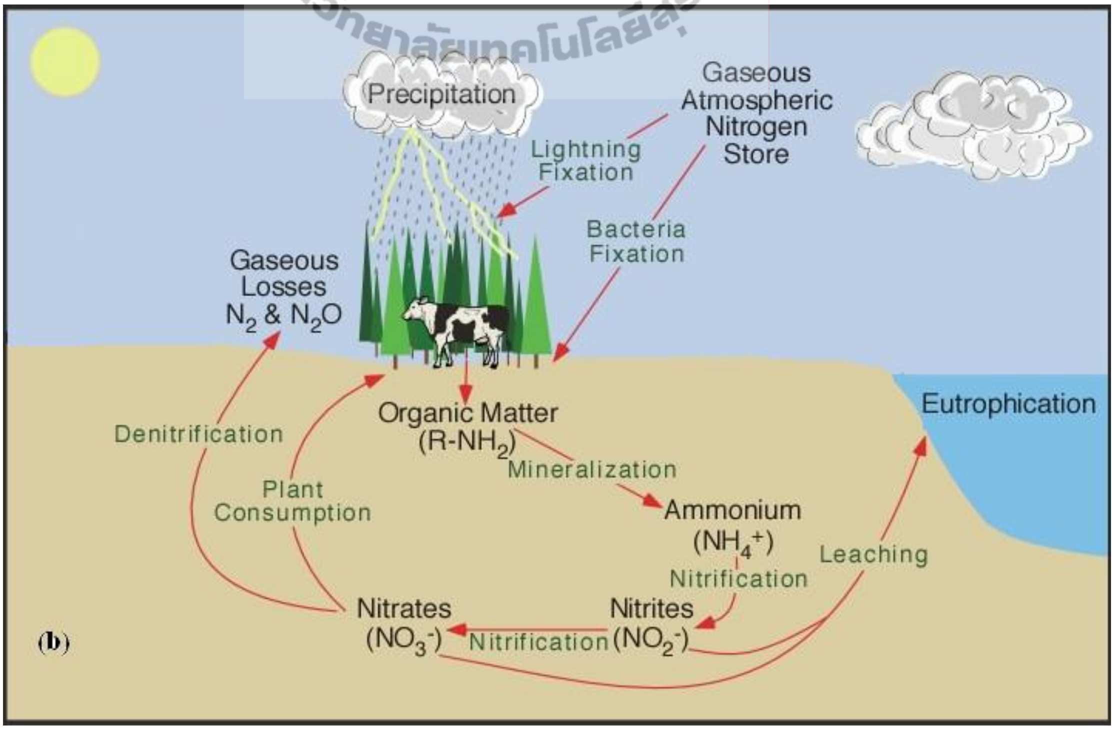
2.1.4 Soil and nutrient management in organic farming

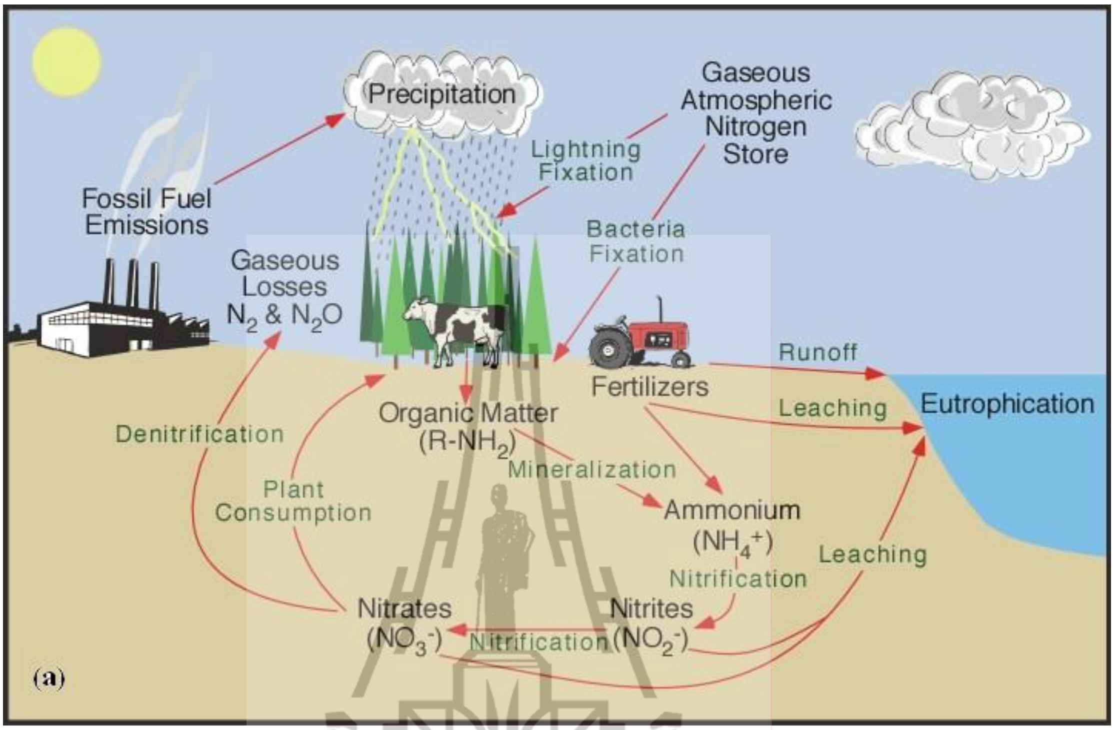
As Figure 2.1 shows, N is the key nutrient in plant growth. It is the most commonly deficient nutrient and is often the controlling factor in plant growth. Organic matter is the primary storehouse of soil N. *Rhizobia* and other organisms add

N to the soil from the atmosphere (Gardiner and Miller, 2004). So the main sources of N fertilizer are organic matter from plant residue and animal manure, and the N fixed from the air by the nitrogen fixing bacteria. Fertilizers are synthesized from the air and the mine by the industries with higher energy or higher heat with high cost, and they are just one of the N resources. Conventional agriculture in the past did not apply fertilizers before industrial movement, but adopted more natural organic matter, animal manure and intercropped with many legumes. Modern agriculture applied a lot of industrial fertilizers to reach the higher productivity. Mono-cropping with hybrid seeds leads to more pests due to the biodiversity losses. When big amounts of pesticides and herbicides are used, the residues accumulated in the crops, soil and water leaches to the environment, subsequently damages the health of human.

Soil organic matter (SOM) is related to the productivity of a soil. Because of this fact, maintaining SOM is an objective of many sustainable crop production systems (Mitchell, 1995). Soil organic matter content is related to the cation exchange capacity (CEC) of the soil, soil water-holding capacity, nitrogen mineralization rates, and microbial activities. It is also related to biogeochemical processes and the cycling of carbon and nitrogen within the upper soil profile. Measurement of changes in the soil organic matter content over time provides a quantitative assessment of the soil capacity to support crops and other plant and animal life. Soil organic matter content is a critical component of soil structure and is vital to all soil processes. It provides the chemical and biological basis for soil components (sand, silt, and clay) to form soil aggregates and is critical in key physical processes (water and gas exchange, penetration resistance, and compaction). Differences in climate, parent material, and management history have produced large regional differences in soil organic matter content. In addition, since soil organic matter is about 60% carbon, the amount of organic matter is a predictor of the amount of carbon in soils. Storage of carbon in soils has become important in international negotiations on the management of greenhouse gas emissions, as increased carbon storage can be useful in offsetting emissions of carbon from fuel burning and other sources (USDA. 2008).

Soil organic matter should be improved. Organic farming systems emphasize frequent additions of diverse source of organic matter from cash crops, crop residues, manures, some forms of organic fertilizer and perennial crops (Reganold *et al.*, 1990; Drinkwater *et al*, 1998). Bio-fertilizer (azotoabactor, *Azolla*, bio-compost, etc), and plant growth-promoting rhizobacteria (PGPR) are also applied in organic farming system (Kristiansen *et al.*, 2006).





*Adapted and modified from Pidwirny, 2006

Figure 2.1 N cycle in (a) modern farming and (b) organic farming

2.2 Organic fertilizer

The term organic in organic farming is closely related with organic fertilizers. Organic fertilizers are the major ones used in organic farming to replace the chemical and maintain the long-term soil quality and soil fertility. Organic fertilizers are composed of naturally occurring materials of either plant or animal origin, including livestock manure, green manures, crop residues, household waste, compost, and woodland litters through natural processes i.e. composting or naturally occurring mineral deposits. The common organic fertilizers are farm yard manure (FYM), green manure, and compost, most of them were fermented under aerobic conditions. Biogas residues (BLRs and BSRs) digested from animal manure under anaerobic condition is a potential best organic fertilizer in an organic farming system.

2.2.1 Farm yard manure (FYM)

Farm yard manure is prepared basically using animal dung, urine, waste straw and other dairy wastes. It is commonly used and rich in nutrients. A small portion of N is directly available to the plants while a larger portion is made available when the FYM decomposes. Availability of potassium and phosphorus from FYM is similar to that from inorganic sources. Application of FYM improves soil fertility and crop productivity. However, application of FYM in organic crops has some limitations and in some situation is prohibited. Fresh FYM could bring more pathogens, and incomplete fermented FYM could bring weed problem to the soil since the weed seeds could still survive due to the incomplete fermentation.

2.2.2 Compost

Compost is the aerobically decomposed remnants of organic matter. It is the main organic matter source and soil amendment for the crops in organic farming, produced from organic waste by microbiological decomposition. It is widely applied by the organic industrials and farmers and strongly recommended by the experts (Birendra, 2007).

Composting is an aerobic process requiring a continuous supply of air. It is a traditional, natural, and microbiological method used for increasing the stability and reducing the odor of organic wastes. The micro-organisms responsible for the degradation are mixed populations of mesophilic and thermophilic bacteria, fungi and actinomycetes. Mechanical mixing and/or forced ventilation provide the required oxygen, and remove the heat and moisture which are generated during composting. The temperature within the pile can rise during the first few days of composting to as high as 75°C or more. Such a high temperature suppresses the activity of micro-organisms which compost (break down the organic matter and provide the heat) the organic matter. This effect is usually exploited in composting processes. If the temperature is not suppressed during the initial days of composting, it deactivates most of the pathogenic micro-organisms within the compost. To achieve the optimal composting rate, shortest composting time and a resulting fully composted material, control of temperature at approximately 55°C is required. It is usually achieved by mixing and/or forced aeration of the composting mass (FEC service, 2003).

The organic content of sludge and soluble wastes can be reduced by controlled bacterial activity. If the bacterial activity is anaerobic, the reduction in organic content is achieved through sludge digestion. If the bacterial activity is aerobic, the reduction in organic content is achieved through sludge stabilization (Michael, 2003). So the compost process is the process of organic matter stabilization while the anaerobic digestion is the process of organic matter degrading.

2.2.3 Green manure

Green manure is a type of cover crop grown primarily to add nutrients and organic matter to the soil. Typically, a green manure crop is grown for a specific period, and then plowed under and incorporated into the soil. Green manures usually perform multiple functions including soil improvement and soil protection. There are *Leguminous* green manures such as clover and vetch containing nitrogen-fixing symbiotic bacteria in root nodules fix atmospheric nitrogen in a form that plants can use. Green manures increase the percentage of organic matter (biomass) in the soil, thereby improving water retention, aeration, and other soil characteristics. The root systems of some varieties of green manure grow deep in the soil and bring up nutrient resources unavailable to shallower-rooted crops. Common cover crop functions of weed suppression and prevention of soil erosion and compaction are often also taken into account when selecting and using green manures. When allowed to flower, some green manure crops provide forage for pollinating insects. Historically, the practice of green manure can be traced back to the fallow cycle of crop rotation, which was used to allow soils to recover. Green manures are widely used in organic farming for nutrient recover.

Azolla is a genus of water fern that can fix atmospheric nitrogen in association with the cyanobacterium *Anabaena azolla* (Moore, 1969; Peters *et al.*, 1978; Van Hope *et al*, 1983). De (1939) recognized the potential importance of N_2-fixation by cyanobacteria in maintenance of soil fertility in paddy soils. Farmers have long been aware of the benefits of *Azolla*, which has been used to enrich the soil. It is worldwide distributed in the rice growing regions in the tropical and temperate zones, and has been used as green manure in rice cultivation in China and Vietnam for centuries (Lumpkin and Plucknett, 1980 and 1982). Six species of *Azolla* were identified by Hills and Gopel (1967), namely *Azolla caroliniana (wild), A. microphylla, A. astrata, A. maxicana, A. pinnata, A. rubra,* and *A. filiculoides* (Hazarika, 2007). Under suitable field conditions, A*zolla* can double in weight every 3-5 days and fix atmospheric N at a rate exceeding that of the legume/Rhizobium symbiotic relationship. *Azolla* can accumulate 2-4 or more kg of N/ha/day (equivalent to 10-20 kg of ammonium sulfate. It can provide potential N source for flood crops such as rice (Lumpkin and Plucknett, 1982). Every 100 kg of live *Azolla* contributes 0.5 kg N, 0.4 kg Ca, 0.5 kg Mg, and 0.6 kg Fe (Singh, 1981). Generally 6 tons of *Azolla* is comparable to 50 kg N. Pillai (1980) reported that additional increase in rice to 200-500 kg/ha is due to *Azolla* alone. *Azolla* can be used as dual cropping with rice or as a green manure by using biomass at 5-10 ton/ha incorporating them into soil after peddling. During the dry season, incorporating of green *Azolla* biomass at the rate of 20 t/ha in soil along with 50 kg N/ha before transplanting increase grain yield of rice by 98% over control (Singh *et al*, 1981). *Azolla* green biomass can be converted into *Azolla* compost by transferring them into *Azolla* pit for a period of 15-20 days and thereafter can be used as a compost fertilizer for upland crops. *Azolla* compost contains 1.51-3.50% N apart from other macro and micronutrients (Hazarika, 2007). In addition to being used as a green manure crop, it can be used as forage fodder for fish (Liu, 1987) poultry and pig (Boonkerd, 1992).

2.3 Biogas

2.3.1 Biogas and anaerobic digestion

Biogas is the product of anaerobic digestion. It is an alternative energy for heating, light, and electricity. It is also a potential for environmental reservation such as protection of forest, soil, water and air, and global environmental benefits. Biogas technology transforms organic waste into high quality fertilizer and also improves hygienic conditions through reduction of pathogens, worm eggs and flies.

Anaerobic digestion consists of a series of bacterial events that convert organic compounds to methane, carbon dioxide, and new bacterial cells. These events are commonly considered as a three-stage process (Figure 2.2) (Mata-Alvarez, 2000; Monnet, 2003).

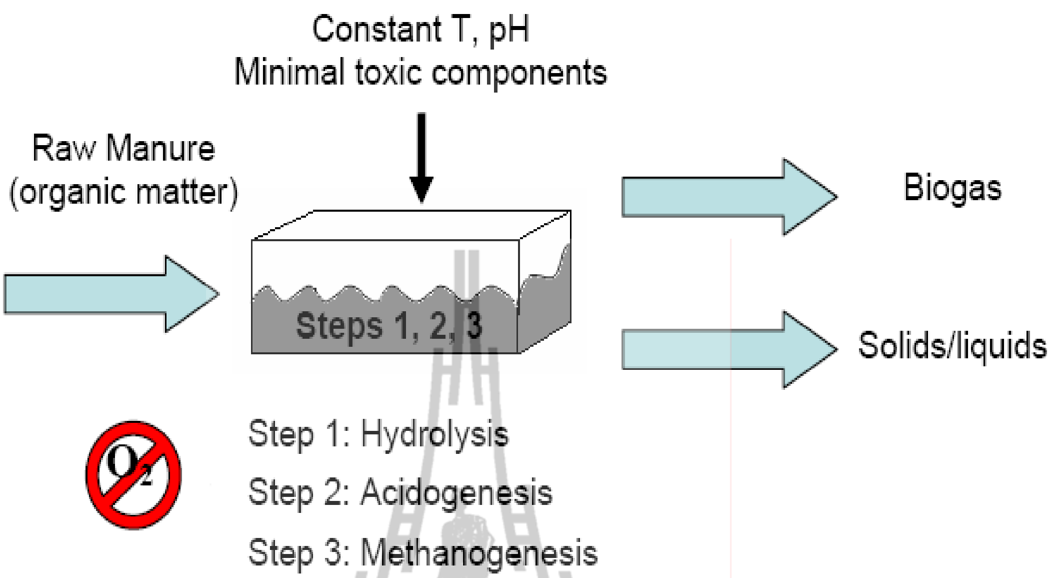


Figure 2. 2 Microbial process of anaerobic digestion

Stage 1: hydrolysis (polymer breakdown stage)

Hydrolysis is the solubilization of particulate organic compounds cellulose and colloidal organic compounds proteins into simple soluble compounds. The waste materials of plant and animal origins consist mainly of carbohydrates, lipids, proteins and inorganic materials. Large molecular complex substances and solids (particulate and colloidal wastes) are solubilized into simplistic, soluble organic compounds (volatile acids and alcohols) that can be absorbed by bacterial cells with the help of extracellular enzyme released by the bacteria. The cellulose consisting of polymerized glucose is broken down to dimeric, and then to monomeric sugar molecules (glucose) by cellulolytic bacteria.

$$\text{cellulose} + H_2O \xrightarrow{\text{hydrolysis}} \text{soluble sugars}$$

$$\text{proteins} + H_2O \xrightarrow{\text{hydrolysis}} \text{soluble amino acids}$$

Stage 2: acidification (acetogenesis)

The monomer such as glucose produced in stage 1 is fermented under anaerobic condition into various acids with the help of enzymes produced by the acid-forming bacteria. At this stage, the acid-forming bacteria break down molecules of six atoms of carbon (glucose) into molecules of less atoms of carbon (acids) in a more reduced state than glucose. Volatile acids and alcohols then are converted to substrates such as acetic acid or acetate (CH_3COOH) and hydrogen gas that can be used by methane-forming bacteria. The principal acids produced in this process are acetic acid, propionic acid, butyric acid and ethanol.

Stage 3: methanization (methanogenesis)

It is the third and final stage of the process and it involves the production of methane (CH_4) and carbon dioxide (CO_2). The principle acids produced in stage 2 are processed by methanogenic bacteria to produce methane. (Karki and Dixit. 1984; Michael, 2003).

Methane production occurs from the degradation of acetate and the reduction of carbon dioxide by hydrogen gas.

$$CH_3COOH \rightarrow CH_4 + CO_2$$

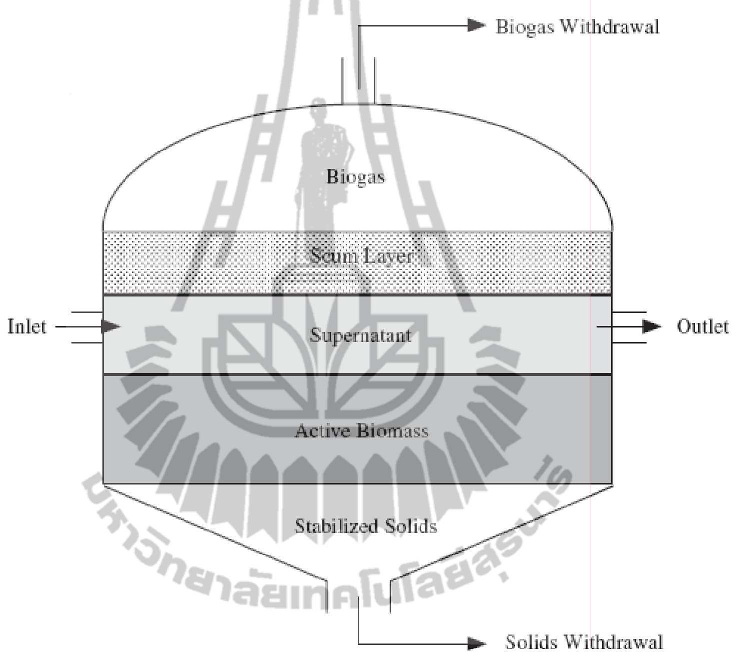
$$CO_2 + 4H_2 \rightarrow CH_4 + 2H_2O$$

Biogas producing bacteria (also known as methane-forming bacteria, methanogens, methanogenic bacteria, methane-producing bacteria) are the bacteria that act upon organic materials and produce methane and other gases in the process of completing their life-cycle in an anaerobic condition. (Alexander, 1961; Lagrange, 1979; Michael, 2003).

In the biogas tank, 5 layers are formed (Figure 2.3). The order of layers from top to bottom is: biogas, scum, supernatant, active biomass or sludge, and stabilized solids.

2.3.2 Biogas composition

Biogas is composed of 50-70% methane, 30-40% carbon dioxide (CO_2) and low amount of other gases (Table 2.1).



*Adapted from Michael, 2003.

Figure 2.3 Anaerobic digestion and layers of sludge degradation

Table 2.1 Composition of biogas (% by volume)

Substances	**Yadav and Hesse (1981)**	**Wheatley (1979)**	**Fox (1984)**	**Hobson *et al.*, (1981)**
Methane (CH_4)	50	52-95	60-70	60-70
Carbon dioxide (CO_2)	30-40	5-40	30-40	30-40
Hydrogen (H_2)	5-10	0.01-1.2	--	2
Nitrogen (N_2)	1-2	0.1-1.8	1	4
Oxygen (O_2)	--	0.02-6.5	--	--
Water vapor (H_2O)	0.3	--	--	--
Hydrogen sulfide (H_2S)	Traces	0.001-5.7	0.05-2	--
Carbon monoxide (CO)	--	0.001-2.1	--	0.001-1
Ammonia (NH_3)	--	Trace	--	--

*Adapted from Constant, 1989

2.3.3 Biogas technology development

Biogas technology has been developed fast in the world to generate energy from waste treatment, reduce global warming, and earn carbon credit. Biogas is used for cooking, heating, lighting, electricity generation, even running engines of vehicles and trains in many European countries (Dieter *et al*., 2008). In 2007 an estimated 12,000 vehicles were being fueled with upgraded biogas worldwide, mostly in Europe, with 70,000 biogas-fueled vehicles predicted by 2010 (Intelligent Energy Europe, 2007). Biogas has been applied for households use in China in present years (17 million biogas tanks, 6.5 billion m^3 of biogas produced annually) (Liu *et al*., 2009 and Li *et al*., 2002). The Chinese fixed dome biogas digester has been successfully adopted in Asian countries recently but not in Thailand.

2.3.4 Biogas residues (liquid residue/slurry and solid residue/sludge)

Biogas is the main product from the biogas digester, but the by-product slurry and sludge is equally important due to its high nutrient content and multiple uses as fertilizer, soil conditioner and even feed for animals. Biogas residues (liquid residue/slurry and solid residue/sludge) are fermented animal manure digested by the anaerobic bacteria in the biogas digester. Biogas residue is the final remnant of the original waste placed into digesters that cannot be utilized by microbes involved in the anaerobic degradation process (Veronica, 2009).

The residue additionally contains the mineralized remains of dead bacterial mass derived from within the digesters (Gerardi, 2003). To ensure that biogas residue is an acceptable crop fertilizer, the waste needs to be of high quality with proven value as an efficient plant nutrient source and/or soil conditioner (Svensson *et al*, 2004). The residues from the biogas digester contain all available plant nutrients. During anaerobic digestion, nutrients contained in the organic matter are conserved and mineralized to more soluble and biologically available forms, providing a more predictable bio-fertilizer. Particularly, BLRs have readily available plant nutrients which could be applied to crops. Most organic matter is digested to inorganic form by the bacteria and dissolved in the liquid solution, and can be easily taken by the plants as soon as possible. Solid residues are the left organic matter that could not be digested during biogas generation, but are still digestible by the combination of aerobic and anaerobic bacteria when applied to the field. Therefore, they could be used as organic fertilizers for crop production.

The application of BR as a fertilization agent that is recycled back to arable land ensures that crops receive the majority of the essential nutrients required for growth (Båth, Rivard, *et al.* and Wang, *et al.* 2000, 1995, and 2008), i.e., soil fertility is conserved (Adediran, 2003), and the soil structure and humus balance is improved (Odlare and Monnet, 2005 and 2003), thus promoting closure of the natural nutrient and energy cycles. Thus, the use of BR as an alternative should not only close the global nutrient cycle, but also indirectly reduce greenhouse gas emissions to the atmosphere through decreased need for inorganic fertilizers and new landfill sites.

The BSR as an organic fertilizer meets the requirements of organic farming. It has an effect on the productivity when it is used on many crops especially home garden vegetables. Presently, China is promoting the biogas tank in the countryside for ecological improvement, and a variety of farming systems involving biogas have been successfully promoted. There are several practices such as “animal raising (pigs, chicken, cattle) – biogas – crops (rice, vegetables, fruits trees, cash crops, fish farming, and mushrooms, etc.)”, but unfortunately a big amount of BLRs and BSRs are wasted since it is difficult to transport in the mountainous areas due to the shortage of transportation facilities and road availability.

2.3.5 Application of BLRs for hydroponic crop

The BLRs from the biogas digester contain all available plant nutrients. Their application for organic hydroponics is interesting but there has been no standard formulation yet. Xu *et al* (1992) suggested adding other nutrients to tomato and cucumber in hydroponic system. Zhang *et al* (1996) also reported narcissus could have earlier flowering and a longer flowering period when added with BLRs as supplement to the hydroponic system. Ning (2004) suggested that the suitable ratio of BLRs and water should be 1:4 for lettuce (*L. sativa* L. cv. Duende) hydroponics. He also suggested adding other nutrients in the hydroponic solution. However, very few investigations have been conducted on organic hydroponics using BLRs. Brandon and Chieri (2005) tried the organic hydroponics for strawberry production with coconut fiber pots with a mixture of coconut coir and perlite (3:7) and grown in modified nutrient film technique system. They placed coconut fiber mats in the organic nutrient solution reservoir to enhance colonization and activities of nitrifying bacteria converting the ammonium to nitrate. Issues as dominant ammonium nitrogen form, solution alkalinity, and dissolved oxygen level of nutrient solution for organic hydroponic strawberry production were identified in their study, but not been solved yet.

2.3.6 Constraints for short-season vegetables in organic vegetable system

Fertilization is the most expensive cultural practice for the increasing numbers of organic vegetable growers. N is the most important and costly nutrient to manage, and cost-effective N management practices are needed for efficient organic vegetable production. Organic N sources are widely available, but varied in cost, N content, N availability, and mineralization. Additional hidden management costs for organic growers could be caused by organic resources' un-uniformity, bulkiness, instability, and inconsistency as a group.

Dahiya and Vasudevan (1986) pointed out that biogas plant slurry could be an alternative to chemical fertilizer. Barbara *et al*. (2005) also studied the digested (broiler litter) liquid effluent in comparison with chemical and certified organic fertilizers with application rates based on soil analyses and crop recommendations. They concluded that the liquid effluent from thermophilic anaerobic digestion of poultry litter could be a potential fertilizer. Gaskell and Smith (2007) mentioned that liquid organic N sources used in micro-irrigation systems may have additional disadvantages caused by loss of valuable nutrient N removed by filters.

Constraints for organic vegetables are the readily available nutrients in organic fertilizer for the short growing organic vegetables. Compost and cover crops are commonly used due to their inexpensiveness and offer additional nutrients or soil improvement qualities in addition to N. Compost, which in particular, is the major organic fertilizer used in organic farming, but the slow release of nutrients from compost could not reach the requirements of fast growing crops and short-term vegetables, which hinders the organic vegetable production.

Mark *et al*. (2000) summarized the organic vegetable production practices in California. They pointed out that the key aspects as soil, insects, and weed management, etc. have not been thoroughly researched and the scientific base was still being developed. Russo and Taylor (2006) studied the effect of soil amendment on yield and economics of organic vegetable production during the transitional period. Their results indicated that conventional practices generally provided more net revenue than did transition to organic production. Gopal (2011) also assessed the adoption and extent of organic vegetable farming in Mahasarakham, Thailand. He pointed out that organic fertilizer was another major influencing factor along with pesticides effect, and organic experiences.

BRs are widely applied to most crops in China, according to hundreds of reports, but little basic nutrients information has been provided. Few researches have been done on the application of BRs in organic vegetable production.

2.3.7 Application of biogas residues (liquid and sludge) for organic vegetable production

Except the carbon lost to form methane as energy gas, 90% of nutrients needed by crops is still in biogas sludge after the anaerobic digestion process. The nitrogen content is even 40-60% higher than the same quantity of compost and easy to be uptake, and the amendment rate of phosphorus and potassium reach 80-90% (Huang *et al.,* 2004; Dai *et al.*, 2000; Huang and Liao 2005). There are not only macro nutrients and organic matter, but also plenty of micro nutrients, amino acid, hormone, and vitamin in the biogas sludge. It is a bio-fertilizer with fast and slower effective nutrients (Zhao and Yao, 1994). The nutrient content in the biogas slurry and sludge is shown in Table 2.2.

Table 2.2 Nutrient content in pig manure, slurry, and sludge

Fertilizers	Biogas liquid	Biogas sludge	Pig manure
OM (g/kg)	--	392.00	150.0
Total N (g/kg)	0.81	12.17	5.6
Total P (g/kg)	0.04	7.31	4.0
Total K (g/kg)	2.53	11.80	4.4
Available N (g/kg)	0.26	2.14	--
Available P (mg/kg)	0.04	2.80	--
Available K (mg/kg)	0.47	1.45	--

*Abstracted from Huang *et al*, 2004

The BSR as one of the outputs of a biogas digester can be returned to the agricultural system. Proper application of the BSR as an organic fertilizer increases agricultural production because of its high content of soil nutrients, growth hormones and enzymes. Dried sludge can also safely replace a part of animal and fish feed concentrates. Furthermore, BSR treatment also increases the feed value of fodder with low protein content. When the digested BSR is placed into the food chain of crops and animals, it leads to a sustainable increase in farm income

(FAO/TCP/NEP/4415-T, 1996).

BSR has proved to be high quality organic fertilizer. Compared to farm yard manure, digested BSR will have more nutrients, because in manure, the nutrients are lost by volatilization (especially N) due to its exposure to the heat of sunlight as well as by leaching.

Farmers need to use chemical fertilizers to increase their crop production. However, if only mineral fertilizers are continuously applied to the soil without adding organic manure to, productivity of land will decline. On the other hand, if only organic manure is added to the soil, desired increase in crop yield cannot be achieved. In China, there are evidences that productivity of agricultural land can be increased to a remarkable extent with the use of BSR produced from biogas digester (Huang *et al.,* 2004).

The application of the biogas sludge can be in liquid form, dry form or compost. Liquid form can be directly applied in the field by discharging it into an irrigation canal. However, there are some limitations. Firstly, not all farmers have irrigation facilities. Secondly, in the cascade system of irrigation in which water is supplied from one field to another, slurry is not uniformly distributed in the fields. Finally, since the digested slurry is in a liquid form, it is difficult to transport it to farms locating far from the biogas digesters. The sludge and slurry could be applied to the crop or to the soil both as basal and top dressings. Whenever it is sprayed or applied to a standing crop, it should be diluted with water at least at the ratio of 1:1. If it is not diluted, the high concentration of available ammonia and the soluble phosphorus contained in the slurry will produce toxic effect on plant growth (FAO/TCP/NEP/4415-T, 1996).

The high water content of the sludge causes difficulties in transporting it to the farms. Even if it is applied wet in the field, tilling is difficult. Due to such difficulties, the farmers usually dry the slurry before transporting it into the fields. When fresh slurry is dried, the available nitrogen, particularly ammonium, is lost by volatilization. Therefore, the time factor has to be considered in applying the slurry and in this regard and immediate use can be a way of optimizing the results.

If the BSR is composted by mixing it with various dry organic materials such as dry leaves, straw, etc., there will be some advantages. The dry waste materials around the farm and homestead can be utilized. One part of the BSR will be sufficient to compost about four parts of the plant materials. Thus, increased amount of compost will be available in the farm. Water contained in the BSR will be absorbed by dry materials. Thus, the manure will be moist and pulverized. The pulverized manure can be easily transported to the fields (FAO/TCP/NEP/4415-T, 1996).

2.3.8 Application of biogas residues (liquid and sludge) for organic rice production

Rice is the staple food for almost half of the world's population and approximately 90% of the world's rice is produced in Asia (De Datta, 1981). BRs are widely applied to rice production in China. Studies conducted in China indicated that the BRs are effective in rice production. Fu (1996) studied the effect of stable higher yield on rice by 10 years of continuous BRs application, rice yield increased 20% and cost was reduced 30% compared with the neighboring rice growers. Hu *et al.* (2006) reported that the rice yield increased 27.4% by using the BRs for seedling compared with conventional nursery techniques in Guizhou, China. Chen (2006) reported that the rice yield increased 33.1% and 22.0% by 75 t/ha of solid sludge and liquid residue applcation, respectively. Huang *et al.* (2004) compared the effect of solid sludge with general rice fertilizer and specific rice fertilizer, yield of rice in 35.7 t/ha of solid sludge plus half amount of specific rice fertilizer increased 0.40% comparing with general rice fertilizer treatment, but decreased 4.6% compared with specific rice fertilizer treatment.

Experiments carried out in China showed that the application of BRs increased the late rice, barley and early rice yields by 44.3%, 79.8% and 31%, respectively compared to no BRs application (Yao, 1989). Not only can BRs application increase crop yield, it can also improve soil quality and fertility (Table 2.3). The application of BRs increased yields of rice, maize and wheat by 6.5%, 8.9% and 15.2%, respectively compared to farm yard manure. The application of BRs along with ammonium bicarbonate (chemical fertilizer) increased the yields of rice and maize by 12.1% and 37.6%, respectively compared to farm yard manure. The results indicate that biogas sludge is of superior quality to farm yard manure. Crop productivity can be significantly increased if the sludge is used in conjunction with appropriate nature and a dose of chemical fertilizer.

Anyhow, few papers compared the effect of different biogas residues with compost as an organic fertilizer in organic system. Most studies mentioned above combined biogas residues with chemical fertilizer due to the higher yield demand under population pressure. Few people reported the effect of biogas residues when used as an organic fertilizer for organic rice production.

Table 2.3 Effect of biogas liquid residue application on soil quality

Treatment	pH	OM (%)	Total N (%)	Total P (%)	Available P (mg/kg)	Density (g/cm^3)
Biogas liquid	6.80	1.210	0.068	0.110	14.40	1.41
Control	6.85	1.040	0.064	0.069	1.32	1.44

*Abstracted from Huang *et al.*, 1999

2.4 Conclusion of literature review

Based on the review of literatures, organic farming is known and accepted widely, but the fertilizers' constraints for organic farming are still a big obstacle for organic farming.

Biogas is developing fast in the world due to its multi-function for environment protection. Most people have focused mainly on the end-use exploration of biogas, technologies for biogas generation from animal manures and waste treatments, etc. Few people have conducted systematic studies to compare biogas generation (amount, duration, gas composition) from common household animal manures as pig, chicken, and cow manure to digest in same condition.

In terms of fertilizer, people mentioned that BRs could be used as fertilizers, but very few people conducted the nutrient dynamics during the fermentation, thus most implementation workers could not provide nutrient content data from the biogas residues. Many studies applied biogas residue based on the amount instead of nutrient content.

Very few studies are found in BLRs application for organic hydroponics. Most people carried out studies based on water dilution level instead of EC level, and only issues as high solution alkalinity, dominant NH_4^+ form of N, and low dissolved O_2 level were identified, but not been solved yet.

Trying BRs in short-season organic vegetables could help to find the readily available nutrient organic fertilizers for organic growers. Also, the optimal application amount could provide technical support for organic growers.

Besides, the nutrient availability for long-season crops of BRs is necessary for organic growers to evaluate the nutrient differences with common organic fertilizers. Furthermore, the combination of *Azolla* with BRs as organic fertilizers in rice production could provide more information in yield potential of organic rice.

Use of compost alone in organic farming cannot help crops reach the highest productivity, particularly the short-season crops such as vegetables since the availability of the nutrients in compost is limited and the organic compounds need a long time to breakdown and release to soil and used by the crops. For the BLRs and BSRs, most digestible organic compounds are digested in the BLRs and BSRs during the fermentation process. The nutrients are soluble, available, and ready to be uptake by the crops. Anaerobic fermentation residues might be the best organic fertilizer compared with the compost.

Both social and economical benefits can be achieved by adopting anaerobic fermentation. Besides the biogas for heat, light, and electricity, the anaerobic fermentation can provide efficient and high quality of organic fertilizers. However, researches on BRs as high quality organic fertilizers have not been conducted much yet.

CHAPTER III

GAS GENERATION FROM ANAEROBIC FERMENTATION OF ANIMAL MANURES AND NUTRIENT DYNAMICS IN THE RESIDUES

3.1 Introduction

Biogas household application has been developed very fast in China in recent years. However, the Chinese fixed dome biogas digester which has been successfully adopted in most Asian countries recently, has not been adopted in Thailand yet.

The residues from the biogas digester contain all available plant nutrients. BLRs, in particularly, have readily available nutrients which could be applied to crops. Most organic matter is digested to inorganic form by the bacteria and dissolved in the liquid, which is readily available for plants. Solid residues are the left organic matter that could not be digested completely during the biogas generation. They could still be digested by the combination of aerobic and anaerobic bacteria when applied to the field, and they can also be used as organic fertilizers for organic crop production.

Understanding the amount of gas generated and quality of organic fertilizer (nutrient content in BRs) could help the organic grower choose suitable animal manures in the organic agriculture system. Knowing the nutrient dynamics also could help to decide on when and how to apply the biogas residues as organic fertilizer.

The objectives of this experiment were to compare biogas generated from 3 different animal manures in the Chinese fixed dome digesters and to determine nutrient dynamics of both liquid and solid residues.

3.2 Materials and methods

All materials for biogas generation including manures, biogas facilities, biogas generation and composition measurement facilities, and biogas residue nutrients analysis material and methods were required as follows.

3.2.1 Materials

(1) Biogas digester

Chinese fixed dome biogas digester (8-10 m^3) was built in the Suranaree University of Technology (SUT) organic farm (Figure 3.1).

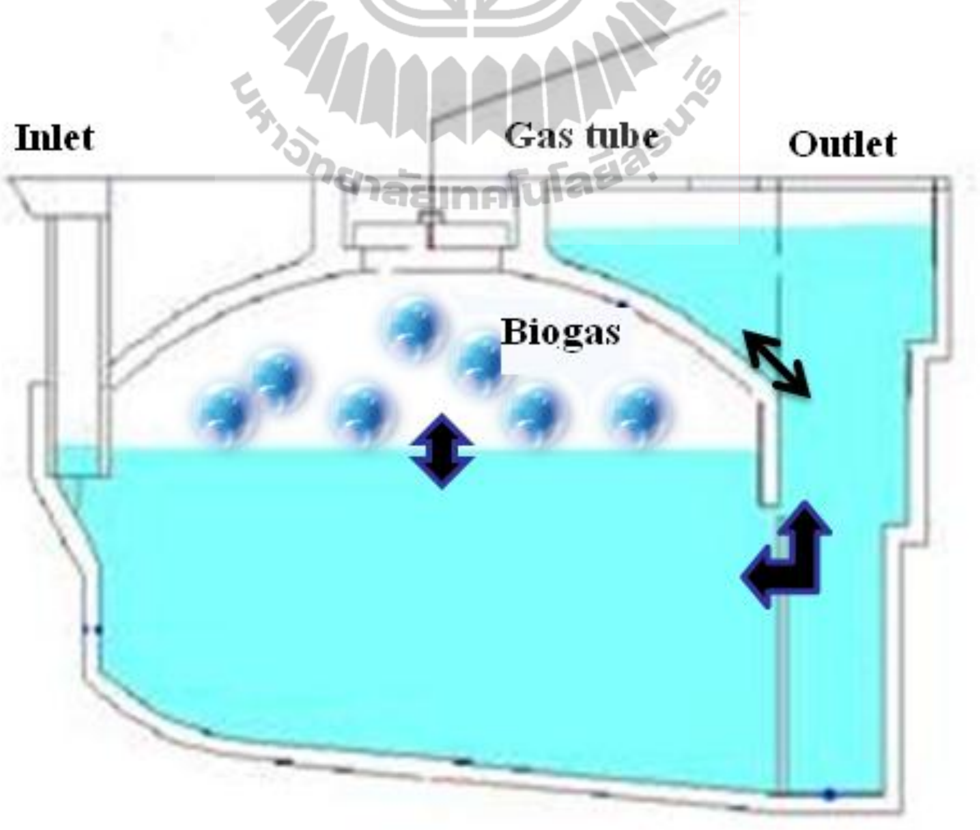


Figure 3.1 Diagram of the Chinese fixed dome biogas digester

(2) Manures

Thousand kilo-gram (dry weight basis) of fresh animal manures (pig, chicken, and cow manure) were digested in the digester by filling it up with 6 m^3 of water. All animal manures were bought from SUT farm, i.e. pig manure from pig farm, chicken manure from egg-laying chicken, and cow manure from dairy cow.

(3) Biogas utility facilities

Gas tube, H_2S reducer (combined with gas pressure meter), end-use combustion equipments were used for checking ignition, burning and cooking.

3.2.2 Data collection

(1) Biogas generation measurement

Gas generation was recorded daily by gas meters connected with the biogas digester.

(2) Biogas composition measurement

Biogas samples were collected every 5 days. Gas chromatography (GC-14, Shimadzu) was used for gas composition measurement. Standard gases (H_2, N_2+O_2, CO, CH_4, CO_2) and carrier gases (N_2, He) were used to measure biogas composition.

(3) Biogas residues nutrient analysis

Air temperature, soil temperature, temperature of inlet, outlet of solution in the digester, pH, and EC of the digestion solution were measured daily.

BLRs and BSRs samples in the digesters were taken every 5 days for chemical analysis to evaluate the nutrient dynamics from the beginning to the end of digestion.

BLRs samples were stored in cool room and filtered, and BSRs were air-dried and oven-dried at 70°C before nutrient analysis. Both BLRs and BSRs were analyzed for OM and plant nutrients (Total N, inorganic N, P, K, Ca, Mg, Na, Fe, Mn, Zn, and Cu).

Organic matter in both BLRs and BSRs was analyzed by Walkley-Black acid digestion. N was analyzed by wet digestion (H_2SO_4 + mixed catalyst digestion) in Kjeldahl method. P and other nutrients were analyzed by wet digestion method (HNO_3 + $HClO_4$ digestion). P was analyzed by spectrophotometer with Baton’s reagent after digestion, it was assumed that all P in liquid were available P, K, Ca, and Na were analyzed by flame spectrophotometer. Mg, Fe, Mn, Zn, and Cu were analyzed by Atomic Absorption Spectrophotometer (AAS).

3.3 Results and discussion

3.3.1 Gas generation

(1) Duration and amount of biogas generation

Unlike the aerobic digestion, the temperature of the fermented solution was not directly affected by air temperature since the digesters were underground. The temperature was affected and changed according to the surrounding soil temperature instead of air temperature changing with the sunlight. It was relatively constant (30 ± 2°C) throughout the fermentation period.

Figure 3.2 showed the daily gas generated from pig, chicken, and cow manures in 150 days. Chicken manure began to generate gas in the first day, then large amount of gas was produced within 30 days, but decreased after 30 days to less than 1 m^3 within 50 days and could not produce significant amount of gas after 90 days. Pig manure had a tendency to produce stable gas amount, the gas generation increased more than 1 m^3 after 30 days, and then was able to generate gas till 150 days. Cow manure could not generate gas at the 1st 5 days, gas increased after 10 days, but after 35 days the gas generation was relatively low and could not produce significant amount of gas after 90 days. The same gas generation tendency was also found by Zeng *et al* (2009) and Chen *at al*. (2009). In their experiments, chicken and cow manures showed similar tendency that generated more gas within 30 days, but decreased and then stable afterwards. Pig manure generated small amount of gas within 30 days, but increased afterwards, and then stably generated gas until 150 days.

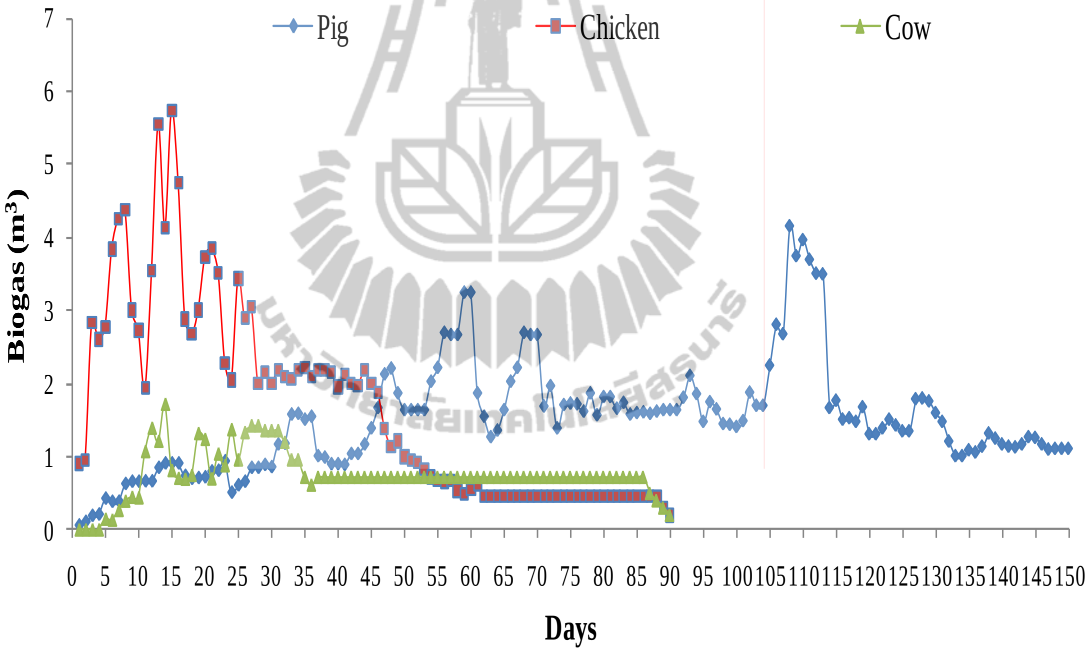


Figure 3.2 The daily gas generated from the anaerobic fermentation of pig, chicken, and cow manures in 150 days.

The total amount of biogas generated in 50 and 90 days showed that chicken manure had the highest amount of gas (132 m^3 and 153 m^3) followed by pig (50 m^3 and 125 m^3) and cow manure (40 m^3 and 70 m^3) (Table 3.1). However, chicken and cow manure could not produce biogas longer than 90 days. The reasons for short duration of gas generation in chicken manure might be due to the high EC level and NH_4^+ in chicken BLR which could prohibit the microbial activities for gas generation. Starkenburg (1997) found that biogas generation was inhibited when NH_4^+ reached 1700 ppm. In this study, the concentration of NH_4^+ was 2465 ppm, therefore, the chicken manure might need more water to dilute the NH_4^+ and reduce the high EC. The low gas generation in cow manure might be contributed by the high C/N ratio and low N content which could not provide enough nutrients for anaerobic bacteria to digest the leftover organic C (lignin, fibers, and cellulose). On the other hand, pig manure could continuously and significantly produce biogas until 150 days which might be due to its suitable C/N ratio and digestibility.

Chen *at al*. (2009) had studied biogas generation by fermenting pig, chicken, and cow manure at 35°C, 25°C, and room temperature for 60 days. They reported that predigested manure could generate gas earlier. Gas from pig manure reached the peak on the 6th, 10th, and 21st day at 35°C, 25°C, and room temperature, respectively while chicken manure reached peak on the 6th, 8th, and 21st day; and cow manure reached peak on the 7th, 7th, and 20th day in the above temperatures. Shi *et al*. (2010) fermented 100 g of dry manures (C/N ratio 14:1, 8:1, and 25:1 in pig, chicken, and cow, respectively) in 1000 ml glass digesters (added 100 ml of active sludge and 900 ml of water) for 20 days. They found that biogas generated amount was 1,964 ± 118.1 ml, 1,278 ± 263.8 ml, and 2,649 ± 123.5 m in pig, chicken, and cow, respectively (equivalent 19.64, 12.78, and 26.49 m^3 per 1000 kg). This study had similar findings for pig and cow, but gas for chicken was much higher than their data indicated. In this study, gas in the first 20 days were 11.3, 51.5, and 20.17 m^3 per

1000 kg; in second 20 days were 19.96, 55.92, and 31.91 m^3 per 1000 kg for pig, chicken, and cow respectively. The digestibility and high gas generation potential for pig was observed after the pre-digestion, especially generated more gas after 40 days, and could last longer, therefore the pre-digestion was important. But for chicken and cow, gas generated decreased very much after 60 days. Their results were different from those of this study which might be attributed to the quality of the manures. Manures in their study were predigested, while in this study, all manures were fresh. More importantly, 20 days of data record in their study could not represent the total gas generation for pig manure. Therefore, gas generation of pig manure was less than the others in their report. According to Zeng *et al* (2009), CH_4 emission from pig, chicken, dairy cow, and beef cow manures were 3.3, 0.26, 21, and 15 kg per head per year, but the gas generation from cow manure digestion took time. According to Weiland (2006), biogas generation could be 30 and 25 m^3 per 1000 kg of wet pig and cow manure. The differences of reported data among research studies might be due to several factors such as digester types, manure : water ratios, environmental conditions, and pre-digestion.

According to the literatures, 1 m^3 of biogas is equivalent to 0.43-0.44 kg of liquefied petroleum gas (LPG), 0.6 L of diesel oil, 0.64 L of kerosene, and 1.25 kW of electricity (Chen, 2009; Shri, 2010; Indian Development Gateway, 2010). Generally, 1 household with 3-4 persons use 0.50 kg of LPG per day which is equivalent to 1.1 m^3 of biogas (15 kg of LPG could be used for 30 days). The 10 m^3 of Chinese fixed dome biogas digester is large enough to meet the gas needs for the daily use of each household. The amount of animal manures could be adjusted depending on the biogas consumption ability of the beneficial families.

Table 3.1 Biogas generated, generation duration, and dry matter changed from the anaerobic fermentation of pig, chicken, and cow manures in the Chinese fixed dome digester

Manures	**C/N**	**Initial dry matter (kg)**	**50 days gas generated (m^3)**	**90 days gas generated (m^3)**	**Total gas generated (m^3)**	**Duration (days)**	**Dry matter left (kg)**
Pig	10:1	1000	50	125	256	150	250
Chicken	5:1	1000	132	153	153	90	450
Cow	20:1	1000	40	70	70	90	600

(2) Gas composition in the biogas generated from pig, chicken, and cow manures Methane (CH_4)

CH_4 increased rapidly in the 10 days and was relatively constant after that until the end of digestion. During the peak, chicken manure had the highest methane composition (79.9%) followed by pig (76.1%), and cow manure (61.9%) (Fig. 3.3). Zhang *et al.* (2005) also found the high methane content in chicken manure digestion (73.1-76.4%). However, concerning the fermentation in Chinese fixed dome digester, all 3 manures produced high enough CH_4 composition for gas utilization. Quality of biogas is higher when CH_4 composition is more than 50%.

Other investigations reported that, the ignition point of biogas should have minimum CH_4 content of 20-30% (Constant, 1989). In this experiment, CH_4 content reached the ignition point (30%) within 10 days in all manures. The burning of the biogas could confirm the gas purity. For pig manure, ignition could be started on the 7th day using flame and the 14th day using starter; for chicken and cow manure on the 10th day using flame and the 14th day using starter.

Carbon dioxide (CO_2)

CO_2 for pig and chicken manure increased in the first few weeks, then it decreased after the peak of CH_4 production. Initial CO_2 composition in cow manure was higher, and it decreased afterwards along with the CH_4 production, and maintained at a constant level (Fig. 3.4).

Nitrogen and oxygen (N_2 + O_2)

N_2 + O_2 were high at the beginning, then were moved out with the CH_4 from the digester, consequently decreased to a relatively low level (around 2%) along with the CH_4 production process (Fig. 3.5).

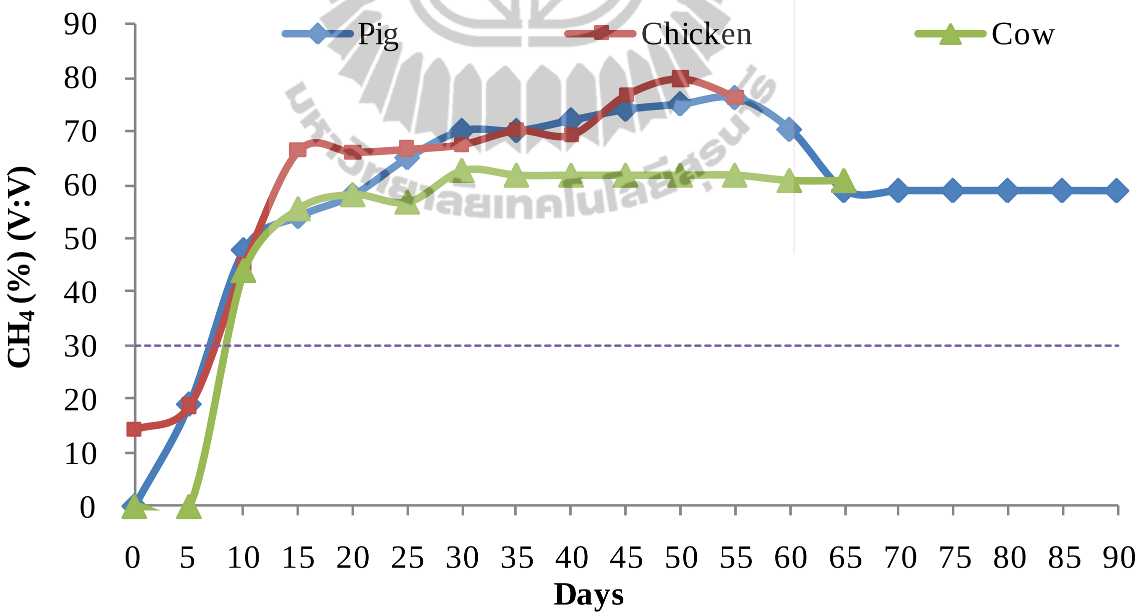


Figure 3.3 CH_4 composition in the biogas generated from the anaerobic fermentation of pig, chicken, and cow manures

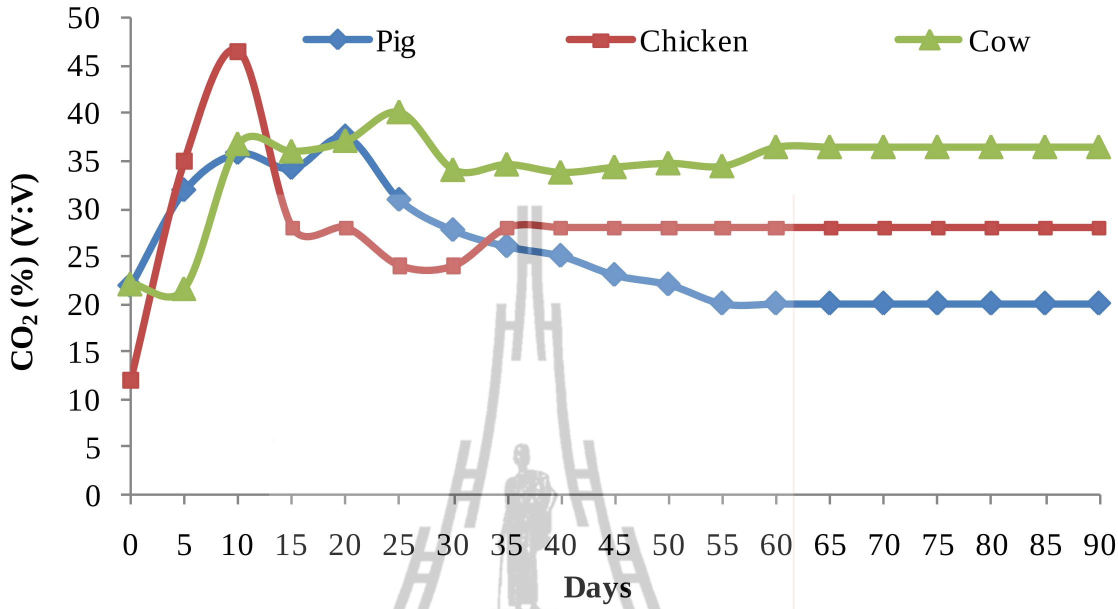


Figure 3.4 CO_2 composition in the biogas generated from pig, chicken, and cow manures

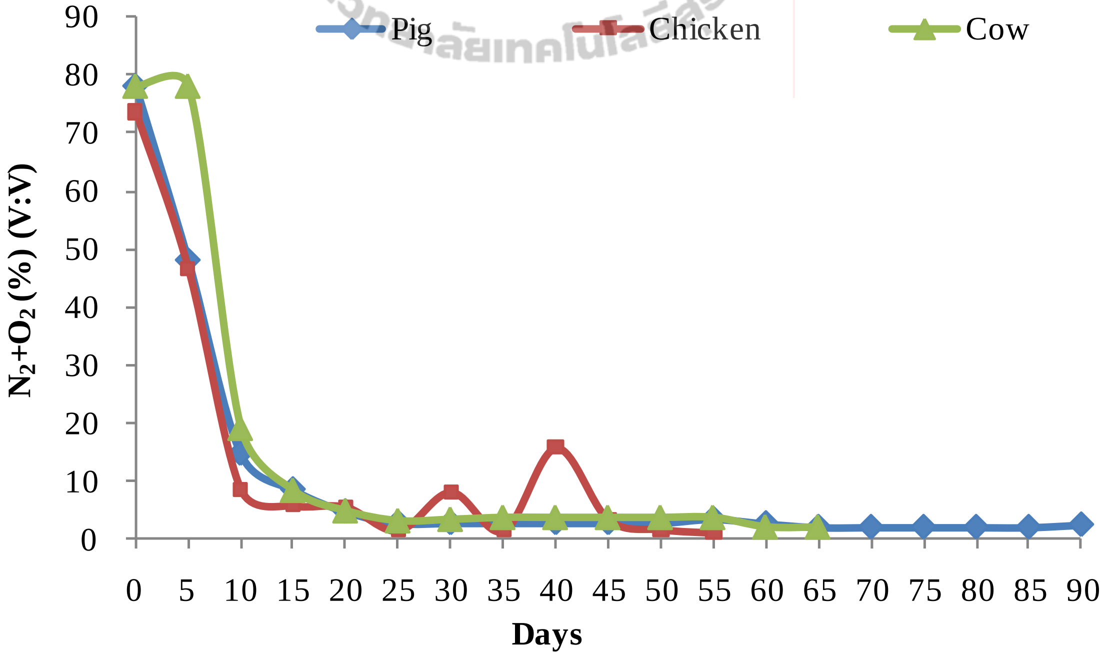


Figure 3.5 N_2+O_2 composition in the biogas generated from the anaerobic fermentation of pig, chicken, and cow manure

3.3.2 Plant nutrient dynamics

Nutrient analysis indicated that the nutrients had dynamics in both BLRs and BSRs. All nutrients had the tendency to the increase in BLRs, and the decrease in BSRs.

(1) Plant nutrient dynamics in BLRs

Acidity (pH)

The pH dynamic confirmed the theory of hydrolysis and acetogenesis/acidification stages. In all manures, pH dropped on the 5th day, and constantly increased after the 10th day (Fig. 3.6). Most studies confirmed the pH dynamic trend in many kinds of manures. Chen *et al.* (2009) reported the effect of temperature on pH change, higher temperature accelerated the hydrolysis, pH in pig manure decreased from 7.41 to 6.54, 6.45, and 6.49 on the 4th, 8th, and 18th day in 35°C, 25°C, and room temperature, respectively. In chicken manure decreased from 6.91 to 6.47, 6.35, and 6.32 on the 4th, 6th, and 8th day, and in cow manure decreased from 7.21 to 6.59, 6.58, and 6.66 on the 4th, 8th, and 20th day in the above temperature levels. Okoroigwe *et al.* (2010) also found the pH decreased to 6.0, and increased after 7 days in the experiment of dog waste treatment.

Electrical conductivity (EC)

In all manures, EC was relatively and initiatively low, and increased during the digestion. Among them, chicken BLR had very high salinity with the highest EC (25.8 mS/cm) at the end of digestion (Fig. 3.7). Few people reported the EC dynamics, which was an important indicator of salinity and nutrient concentration. In this study EC values were closely related to nutrient contents in the BLRs.

Organic matter (OM)

Organic matter was the major digested material and was broken down by the anaerobic bacteria. Small particles of organic matter dissolved into the BLRs (Fig. 3.8). It increased and reached the highest amount between 30-35 days in all manures, then it continued to be digested and decreased in BLRs afterwards. It increased from 0.05% to 0.62%, then decreased to 0.51%, from 0.01% to 0.60%, then 0.41%, and from 0.04% to 0.32%, then decreased to 0.29% in pig, chicken, and cow BLRs, respectively. The BLRs of all manures became clear when the digestion was complete. It could also be observed by the turbidity from the BLRs.

Total N

Total N increased very fast in chicken BLR after the hydrolysis phase (from 140 to 3690 ppm), moderately increased in pig manure (from 230 to 1660 ppm), while it slowly increased and was very less in cow BLR (from 60 to 300 ppm) (Fig. 3.9). Gupta (1991) mentioned that the total N in pig manure BLR could reach 1.6% if the BLR is digested by mixing it with various dry organic materials such as dry leaves, straw, etc.

Ammonium (NH_4^+)

NH_4^+ was the major form of inorganic N in the BLRs, which increased from 171 to 580 ppm, 62 to 2465 ppm, and 31 to 160 ppm in pig, chicken, and cow BLRs, respectively. NH_4^+ in chicken BLR was 15 times higher than that in cow BLR, and 4 times higher than in pig BLR (Fig. 3.10). Chen *et al.* (2009) reported the same dynamic trend of NH_4^+ in the digested BLRs since the organic N in the manure was digested and dissolved in the BLRs. Only Shi *et al*. (2010) reported that NH_4^+ decreased in the first 5 days. Starkenburg (1997) found that gas generation was inhibited when NH_4^+ reached 1700 ppm. Feng (1989) also found gas generation inhibition when NH_4^+ was 1500-3000 ppm, and pH > 7.4, gas generation could be terminated when NH_4^+ > 3000 ppm in any pH value due to the high toxicity of NH_4^+ to the anaerobic bacteria. In this study, the high amount of NH_4^+ in chicken BLR also inhibited the gas generation, therefore, additional water might be needed for the digestion of chicken manure.

Nitrate (NO_3^-)

NO_3^- in all manure BLRs increased in the 10th day during the hydrolysis and acetogenesis stage, and then decreased and was constant after that due to the anaerobic condition. It was 62, 93, and 31 ppm in pig, chicken, and cow BLRs, respectively (Fig. 3.11).

Available P, K, Ca, Mg, and Na

P increased from 70 to 244, 10 to 146, and 34 to 105 ppm, K from 250 to 1800, 320 to 4130, and 550 to 2520 ppm, Ca 34 to 228, 56 to 300, and 106 to 501 ppm, Mg from 47 to 172, 22.8 to 151, and 22 to 187 ppm, and Na from 15 to 200, 65 to 594, and 57 to 238 ppm in pig, chicken, and cow BLRs, respectively (Fig.3.12-3.16). P was very low in the BLRs since it was very active in this pH condition (pH > 7 for all BLRs). It probably reacted with the high concentration of Ca and precipitated to the BSR afterwards. Result showed that Fe and Mn were relatively high, perhaps due to the equipment contamination. The nutrient values in the pig BLR were in the range as Xu *et al*. (2005) reported (total N 300-800 ppm, P 200-300 ppm, and K 490-700 ppm). Gupta (1991) mentioned that total P in BLRs could reach 1.6%, and K could reach 1.0% if the BLR is digested by mixing it with various dry organic materials such as dry leaves, straw, etc.

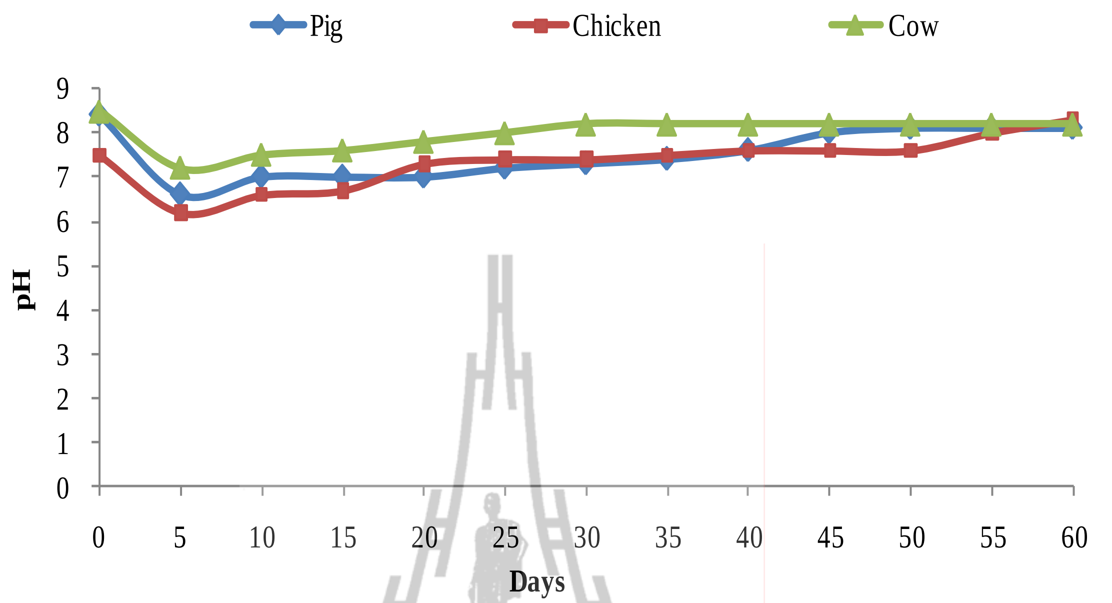


Figure 3.6 pH in BLRs digested from the anaerobic fermentation of pig, chicken, and cow manures

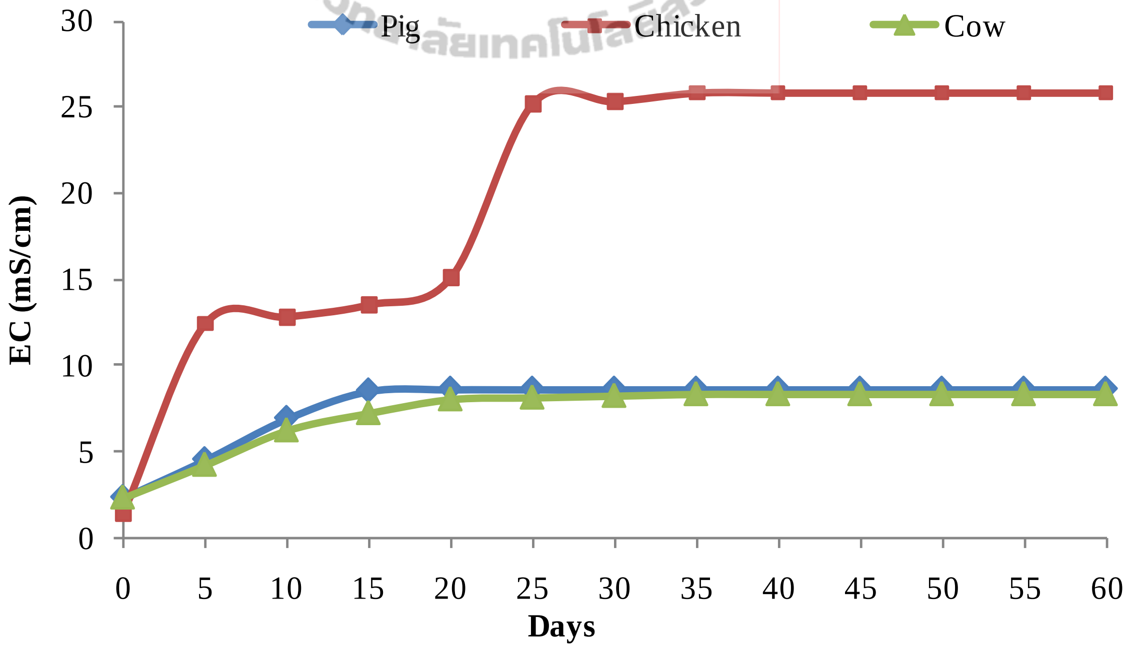


Figure 3.7 EC in BLRs digested from the anaerobic fermentation of pig, chicken, and cow manures

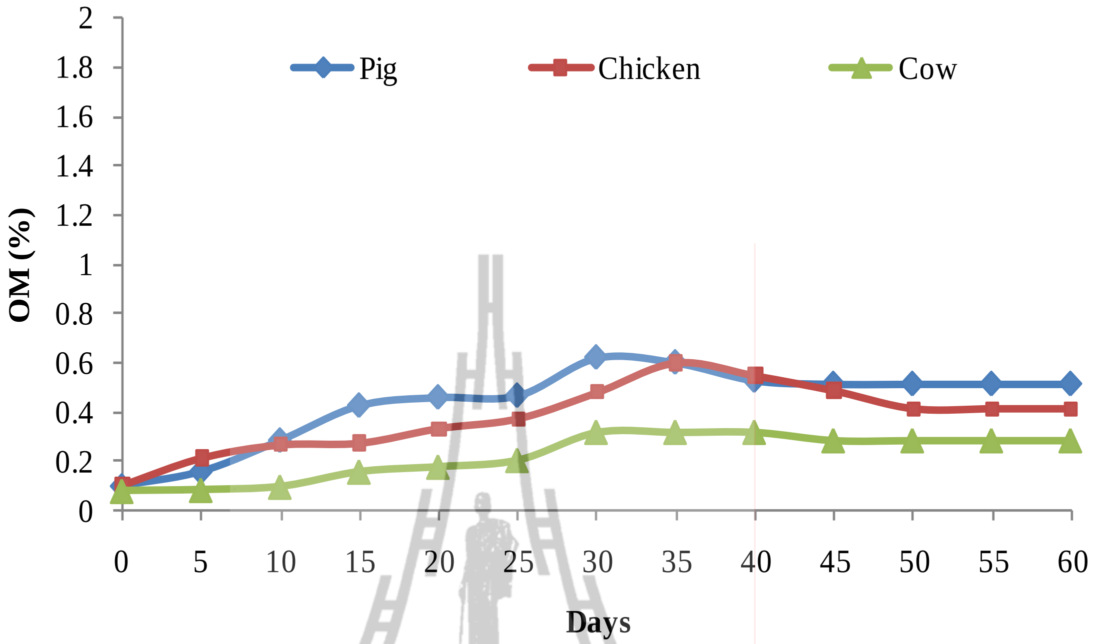


Figure 3.8 OM in BLRs digested from the anaerobic fermentation of pig, chicken, and cow manures

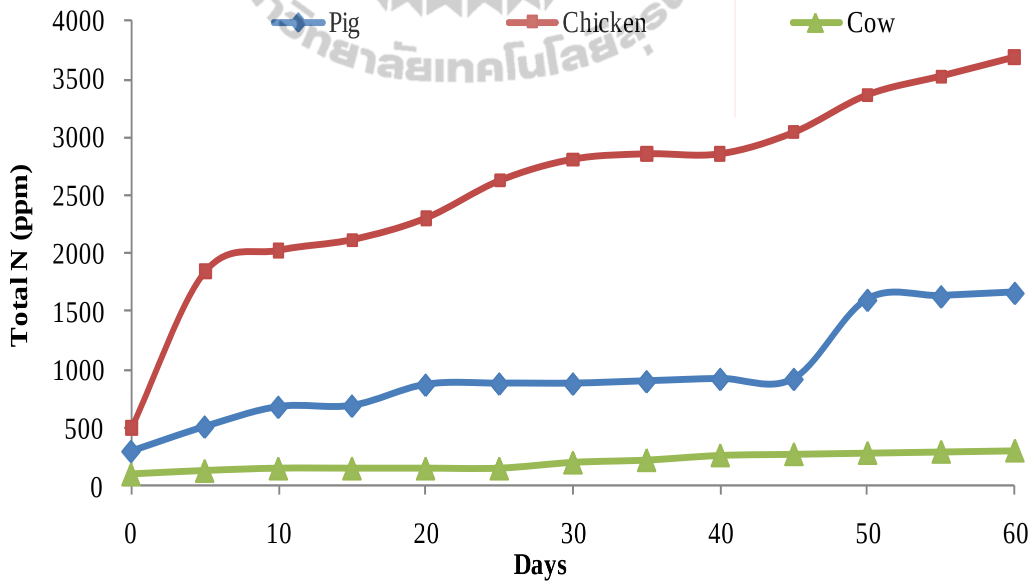


Figure 3.9 Total N in BLRs digested from the anaerobic fermentation of pig, chicken, and cow manures

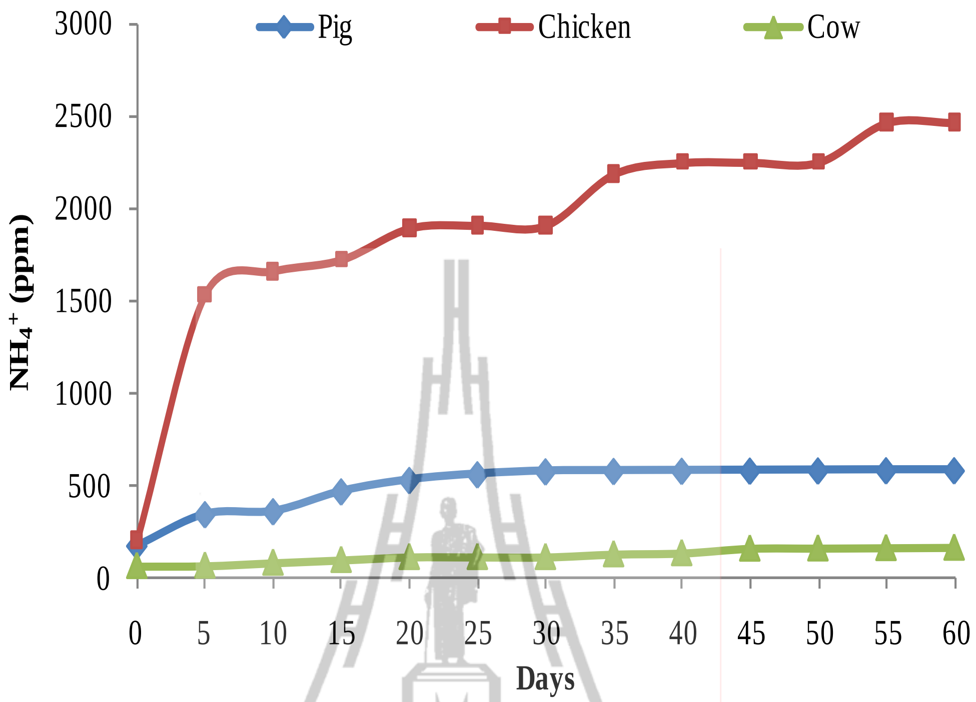


Figure 3.10 NH_4^+ in BLRs digested from the anaerobic fermentation of pig, chicken, and cow manures

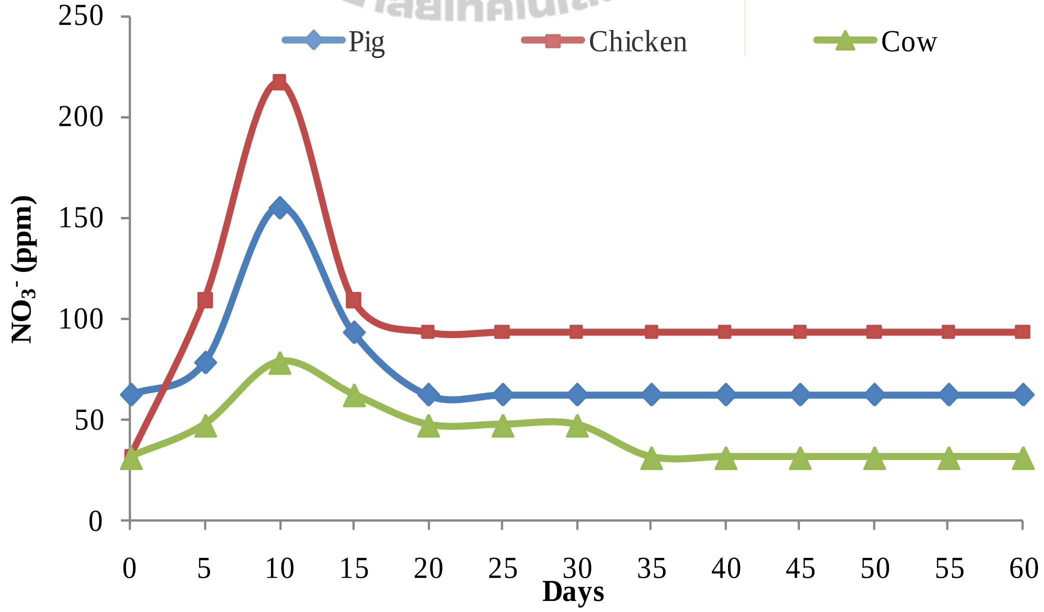


Figure 3.11 NO_3^- in BLRs digested from the anaerobic fermentation of pig, chicken, and cow manures

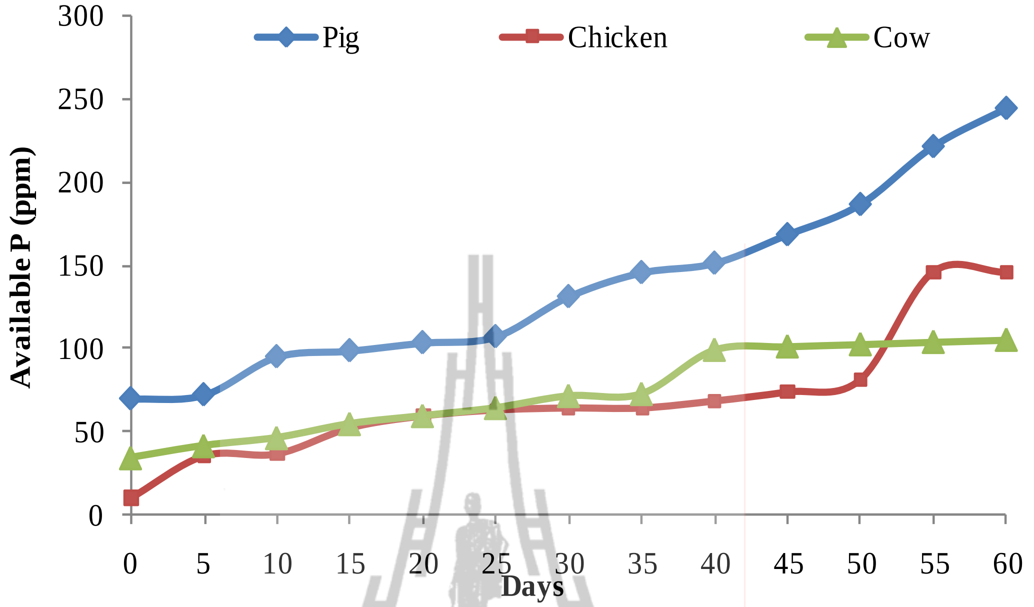


Figure 3.12 Available P in BLRs digested from the anaerobic fermentation of pig, chicken, and cow manures

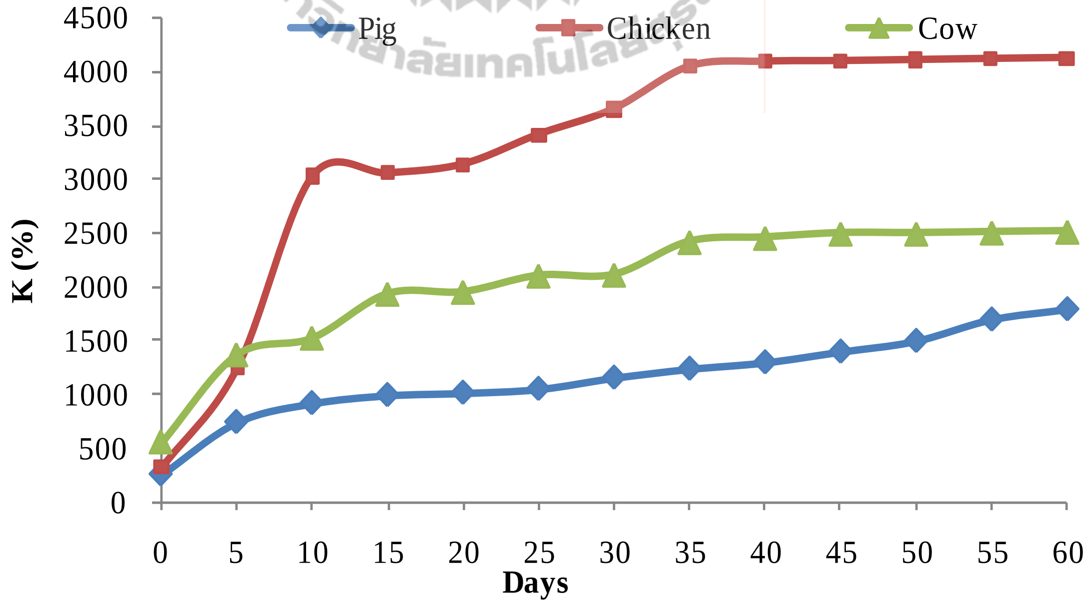


Figure 3.13 K in BLRs digested from the anaerobic fermentation of pig, chicken, and cow manures

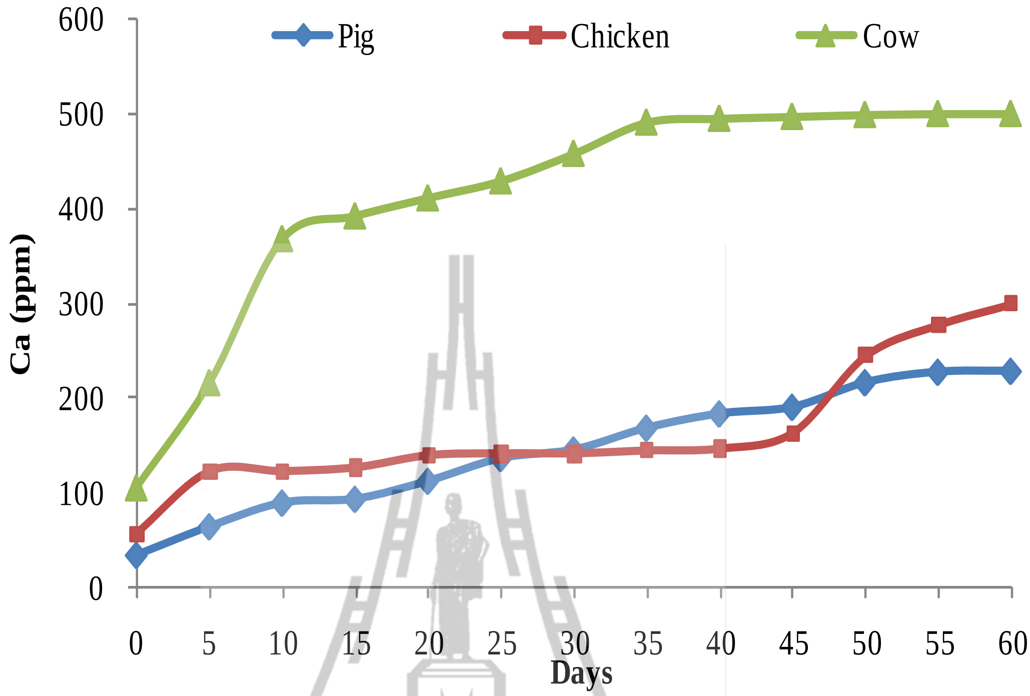


Figure 3.14 Ca in BLRs digested from the anaerobic fermentation of pig, chicken, and cow manures

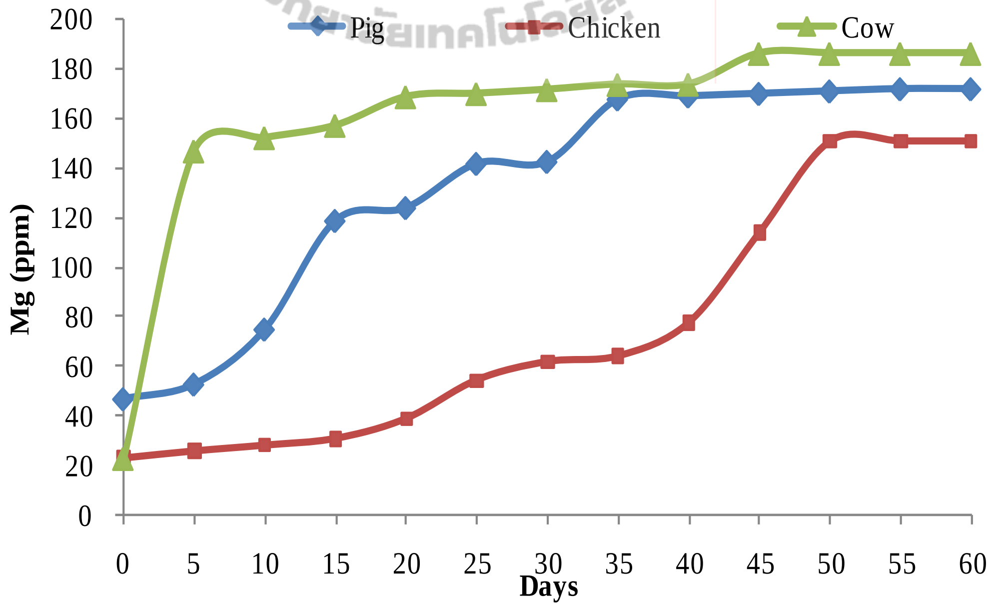


Figure 3.15 Mg in BLRs digested from the anaerobic fermentation of pig, chicken, and cow manures

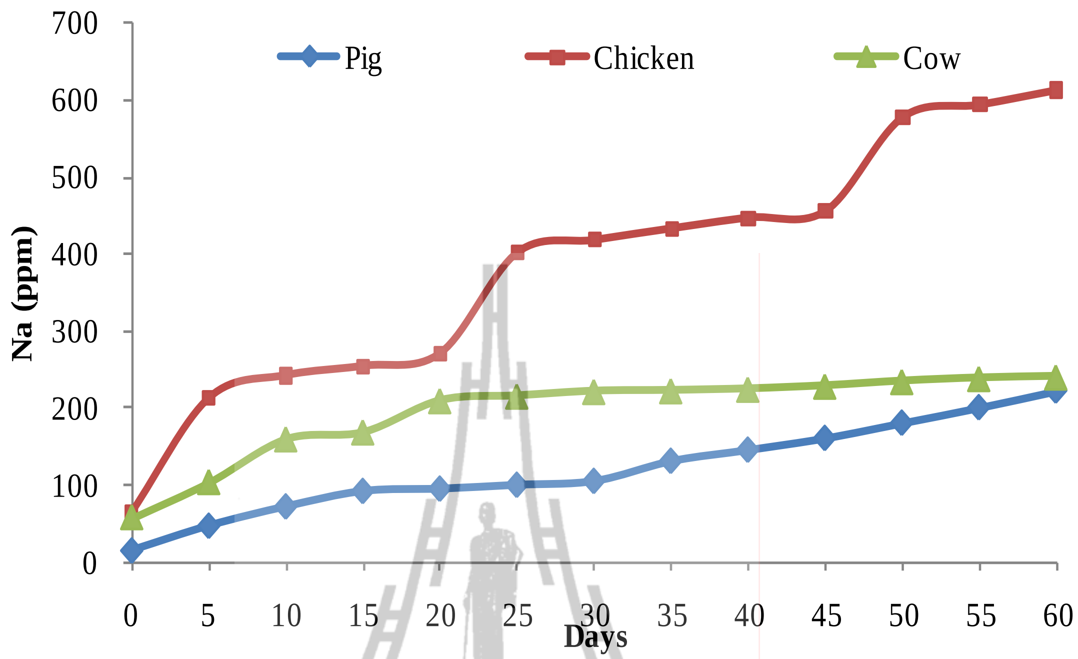


Figure 3.16 Na in BLRs digested from the anaerobic fermentation of pig, chicken, and cow manures

(2) Nutrient dynamics in biogas solid residues (BSRs)

In the digested BSR, all nutrients decreased due to the digestion, degradation, and dissolved into the BLRs solution.

OM

Organic matter was the one digested by anaerobic bacteria, which decreased 10%, 12%, and 20% from 55.02% to 44.60%, 43.26% to 31.73%, and 49.63% to 30.35% in pig, chicken, and cow sludge, respectively (Fig. 3.17).

Total N

Total N decreased from 3.2 to 1.7%, 6.3 to 2.2%, and 3.0 to 1.2% in pig, chicken, and cow sludge, respectively (Fig. 3.18).

NH_4^+

NH_4^+ increased during the peak, but decreased afterwards since it dissolved into the liquid, consequently, it was 724 ppm, 517 ppm, and 517 ppm in pig, chicken, and cow BSR, respectively (Fig. 3.19).

NO_3^-

NO_3^- also increased during the peak, but decreased after due to the absence of O_2. It was 207, 310, and 310 ppm in pig, chicken, and cow BSR, respectively (Fig. 3.20).

Total P, K, Ca, Mg, and Na

P decreased from 3.94 to 1.81%, 2.76 to 0.84%, and 0.86 to 0.37%, K from 1.70 to 0.69%, 5.20 to 3.23%, and 1.50 to 0.98%, Ca 1.13 to 0.48%, 3.28 to 2.15%, and 0.63 to 0.31%, Mg from 0.29 to 0.23%, 0.68 to 0.28, and 0.34 to 0.24%, and Na from 0.23 to 0.12%, 0.91 to 0.29%, and 0.15 to 0.11% in pig, chicken, and cow BSR, respectively (Fig.3.21-3.26). Results of pig BSR was also shown in the range as Xu *et al.* (2005) mentioned (OM 36.0-49.9%, N 0.78-1.61%, P 0.4-0.6%, K 0.61-1.3%). P in this study was higher than their results.

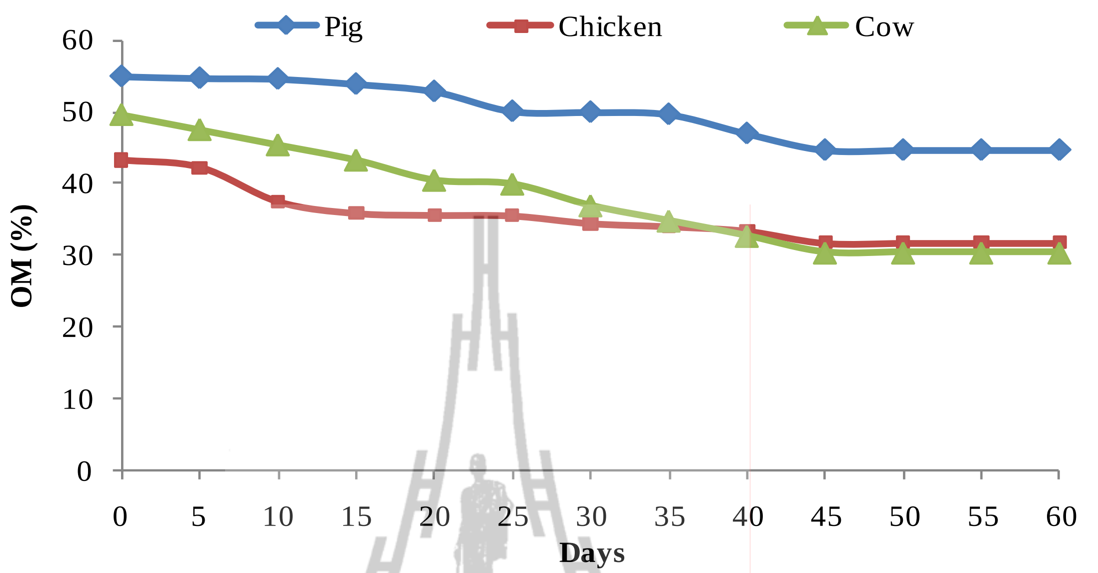


Figure 3.17 OM in BSRs digested from the anaerobic fermentation of pig, chicken, and cow manures

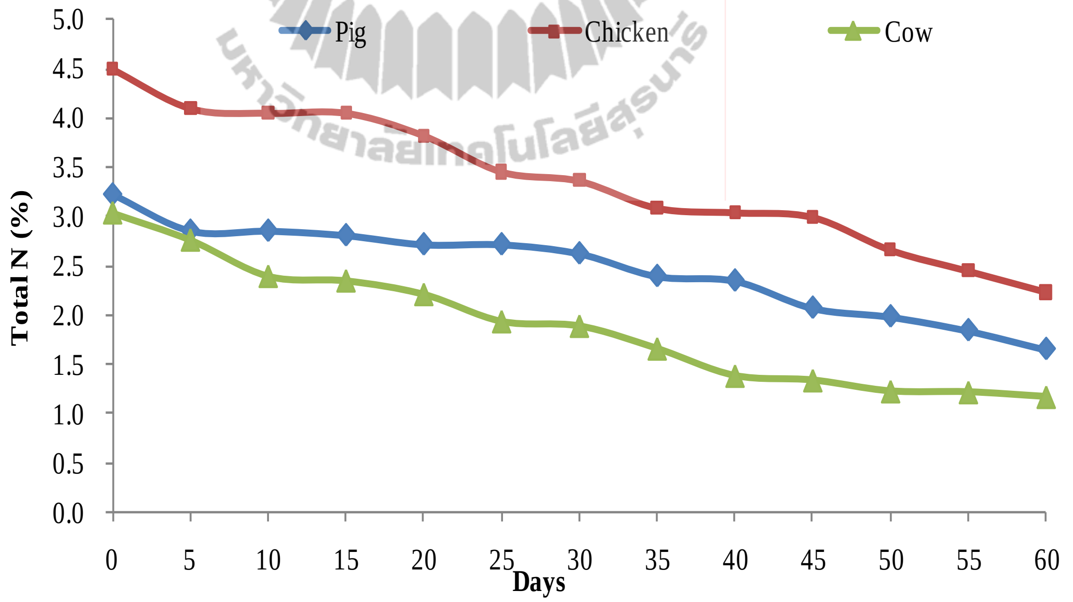


Figure 3.18 Total N in BSRs digested from the anaerobic fermentation of pig, chicken, and cow manures

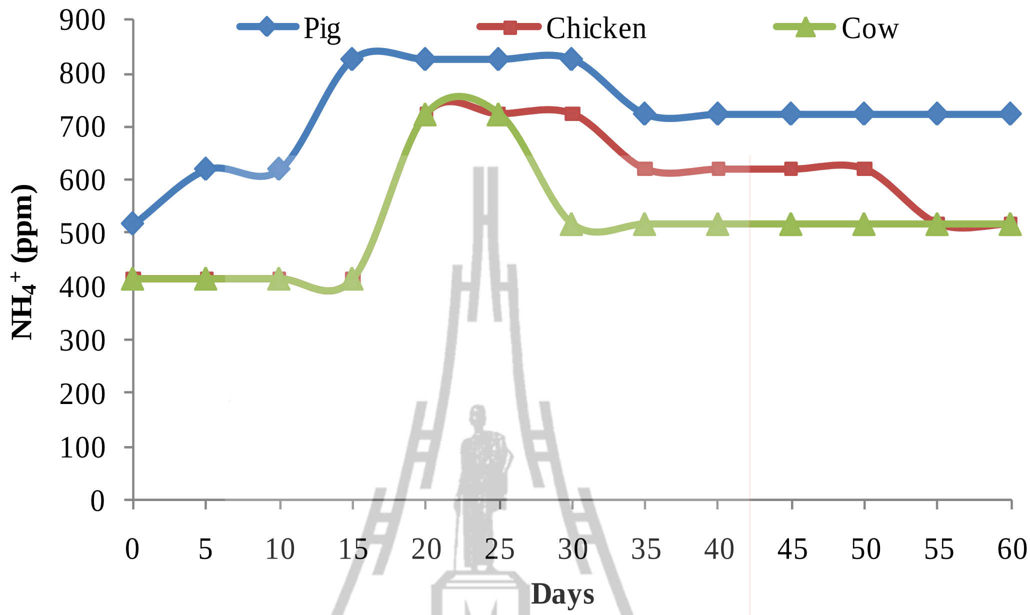


Figure 3.19 NH_4^+ in BSRs digested from the anaerobic fermentation of pig, chicken, and cow manures

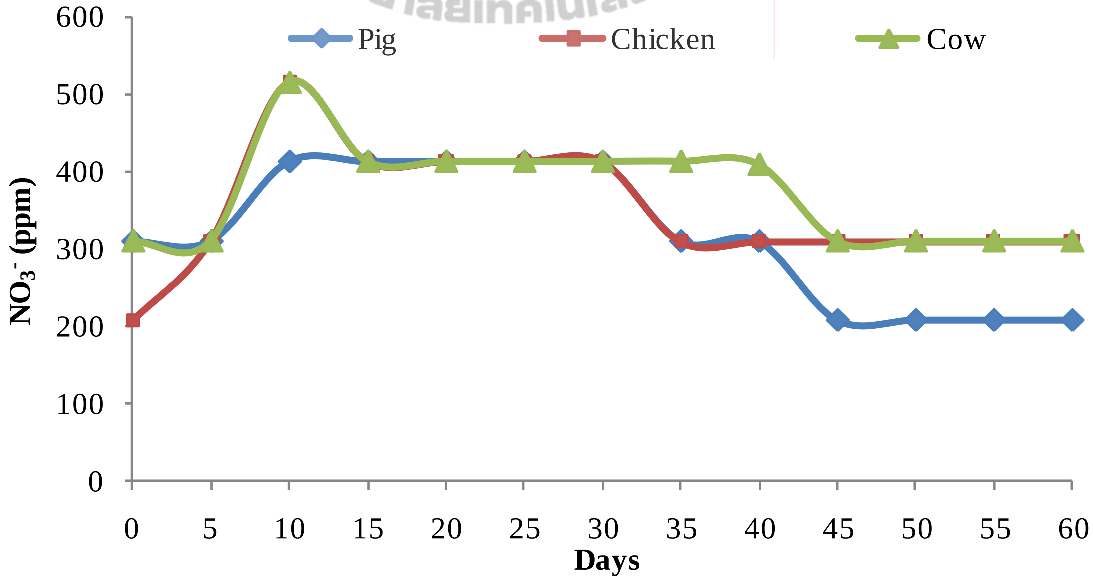


Figure 3.20 NO_3^- in BSRs digested from the anaerobic fermentation of pig, chicken, and cow manures

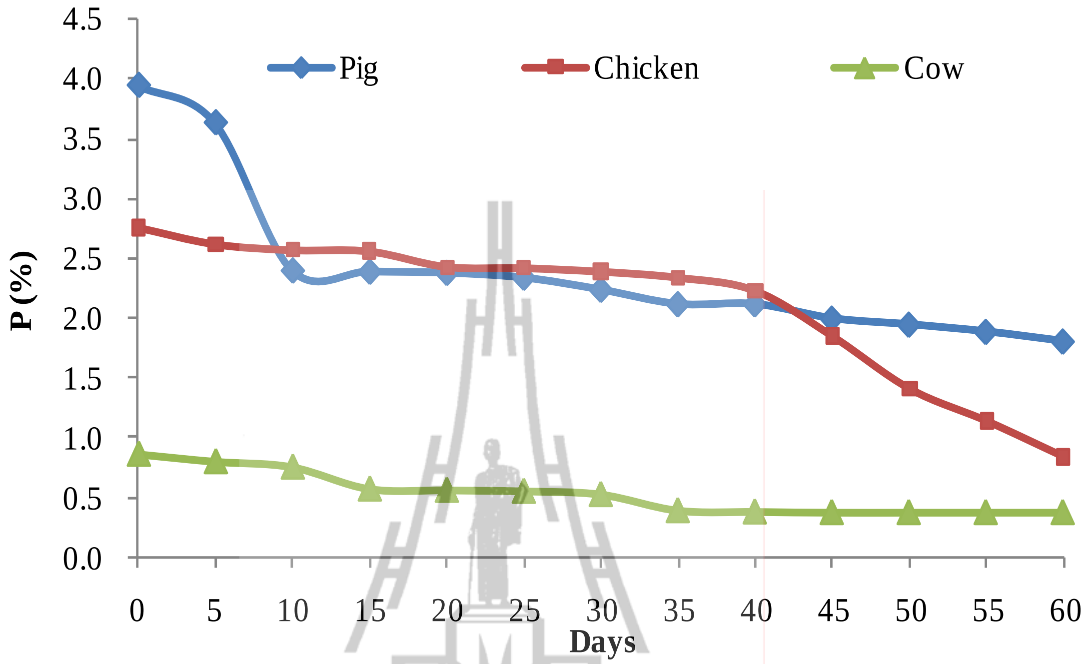


Figure 3.21 P in BSRs digested from the anaerobic fermentation of pig, chicken, and cow manures

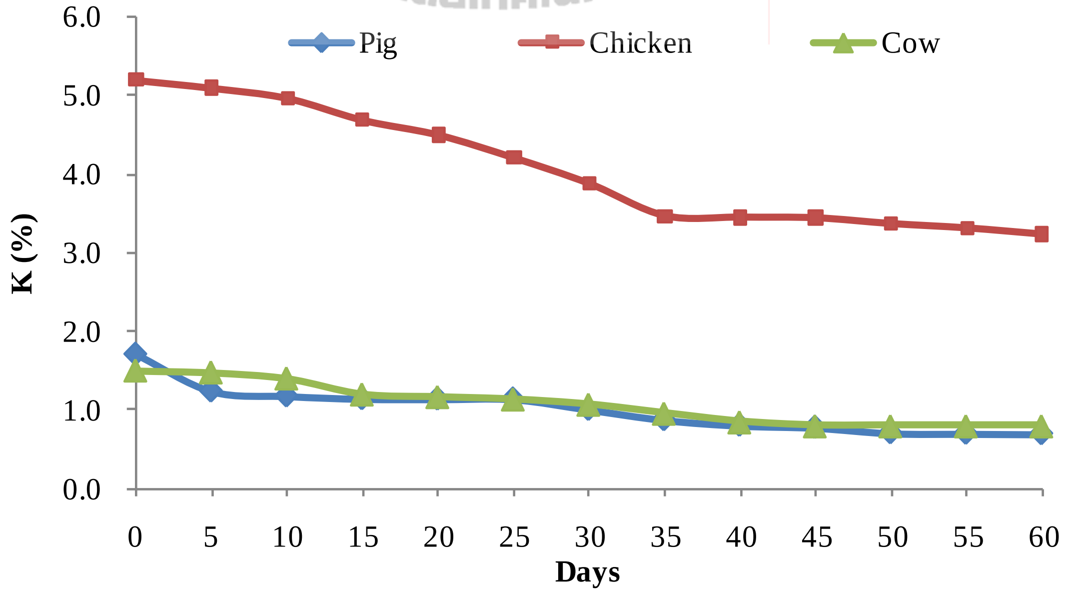


Figure 3.22 K in BSR from the anaerobic fermentation of pig, chicken, and cow manures

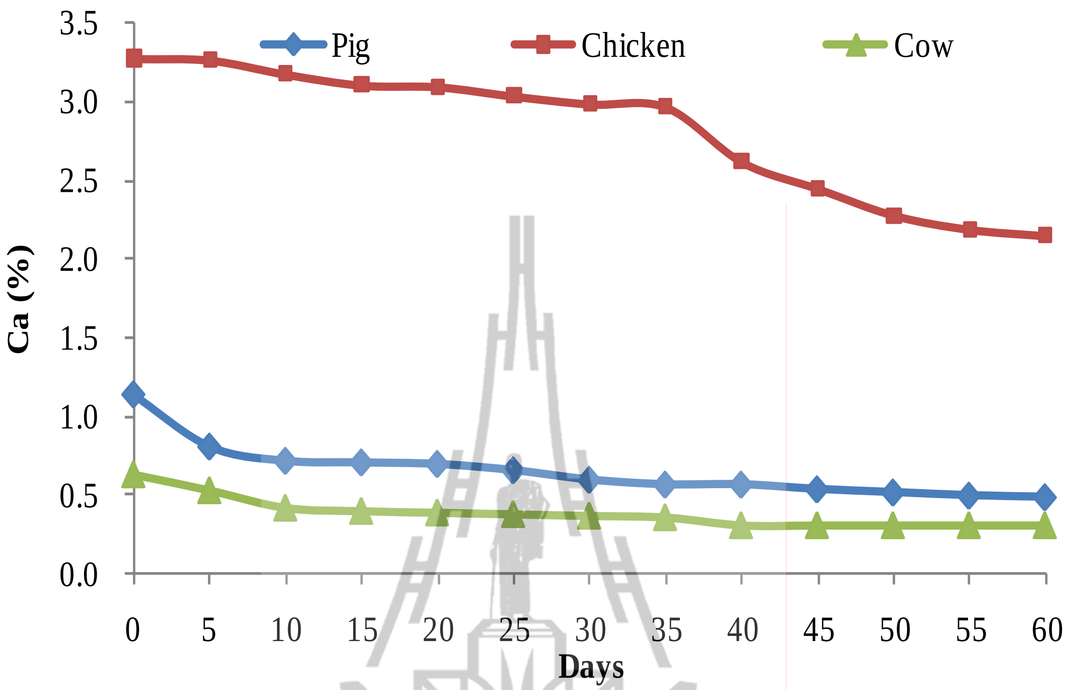


Figure 3.23 Ca in BSR from the anaerobic fermentation of pig, chicken, and cow manures

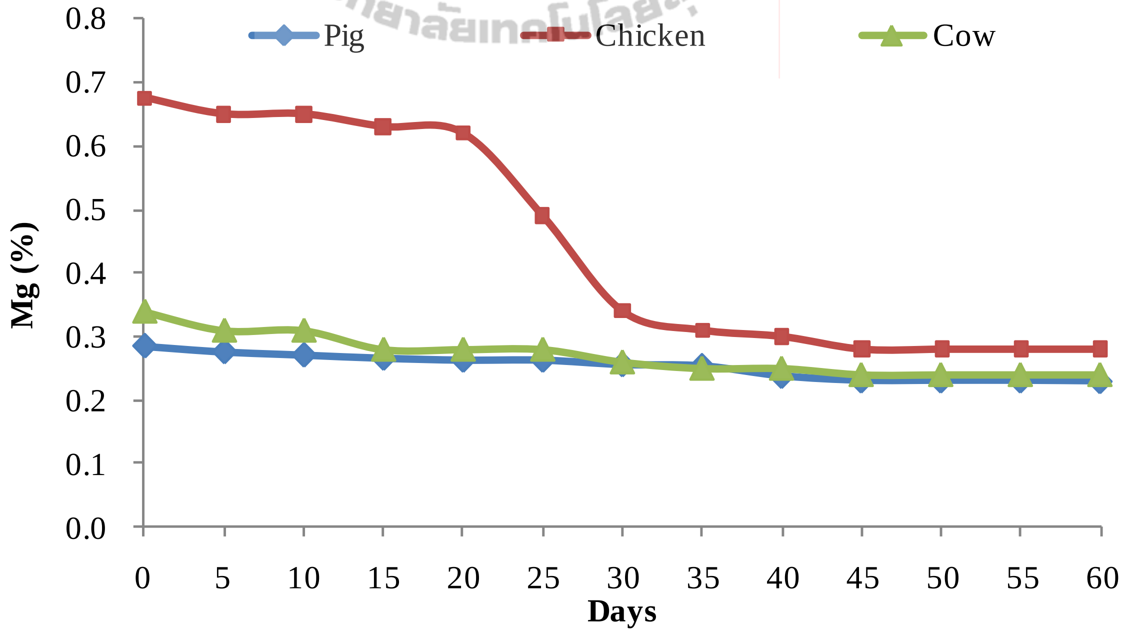


Figure 3.24 Mg in BSRs digested from the anaerobic fermentation of pig, chicken, and cow manures

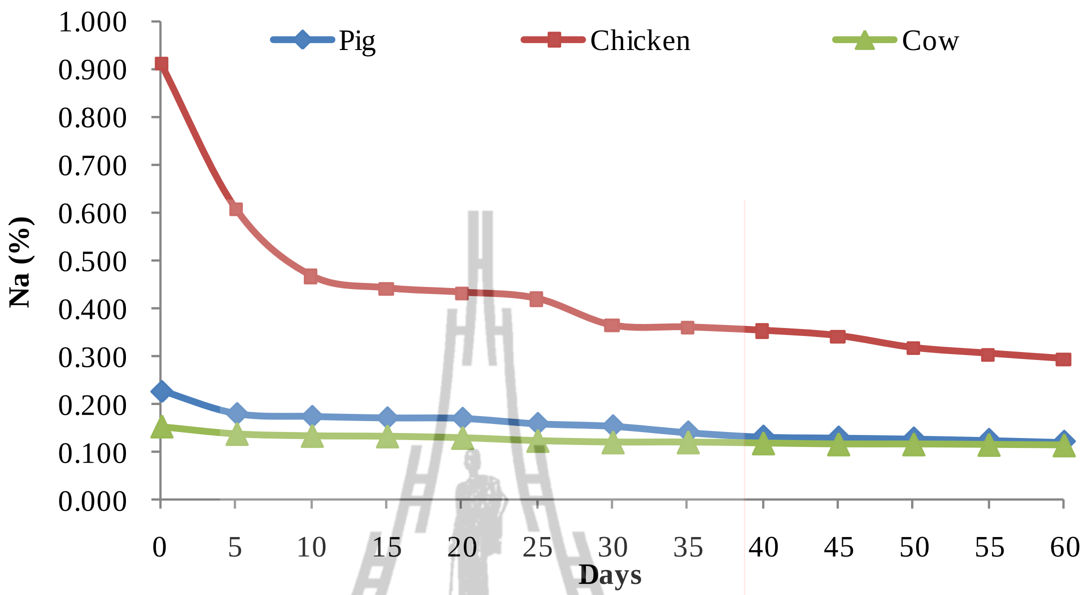


Figure 3.25 Na in BSRs digested from the anaerobic fermentation of pig, chicken, and cow manures

Overall nutrients dynamics in both BLRs and BSRs

Most nutrients in the initial raw manures with regard to the organic form were digested and converted to the inorganic form. They were dissolved into BLRs during the fermentation process. Take N as an example based on the calculation of nutrient balance, there was initial N of 32, 45, and 30 kg in pig, chicken, and cow manures (3.2, 4.5, and 3.0% in 1000 kg dry matter) (Table 3.2). After the fermentation completed, there were about 27, 35, and 23 kg of N in the BLRs. Among them, 17, 30, and 3 kg of N were in the inorganic form and were dissolved, and 10, 5, and 20 kg of N were in the organic form suspended in BLRs. There were about 5, 10, and 7 kg of N left in pig, chicken, and cow BSR, respectively and most of them were in the organic form. This experiment showed that there was low N loss to the atmosphere. The values of BRs as fertilizer depend on the amount of the residues, their nutrients concentration and balance, and the availability of the nutrients. This might be confirmed by further field crops studies.

Table 3.2 Nutrient concentration in initiative manures before anaerobic fermentation, and in BLRs and BSRs at the end of anaerobic fermentation of pig, chicken and cow manure

Residues	Total N (%)	NH_4^+ (ppm)	NO_3^- (ppm)	P (%)	K (%)	Ca (%)	Mg (%)	Na (%)
Manure								
Pig	3.230	517	310	3.940	1.700	1.130	0.285	0.228
Chicken	4.500	414	207	2.760	5.200	3.280	0.675	0.914
Cow	3.040	414	310	0.860	1.500	0.630	0.340	0.153
BLRs								
Pig	0.166	580	62	0.024	0.180	0.022	0.017	0.022
Chicken	0.369	2465	93	0.015	0.413	0.030	0.015	0.061
Cow	0.030	160	31	0.011	0.252	0.050	0.019	0.024
BSR								
Pig	1.654	724	207	1.810	0.693	0.480	0.230	0.122
Chicken	2.235	517	310	0.840	3.233	2.150	0.280	0.294
Cow	1.168	517	310	0.370	0.975	0.310	0.240	0.115

Micro nutrients in both BLRs and BSRs

Similar to the primary and secondary nutrient, dynamics of micronutrients showed that, in the BLRs, Fe increased from 461 to 608, 484 to 671, and 330 to 643 ppm, Mn from 89 to 121, 81 to 122, and 54 to 98 ppm, Zn 1.25 to 18.23, 0.29 to 24.11, and 0.04 to 12.29 ppm, and Cu from 3.25 to 4.38, 3.37 to 12.39, and 3.61 to 4.60 ppm in pig, chicken, and cow liquid, respectively (Table 3.3).

While in the BSR, Fe decreased from 1.44 to 1.13, 1.33 to 0.28, and 0.42 to 0.18%, Mn from 2531 to 1560, 3132 to 540, and 559 to 180 ppm, Zn from 1134 to 427, 994 to 509, and 110 to 21 ppm, and Cu from 52 to 2.5, 433 to 15, and 240 to 15 ppm in pig, chicken, and cow liquid, respectively.

Table 3.3 Micro-nutrient dynamics in fermented BLRs and dry BSRs

Item	Days	0	5	10	15	20	25	30	35	40	50	60
Fe	Pig BLR (ppm)	461	489	497	525	541	551	573	583	589	601	608
	Chicken BLR (ppm)	484	490	503	504	541	554	564	565	576	621	671
	Cow BLR (ppm)	330	399	480	496	512	514	579	611	612	631	643
	Pig BSR (%)	1.440	1.410	1.370	1.340	1.300	1.300	1.270	1.240	1.160	1.140	1.130
	Chicken BSR (%)	1.329	1.202	1.164	1.033	0.484	0.400	0.396	0.381	0.363	0.280	0.280
	Cow BSR (%)	0.423	0.388	0.377	0.370	0.368	0.339	0.285	0.272	0.232	0.178	0.178
Mn	Pig BLR (ppm)	89	92	101	104	115	116	120	120	121	121	121
	Chicken BLR (ppm)	81	84	87	88	89	91	96	96	116	116	122
	Cow BLR (ppm)	54	65	79	82	82	82	91	92	95	96	98
	Pig BSR (ppm)	2531	2492	2451	2426	2376	2217	2138	2100	1985	1870	1560
	Chicken BSR (ppm)	3132	2686	2461	2110	823	784	686	609	557	550	540
	Cow BSR (ppm)	559	408	394	371	336	324	318	304	244	190	180
Zn	Pig BLR (ppm)	1.25	1.52	2.04	3.31	4.50	8.90	9.12	14.30	15.20	17.13	18.23
	Chicken BLR (ppm)	0.29	0.48	0.49	1.01	1.35	1.54	3.37	5.24	8.50	23.23	24.11
	Cow BLR (ppm)	0.04	1.12	1.56	1.59	1.63	1.79	2.41	5.67	7.77	9.98	12.29
	Pig BSR (ppm)	1134.0	1111.0	1109.0	979.0	951.0	947.0	935.0	853.0	817.0	545.0	427.0
	Chicken BSR (ppm)	994.0	945.0	878.0	763.0	720.0	707.0	693.0	680.0	531.0	518.0	509.0
	Cow BSR (ppm)	109.8	63.9	59.0	49.7	45.9	43.8	44.3	42.6	41.6	34.2	21.3
Cu	Pig BLR (ppm)	3.25	3.44	3.58	3.78	3.97	4.04	4.10	4.18	4.23	4.33	4.38
	Chicken BLR (ppm)	3.37	3.69	3.74	3.84	3.84	3.85	3.88	4.40	4.55	6.88	12.39
	Cow BLR (ppm)	3.61	3.83	3.86	3.95	4.04	4.20	4.21	4.31	4.31	4.52	4.60
	Pig BSR (ppm)	51.88	20.60	11.83	10.26	6.17	4.77	3.38	3.21	2.86	2.53	2.46
	Chicken BSR (ppm)	432.50	409.00	286.40	227.80	159.50	62.70	15.90	15.30	15.10	14.90	14.80
	Cow BSR (ppm)	240.10	147.40	101.70	75.70	74.70	70.60	69.30	53.10	50.80	30.50	14.70

3.4 Conclusions

The Chinese fixed dome digester was successfully applied in the Northeastern tropical conditions for manures treatment and organic fertilizer production. It was found that pig manure had the longest biogas generation duration and produced the highest amount of gas. Therefore, it could be concluded that pig manure was the best material for biogas generation in the Chinese fixed dome digester.

BLRs digested from pig and chicken manures contained high amount of available N. During the digestion, NH_4^+ increased, while NO_3^- decreased after the hydrolysis phase, and most N was in NH_4^+ form. P, K, Ca, Mg, and other micronutrients also increased in the BLRs. All nutrients decreased in the BSRs due to the digestion, degradation, and dissolution into the liquid solution.

P was relatively low in all BLRs (240, 80, and 110 ppm in pig, chicken, and cow, respectively). The balance of P in application of liquid as a kind of organic fertilizer should be considered. However, the biogas residues from pig and chicken manures had relatively more balance nutrients than those from cow manure which had very low N content. Both of them would be the good sources of organic fertilizers for crop production.

In conclusion, the Chinese fixed dome biogas digester could be effectively applied to households in the environmental conditions of Northeast Thailand. Pig manure was the best material in terms of biogas production. The biogas residues from pig and chicken manures had relatively more balance nutrients than those from cow manure. Both of them would be the good sources of organic fertilizers for organic crops.

CHAPTER IV

ORGANIC HYDROPONICS USING ANAEROBIC FERMENTATION LIQUID RESIDUES OF ANIMAL MANURES FROM BIOGAS GENERATION

4.1 Introduction

The BLRs from the biogas digester are organic fertilizer with all available plant nutrients. The application of these BLRs solutions for organic hydroponic is interesting since organic crops have good market price. Conventional hydroponics uses pure chemicals as plant nutrients. BLRs have potential to be used as organic fertilizer for organic hydroponic crops since they contain available nutrients, which are similar to chemical fertilizer. However, not many people have studied the organic hydroponics, and no standard formulation for organic hydroponics has been developed yet.

Previous researches found that narcissus had earlier flowering and a longer flowering period when BLRs supplement were added to the hydroponics. Tomato and cucumber hydroponics have also been tried. Most people suggested 1:4 dilution levels of BLRs and water, and they suggested adding other nutrients in hydroponics solution. Nevertheless, very few papers reported organic hydroponics using BLRs. Organic hydroponics for strawberry was studied by Jewell and Kubota (2005). They identified the issues as dominant ammonium nitrogen form, solution alkalinity, and low dissolved O_2 level of nutrient solution for organic hydroponics, but these problems have not been solved yet.

The objectives of this study were to determine and compare nutrient availability of the BLRs and their potential to be used in organic hydroponics.

4.2 Materials and methods

4.2.1 BLRs

After the fermentation of pig, chicken, and cow manure for biogas production in the digester from the previous study, all BLRs were compared as nutrient solutions in a cycling hydroponic system.

4.2.2 Crops

Morning glory (*I. aquatica* Forsk) as a resistant crop and lettuce (*L. sativa* L. cv. Duende) as a sensitive crop were used to evaluate the nutrient availability of all BLRs.

4.2.3 Cycling hydroponic system

The experiment was conducted in 1+3×6 factorial in CRD design with 3 replications. All residues were filtered by sand and diluted with reversed osmosis (RO) water to 6 concentration levels (1.0, 1.5, 2.0, 2.5, 3.0, and 3.5 mS/cm).

Control= tap water

Factor 1 was kinds of BLRs (pig, chicken, and cow BLR).

Factor 2 was concentration level (EC= 1.0, 1.5, 2.0, 2.5, 3.0, 3.5 mS/cm).

All the combination treatments were:

(1) Tap water as control (ck)

(2) Pig BLR (EC = 1.0)

(3) Pig BLR (EC = 1.5)

(4) Pig BLR (EC = 2.0)

(5) Pig BLR (EC = 2.5)

(6) Pig BLR (EC = 3.0)

(7) Pig BLR (EC = 3.5)

(8) Chicken BLR (EC = 1.0)

(9) Chicken BLR (EC = 1.5)

(10) Chicken BLR (EC = 2.0)

(11) Chicken BLR (EC = 2.5)

(12) Chicken BLR (EC = 3.0)

(13) Chicken BLR (EC = 3.5)

(14) Cow BLR (EC = 1.0)

(15) Cow BLR (EC = 1.5)

(16) Cow BLR (EC = 2.0)

(17) Cow BLR (EC = 2.5)

(18) Cow BLR (EC = 3.0)

(19) Cow BLR (EC = 3.5)

Acetic acid was used to adjust the nutrient solution to pH 6 regularly. The solution tanks were emptied and refilled with new BLRs every 4 days. Seedlings were transplanted to the above BLRs solutions about 1 week of germination in tap water when the roots appeared and elongated from the mini pot.

The experiment was conducted using nutrient film technique (NFT) hydroponic system in green house at the Suranaree University of Technology (SUT) organic farm.

4.2.4 Data collection

Morning glory samples were taken after 30 days and lettuce after 45 days to evaluate the growth, yield, and yield components. Samples were oven-dried at 70°C to measure dry weight, and ground to analyze nutrient contents.

4.2.5 Data analysis

Analysis of variance was performed using the Statistical Package for the Social Sciences (SPSS) for Windows (version 14.0). Differences among means were compared by Duncan's New Multiple Range test at 5% level of significance.

4.3 Results and discussion

4.3.1 Nutrient content of BLRs

Nutrient analysis results showed that there were complete plant nutrients in all the BLRs. All BLRs had high pH (>8). Chicken BLR had the highest salinity (EC=25.8 mS/cm), and higher N content, NH_4^+, and NO_3^-, the highest K, Zn, Cu, and Na. However, P in chicken BLR was lower, and other micro-nutrients were not very different (Table 4.1). Nutrient concentration at all EC levels was also shown in Table 4.1. It could be noticed that most cow BLR had relatively low N but high K compared to pig and chicken BLRs.

Table 4.1 Nutrient content (ppm) in original fermented BLRs under different EC levels from pig, chicken, and cow based on dilution factor

Liquid	pH	EC (mS/cm)	OM (%)	N	NH_4^+	NO_3^-	P	K	Ca	Mg	Na	Fe	Mn	Zn	Cu
Original liquid															
Pig	8.1	8.6	0.426	1660	580	62.0	240	1800	228	172	242	608	121	18.2	4.38
Chicken	8.3	25.8	0.211	2860	2465	93.1	80	4130	300	151	613	671	116	24.1	12.40
Cow	8.2	8.3	0.205	290	160	31.0	110	2520	501	187	240	643	102	12.3	4.60
EC 1.0															
Pig	8.0	1.0	0.050	193	67	7	28	209	27	20	28	71	14	2	0.51
Chicken	8.0	1.0	0.007	95	82	3	3	138	10	5	20	22	4	1	0.41
Cow	8.0	1.0	0.025	35	19	4	13	304	60	23	29	77	12	1	0.55
EC 1.5															
Pig	8.0	1.5	0.075	291	102	11	42	316	40	30	42	107	21	3	0.77
Chicken	8.0	1.5	0.008	110	95	4	3	159	12	6	24	26	4	1	0.48
Cow	8.0	1.5	0.037	53	29	6	20	458	91	34	44	117	19	2	0.84
EC 2.0															
Pig	8.0	2.0	0.099	386	135	14	56	419	53	40	56	141	28	4	1.02
Chicken	8.0	2.0	0.011	143	123	5	4	207	15	8	31	34	6	1	0.62
Cow	8.0	2.0	0.049	69	38	7	26	600	119	45	57	153	24	3	1.10
EC 2.5															
Pig	8.1	2.5	0.125	488	171	18	71	529	67	51	71	179	36	5	1.29
Chicken	8.1	2.5	0.015	204	176	7	6	295	21	11	44	48	8	2	0.89
Cow	8.1	2.5	0.062	88	48	9	33	764	152	57	73	195	31	4	1.39
EC 3.0															
Pig	8.2	3.0	0.147	572	200	21	83	621	79	59	83	210	42	6	1.51
Chicken	8.2	3.0	0.018	238	205	8	7	344	25	13	51	56	10	2	1.03
Cow	8.2	3.0	0.073	104	57	11	39	900	179	67	86	230	36	4	1.64
EC 3.5															
Pig	8.2	3.5	0.170	664	232	25	96	720	91	69	97	243	48	7	1.75
Chicken	8.2	3.5	0.021	286	247	9	8	413	30	15	61	67	12	2	1.24
Cow	8.2	3.5	0.085	121	67	13	46	1050	209	78	100	268	43	5	1.92

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4.3.2 Growth and yield of morning glory

BLRs digested from pig and chicken manures contained high amount of available N, which was suitable for organic hydroponics. Morning glory could be grown in pig and chicken manure BLRs. Cow manure BLR was not applicable due to its low N content, morning glory in cow BLR showed yellowish and stunt.

Stem height

In pig BLR, EC 2.5 stem height was the highest (19.9 cm), in EC 3.5 and EC 2.0 was the shortest (11.8 and 10.5 cm) (Figure 4.1). It decreased when EC was higher than 2.5 mS/cm. Chicken BLR with EC 1.5 mS/cm was found to be the best, stem height in chicken BLR EC 1.5 was the highest in all treatments (27.9 cm). Stem height in cow BLR, no treatment was better than control which had stem height of 13.7 cm.

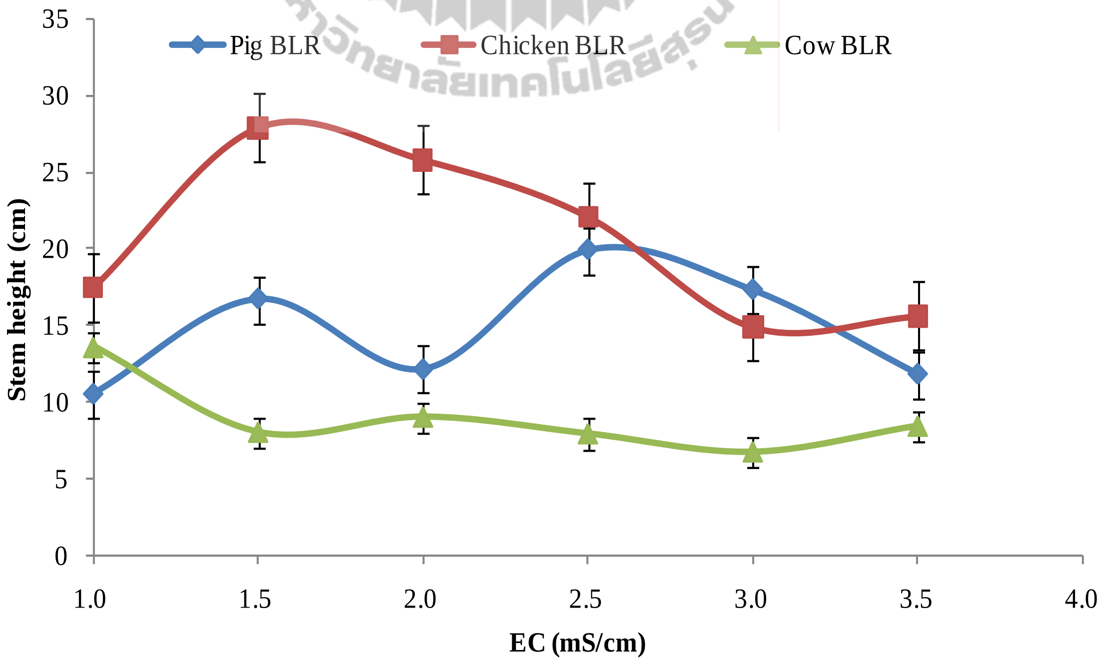

Figure 4.1 Effect of different BLRs concentration (EC) on stem height of morning glory

Fresh weight

In pig BLR, fresh weight of morning glory EC 2.5 was highest (10.70 g/plant), EC lower or higher than 2.5 mS/cm, fresh weight were lower (Figure 4.2). It meant in the pig BLR EC lower or higher than 2.5 mS/cm, nutrients were not more balanced than in EC 2.5 mS/cm. Fresh weight in chicken BLR EC 1.5 was the highest in all treatments (12.36 g/plant), EC lower or higher than 1.5 mS/cm, fresh weight was lower. It also meant that chicken BLR EC 1.5 mS/cm had more balanced nutrients than other EC levels. Fresh weight in cow BLR, none of the treatments was higher than the control (1.26 g/plant). It might be due to the nutrient content in cow BLR was quite low and not balanced.

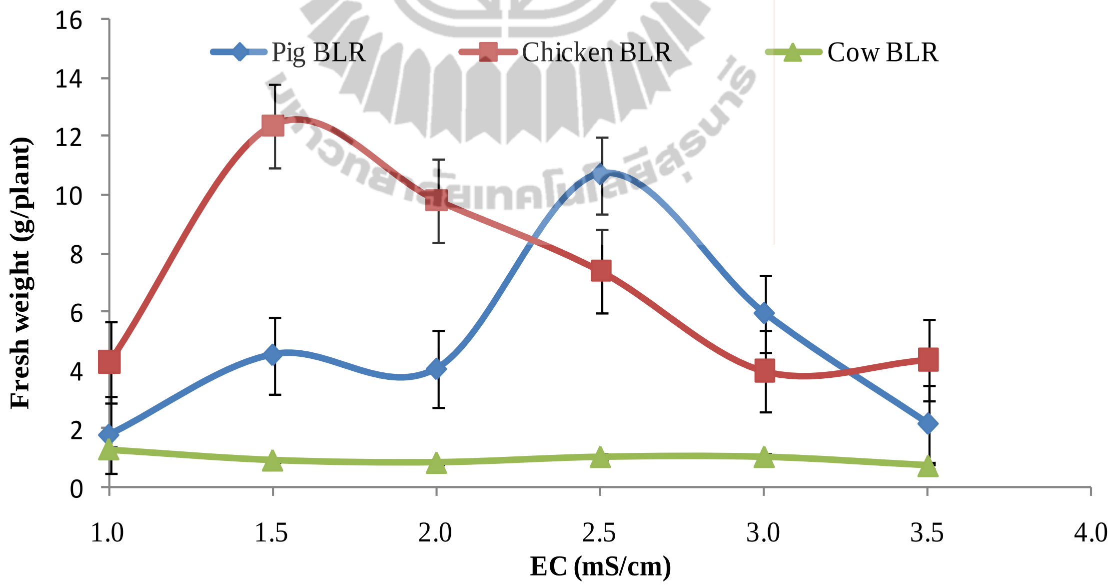

Figure 4.2 Effect of different BLRs concentration (EC) on fresh weight of morning glory

Dry weight

Dry weight and fresh weight had the same tendency. Dry weight in pig BLR EC 2.5 was the highest (1.13 g/plant), in chicken BLR EC 1.5 was also the highest (1.63 g/plant) (Figure 4.3). None in cow treatment was higher than control (0.3 g/plant). It meant in the pig BLR EC lower or higher than 2.5 mS/cm, nutrients were not more balanced than in EC 2.5 mS/cm. EC 1.5 mS/cm in chicken BLR had more balanced nutrients than other EC levels. The nutrient content in cow BLR was quite low and not balance compared with pig and chicken BLRs.

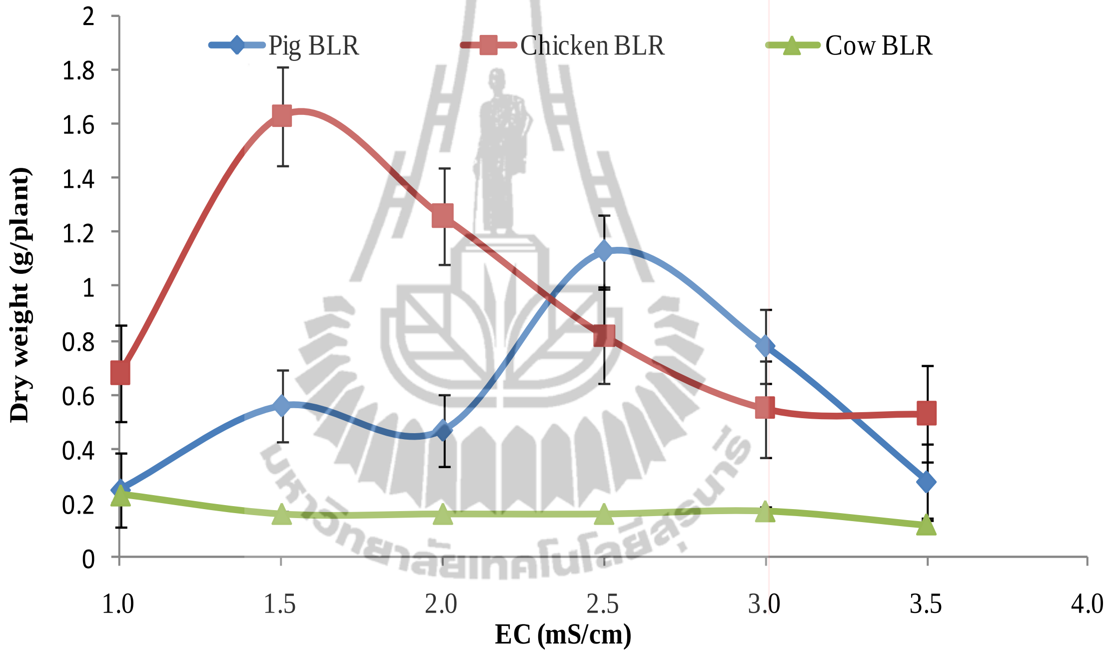

Figure 4.3 Effect of different BLRs concentration (EC) on dry weight of morning glory

4.3.3 Growth and yield of lettuce

Lettuce also could be grown in pig and chicken manure BLRs. Cow manure BLR was not applicable due to its low N content, lettuce in cow BLR also showed yellowish and stunt. EC of 1.5 mS/cm for chicken BLR and EC 2.5 mS/cm of pig BLR were the best for lettuce.

Stem height

Stem height of lettuce in pig BLR EC 2.5 was the highest (17.7 cm), in other EC levels of BLRs stem height were shorter (Figure 4.4). Stem height in chicken BLR EC 1.5 was higher than other EC levels (12.1 cm). Stem height in cow BLR was close to the control (2.6 cm). It meant that lettuce was more sensitive to the P deficiency in chicken BLR compared with morning glory.

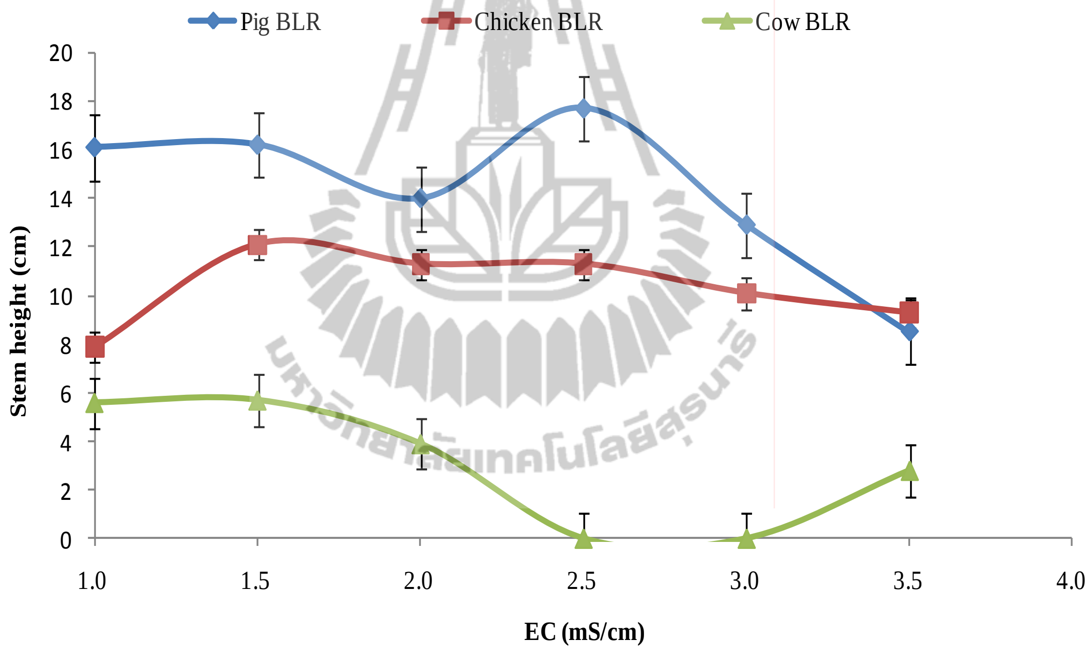

Figure 4.4 Effect of different BLRs concentration (EC) on stem height of lettuce

Fresh weight

Fresh weight of lettuce in pig BLR EC 2.5 was the highest in all treatments (62.11 g/plant), EC lower or higher than 2.5 mS/cm, fresh weight was lower (Figure 4.5). In chicken BLR, fresh weight in EC 1.5 was highest (28.21 g/plant), EC lower or higher than 1.5 mS/cm, fresh weight was also lower. Fresh weight in cow BLR was not better than control.

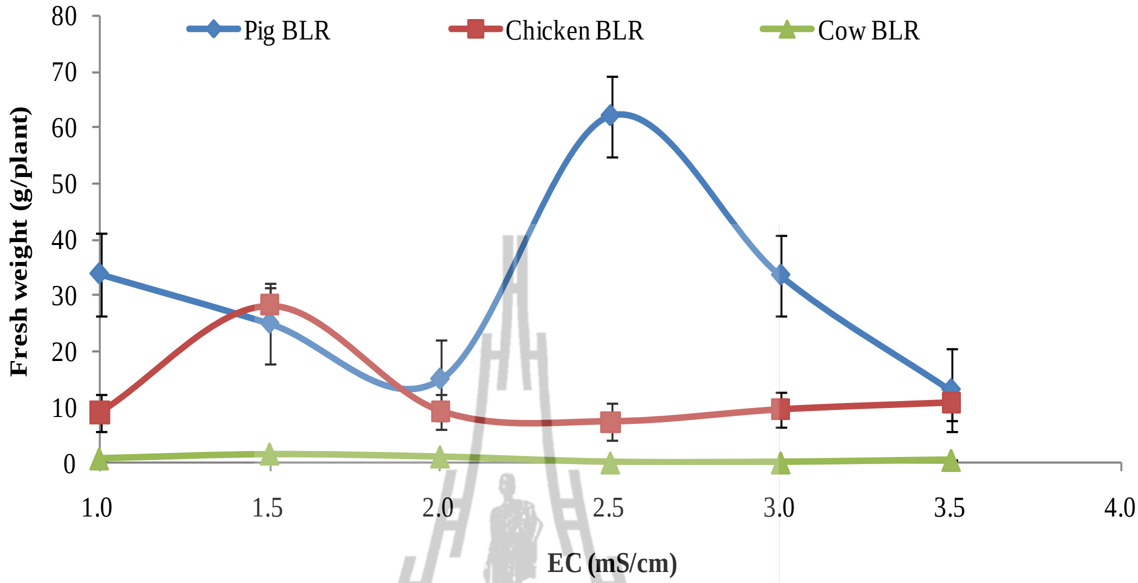

Figure 4.5 Effect of different BLRs concentration (EC) on fresh weight of lettuce

Dry weight

Dry weight and fresh weight had the same tendency. Dry weight of lettuce in pig BLR EC 2.5 was the highest (3.49 g/plant), in chicken BLR EC 1.5 was also the highest (1.49 g/plant) (Figure 4.6). Dry weight in cow treatments was not higher than control.

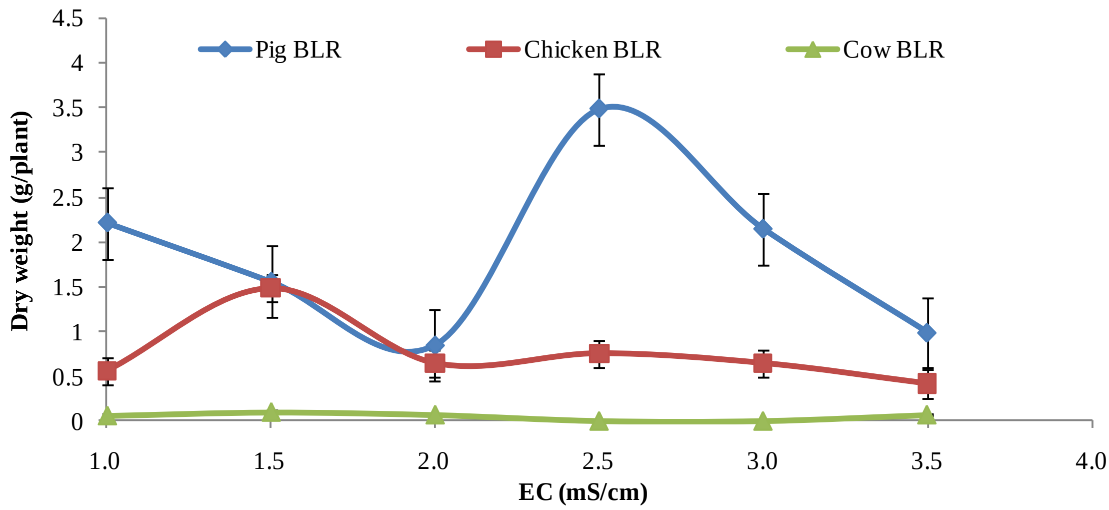

Figure 4.6 Effect of different BLRs concentration (EC) on dry weight of lettuce

Chicken BLR required a big amount of water to dilute and reduce the high salinity. Compared with lettuce, the result could explain that morning glory had higher resistance to the toxicity in higher EC BLRs, and it could grow in many sewage ditches, cannels, paddy fields, and even flooded areas.

Among the 3 kinds of BLRs, pig manure BLR was the best material for organic hydroponic vegetable production. It was moderate and optimal. Cow BLR has low nutrient content. Especially, nutrient balance in the BLRs was important for the crops, and NPK ratio in chicken BLR EC 1.5 was N 110 ppm (NH_4^+ 95ppm), P 3 ppm, and K 159 ppm. In pig EC 2.5, N was 488 ppm (NH_4^+ 171 ppm), P 71 ppm, and K 529 ppm. Major N form was NH_4^+, and NO_3^- content was very low, 7-25 ppm in pig BLR, 3-9 ppm in chicken from all EC levels. After being diluted, P showed quite less in the liquid. N in all EC levels of cow BLR was much less, EC 1.0- EC 3.5, N was 35-121 ppm. Higher EC had toxicity to lettuce, it showed tip burn, and Pythium were found on stems and leaves when EC > 3.0. Besides, big layer of algae were found in the pipes and solutions. It was one of the reasons for the increase of pH.

4.3.4 Nutrient uptake of morning glory

In morning glory, nutrient uptake reflected and correlated with the growth and yield in the BLRs solutions.

Nitrogen (N)

N uptake of morning glory in pig BLR EC 2.5 mS/cm was the highest, and significant with other EC treatment, also reflected with the yield (Table 4.2). And then it was followed by pig BLR EC 2.0-3.5 (N content 6.81% and 6.18%). After high level of dilution, N in chicken BLR showed lower than that in pig BLR. In chicken BLR treatment, EC 2.0 mS/cm was the highest among them (even yield in EC 1.5

mS/cm was the highest), and followed by chicken BLR EC 2.5 and 3.5 mS/cm. It seemed that NPK ratio in chicken BLR EC 2.0-2.5 was better for uptake, EC higher than 3.0, showed toxic, lower, there was imbalance. Pig BLR EC < 1.5, showed deficiency. EC > 3.0, showed toxic. Like in pig BLR, N showed deficiency in chicken BLR, EC<1.5; and showed toxic when EC > 3.0. N in all EC levels in cow BLR did not show any difference, it reflected that N in all cow BLR was very low from 35 to 121 ppm. It might be in a deficiency level.

Phosphorus (P)

P uptake in pig BLR EC 2.5 mS/cm showed significant from other treatment. P in all levels of pig BLR was higher than in both chicken BLR, followed by EC 3.0, 1.5, 3.5, 2.0, 1.0. It showed much less in pig BLR EC 1.0 mS/cm. It might be deficient. Then P content was followed by different levels of chicken and cow, higher level EC had high P, but with NH^{4+} form of N, but with toxicity. Lower level EC level had lower P, but had N deficiency.

Potassium (K)

Research showed there was no K deficiency in all BLRs. K in all chicken BLRs had higher uptake. It was ranked by EC 3.5, 1.5, 3.0, 2.5, and 2.0 mS/cm. K uptake in pig BLR was lower than that in chicken BLR. It was ranked by pig EC 2.5, 3.0, 3.5, 2.0, and 1.5 mS/cm. K uptake was higher in cow 3.0 and 3.5 mS/cm, lower in other level of cow BLR.

Calcium (Ca)

Ca uptake in all chicken BLRs was higher than both cow and pig BLRs. It was highest in chicken BLR EC 1.5, and then followed by chicken BLR EC 2.0, 2.5, 1.0, and 3.0 mS/cm. Ca uptake in cow BLR was higher than in pig BLR, it might be due to the cation antagonistic. Ca uptake in all levels of pig BLRs was lower than both cow and chicken BLRs.

Magnesium (Mg)

On the contrary, Mg uptake in all cow BLR was higher than in pig and chicken BLRs.

Table 4.2 Nutrient content of morning glory in organic hydroponics

Nutrient	Liquid	EC1.0	EC1.5	EC2.0	EC2.5	EC3.0	EC3.5
N (%)	Pig	2.03c-g	2.23a-e	2.73ab	2.87a	2.26a-e	2.47abc
	Chicken	1.72d-g	2.05c-f	2.45abc	2.32a-d	1.92c-g	2.08b-f
	Cow	1.38g	1.64efg	1.71d-g	1.83c-g	1.93c-g	1.55fg
	Control			0.75h			
P (%)	Pig	0.20cde	0.29bc	0.27bcd	0.51a	0.37b	0.27bcd
	Chicken	0.12ef	0.14ef	0.12ef	0.13ef	0.12ef	0.18def
	Cow	0.17ef	0.10f	0.12ef	0.11ef	0.13ef	0.18def
	Control			0.10f			
K (%)	Pig	2.34e-h	2.93def	2.97def	3.48cd	3.16de	3.14de
	Chicken	2.64efg	5.16a	4.22bc	4.76ab	4.78ab	5.20a
	Cow	2.02gh	1.70h	2.14fgh	2.26fgh	2.94def	2.49e-h
	Control			1.53i			
Ca (%)	Pig	0.85efg	0.90efg	0.69fgh	0.55gh	0.38h	0.43h
	Chicken	1.50bc	2.10a	1.73b	1.64b	1.37bcd	1.16cde
	Cow	1.19cde	1.08de	0.88efg	0.94ef	1.05def	1.09de
	Control			1.24cde			
Mg (%)	Pig	0.26d	0.32bc	0.32bc	0.33bc	0.31cd	0.37ab
	Chicken	0.33abc	0.37ab	0.32bc	0.33bc	0.29cd	0.29cd
	Cow	0.36ab	0.38a	0.38a	0.37ab	0.38a	0.38a
	Control			0.35ab			
Na (%)	Pig	0.49de	0.49de	0.51de	0.73ab	0.70abc	0.78a
	Chicken	0.55de	0.64a-d	0.59cde	0.64a-d	0.64a-d	0.71abc
	Cow	0.36fg	0.36fg	0.34g	0.32g	0.30g	0.31g
	Control			0.57de			
Fe (%)	Pig	0.50i	0.69hi	0.88e-h	0.76gh	0.81e-h	0.84e-h
	Chicken	1.24abc	1.27ab	1.22abc	1.33a	1.17a-d	1.32a
	Cow	0.77fgh	0.97d-g	1.04b-e	1.22abc	1.01c-f	1.04b-e
	Control			0.69hi			
Mn (%)	Pig	0.11d-h	0.15a-d	0.12c-f	0.15a-d	0.15a-d	0.17ab
	Chicken	0.07e-i	0.09e-i	0.06hi	0.05i	0.12c-f	0.14b-e
	Cow	0.17abc	0.20a	0.20a	0.07e-i	0.17abc	0.10e-i
	Control			0.13c-f			
Zn (ppm)	Pig	147.84b	72.15b	130.21b	204.09b	79.37b	143.83b
	Chicken	159.93b	49.40b	62.85b	88.91b	82.81b	54.59b
	Cow	235.82b	179.95b	212.26b	715.10a	146.59b	274.37b
	Control			140.44b			
Cu (ppm)	Pig	168.62a	74.78b	69.26b	113.39ab	81.86b	52.25b
	Chicken	90.66ab	101.01ab	91.06ab	99.81ab	95.68ab	90.34ab
	Cow	77.71b	51.15b	83.34b	86.50b	86.61b	116.38ab
	Control			119.67ab			

Means in an element followed by the same letters are not significantly different at 5% level by DMRT

4.3.5 Nutrient uptake of lettuce

Nutrient uptake of lettuce reflected and correlated with the growth and yield in the BLRs solutions.

Nitrogen (N)

N uptake of lettuce in pig BLR EC 2.0 mS/cm were highly significantly greater with other treatments even within different level of pig BLR (even had higher yield in EC 2.5 mS/cm) (Table 4.3). It was followed by pig 1.5 mS/cm. Pig BLR 3.5, Chicken 1.0, 2.0, and 1.5 mS/cm had same N uptake level. Chicken 3.0 mS/cm showed toxic. All cow BLR levels except cow 1.5 mS/cm showed very less N uptake.

Phosphorus (P)

P in all pig BLR level was higher than both chicken and cow. P uptake in cow was the lowest since less N uptake.

Potassium (K)

K in only cow 2.0 was higher. It was followed by all level of chicken BLR, pig BLR, and other level of cow BLR. It indicated that pig BLR EC 2.5 mS/cm was the best NPK ratio for lettuce hydroponic production.

Calcium (Ca)

Like in morning glory, Ca in Chicken 1.0 mS/cm and other levels of cow BLR was higher, and then followed by chicken and pig BLR.

Magnesium (Mg)

Mg in low EC lever of cow BLR (cow 1.0, 2.0, and 1.5 mS/cm) was higher. Its order for pig BLR was pig EC 2.0, 1.0, 1.5, 2.5, 3.0 and 3.5 mS/cm. Mg was low uptake in all levels of chicken BLR.

Nutrient balance in the BLR was important for the crops. NPK ratio in chicken BLR EC 1.5 was N 110 ppm (NH_4^+ 95ppm), P 3 ppm, and K 159 ppm. In pig EC 2.5 was N 488 ppm (NH_4^+ 171 ppm), P 71 ppm, and K 529 ppm. NPK in chicken BLR EC 1.5 and pig EC 2.5 was more balanced than other treatment, toxicity of chicken BLR in EC 1.5 was less than higher EC level, in low EC level, N was lower (35 ppm). Major N form was NH_4^+, and NO_3^- content was very low, 7-25 ppm in pig BLR, 3-9 ppm in chicken from all EC levels. After being diluted, P showed quite less in the BLR. N in all EC levels of cow BLR was much less, EC 1.0- EC 3.5, N was 35-121 ppm.

P uptake in morning glory (Table 4.2) and lettuce (Table 4.3) showed that morning glory was not as sensitive as lettuce to P deficiency. It also could explain that morning glory could be grown easily in the water body and soil with P deficiency better than that of lettuce.

Obviously unlike the morning glory, the nutrients uptake of lettuce correlated with the yield (stem height, fresh weight, and dry weight). This also can explain the sensitivity of lettuce to the toxicity in all the BLR solutions.

All the data in yield and nutrient uptake showed that none of the levels of the cow BLR solutions was applicable for both morning glory and lettuce; the only reason should be due to its lowest N in the BLR solutions.

Table 4.3 Nutrient content of lettuce in organic hydroponics

Nutrient	Liquid	EC1.0	EC1.5	EC2.0	EC2.5	EC3.0	EC3.5
N (%)	Pig	2.21c-f	2.73b	3.37a	2.28b-f	1.94ef	2.54bc
	Chicken	2.68bc	2.50bcd	2.52bc	2.25b-f	2.31b-e	--
	Cow	1.81f	2.48bcd	2.02d-f	--	--	0.63h
	Control			1.34g			
P (%)	Pig	0.40bc	0.49b	0.64a	0.47bc	0.38c	0.42bc
	Chicken	0.17e	0.21de	0.24de	0.23de	0.25de	--
	Cow	0.23de	0.27d	0.21de	--	--	0.05f
	Control			0.12e			
K (%)	Pig	6.07c-f	5.75d-f	6.02c-f	6.21c-f	5.62ef	5.42f
	Chicken	5.98c-f	6.34cde	6.59bcd	6.66bc	7.28b	--
	Cow	3.99g	5.40f	9.25a	--	--	2.21h
	Control			2.67h			
Ca (%)	Pig	1.46ab	0.90cd	0.65def	0.79de	0.53def	0.63def
	Chicken	1.70a	1.40ab	1.24bc	0.39efg	0.31fg	--
	Cow	1.64ab	1.47ab	1.67a	--	--	1.24bcd
	Control			0.92cd			
Mg (%)	Pig	0.41bcd	0.40cd	0.44b	0.37de	0.34e	0.34e
	Chicken	0.35e	0.28f	0.27fg	0.21h	0.23gh	--
	Cow	0.48a	0.43bc	0.45ab	--	--	0.20h
	Control			0.27f			
Na (%)	Pig	0.76cd	0.90bc	1.03ab	1.05ab	1.00ab	1.12a
	Chicken	0.63d	0.60d	0.58d	0.57e	0.72cd	--
	Cow	0.74cd	0.73cd	0.62d	--	--	0.27e
	Control			0.54d			
Fe (%)	Pig	0.66ab	0.68ab	0.68ab	0.66ab	0.69ab	0.63ab
	Chicken	0.60ab	0.63ab	0.70a	0.66ab	0.53b	--
	Cow	0.67ab	0.69ab	0.72a	--	--	0.64ab
	Control			0.66ab			
Mn (%)	Pig	0.13c	0.21ab	0.19bc	0.21ab	0.23ab	0.19bc
	Chicken	0.27a	0.23ab	0.23ab	0.24ab	0.27a	--
	Cow	0.22ab	0.20ab	0.21ab	--	--	0.27a
	Control			0.19bc			
Zn (ppm)	Pig	183.58ns	262.57ns	273.82ns	566.06ns	616.41ns	127.45ns
	Chicken	150.76ns	121.31ns	496.01ns	122.19ns	295.13ns	--
	Cow	647.85ns	535.56ns	136.90ns	--	--	12.01ns
	Control			16.74ns			
Cu (ppm)	Pig	83.00ns	85.33ns	93.46ns	79.43ns	91.42ns	93.38ns
	Chicken	100.30ns	98.01ns	96.03ns	107.55ns	98.26ns	--
	Cow	100.84ns	109.04ns	89.12ns	--	--	91.30ns
	Control			109.60ns			

Means in an element followed by the same letters are not significantly different at 5% level by DMRT

4.4 Conclusions

The results indicated that both vegetables could be successfully grown in pig and chicken manure BLR which contained high amount of available N, but cow manure BLR was not applicable.

It can be concluded that pig manure BLR was the best material for organic hydroponic vegetable production, since chicken BLR needed big amount of water to dilute due to its higher salinity, and that other nutrients such as P could be deficient along with high dilution level.

Based on this experiment and many preliminary studies, like the conventional hydroponics, EC is the critical indicator instead of water dilution level for BLRs in organic hydroponics. EC of 1.5 mS/cm for chicken and 2.5 mS/cm for pig were found to be the best for both crops. Cow manure BLR was not applicable for the organic hydroponics due to its low nitrogen content.

However, pH value increased very fast in the organic solution. It increased to 8.0 just in 24 hrs, and needed to be adjusted daily.

It is also recommended that BLRs have to be well filtered since organic substrates in the BLRs will be a growing media for algae and plant pathogens.

Higher EC showed toxicity to lettuce, and morning glory showed higher resistance to the toxicity in higher EC of BLR. It confirmed and explained why the morning glory can grow in the sewage system, streams and ditches, etc.

In line with Jewell and Kubota's findings (2005) on organic hydroponics for strawberry, issues as dominant ammonium nitrogen form, solution alkalinity, and dissolved oxygen level of nutrient solution for organic hydroponic production should be solved.

The conversion of NH_4^+ to NO_3^- by adding H_2O_2 and pumping air or O_2 to the solution might be necessary. Therefore, ammonium N in BLRs could be uptake by crops more efficiently, and organic hydroponics could be more adoptable.

CHAPTER V

EFFECTS OF BIOGAS RESIDUES AND COMPOST ON ORGANIC VEGETABLE PRODUCTION

5.1 Introduction

Fertilization is the most expensive cultural practice for organic vegetable production. N is the most important and costly nutrient to manage, and cost-effective N management practices are needed for efficient organic vegetable production. Organic N sources were widely available, but varied in cost, N content, N availability, and mineralization. Additional hidden management costs for organic growers could be caused by organic resources, un-uniformity, bulkiness, instability, and inconsistency as a group.

Constraints for organic vegetable are the readily available nutrients in organic fertilizer for the short-season organic vegetables. Compost and cover crops are commonly used due to their inexpensiveness and offer additional nutrients or soil improvement qualities in addition to N. Especially compost is the major organic fertilizer used in organic farming, but the slow release of nutrients from compost could not meet the requirement of fast growing crops and short-season vegetables, which constrains the organic vegetable production.

BR might be an alternative to chemical fertilizer since it contained essential plant nutrients in an available form. BRs are widely applied to most crops in China, according to numerous reports, but little basic nutrient information has been provided, and few people have studied the application of biogas residues in organic vegetable production.

The objective of this experiment was to compare the effects of BRs (BLRs and BSRs) and composts on organic vegetable production.

5.2 Materials and methods

5.2.1 Organic fertilizers

BLRs, BSRs, composts from pig, chicken, and cow manure were tested in this experiment.

5.2.2 Organic vegetable

Morning glory (*I. aquatica* Forsk) was used as the representative of short-season organic vegetable.

5.2.3 Experimental design

The experimental design was 1+3×3 factorial in RCB with 3 replications. The experiment was conducted at the Suranaree University of Technology organic farm. The treatments were as follows:

Control= no fertilizer application

Factor 1 = 3 kinds of manures (pig, chicken, and cow manure)

Factor 2 = 3 forms of organic fertilizers (BLRs, BSRs, and compost)

All treatments were:

(1) Pig BLR

(2) Chicken BLR

(3) Cow BLR

(4) Pig compost

(5) Chicken compost

(6) Cow compost

(7) Pig BSR

(8) Chicken BSR

(9) Cow BSR

(10) Control (ck)

The amount of all organic fertilizers was based on the same amount of N (342 kg/ha). This amount of N was used according to the recommended rate of compost for organic vegetable production (≌10 t/ha). Amounts of other organic fertilizers were calculated accordingly.

Morning glory seeds 10 g/m^2 were sowed in 6 rows in each plot with 1×5 m^2. Dry organic fertilizers were applied as base fertilizer, while BLR fertilizers were added daily after seeds were sown.

BLRs were sprayed until the soil was wet to avoid leaching. Chicken BLR treatment was followed by application of water to wash the plants to avoid leaf burn by high salinity BLR. Plants were watered by sprinkling irrigation daily until harvesting.

5.2.4 Morning glory samples

Morning glory from the center 4 rows with 2 m long was harvested. Stem height, fresh weight, and dry weight were measured.

Samples were oven-dried at 70°C to measure dry weight, and then they were ground to analyze the plant nutrient content.

5.2.5 Soil analysis

Soil samples in each plot were taken, air dried, and sieved to analyze soil nutrient content and other chemical properties.

5.2.6 Statistical analysis

Analysis of variance was performed using the Statistical Package for the Social Sciences (SPSS) for Windows (version 14.0). Differences among means were compared by Duncan's New Multiple Range test at 5% level of significance.

5.3 Results and discussion

5.3.1 Nutrient content in experimental soil

Results of experimental soil nutrient analysis before planting showed that soil had OM 2.96%, N 0.140%, P 217 ppm, K 320 ppm, Ca 2241 ppm, and Mg 640 ppm (Table5.1).

Table 5.1 Soil nutrient content before experiment

Item	pH	EC (µS/cm)	OM (%)	N (%)	P (ppm)	K (ppm)	Ca (ppm)	Mg (ppm)
Soil	7.57	167	2.96	0.140	217	320	2241	640

5.3.2 Nutrient content in all organic fertilizers

Nutrient analysis results indicated that based on the same amount of N content, all composts and BSRs had higher amount of P than BLRs (Table 5.2). P was low in all BLRs probably because of its active reaction. It might reacted with other nutrients and precipitated. P in chicken BLR was the lowest, followed by that in pig BLR. K content was very high in the BLRs probably due to its higher solubility during the digestion process, which was about 2-4 times higher than in the compost and BSRs. Ca was also the lowest in the BLRs. It was about 6 times lower than in compost and BSR. Mg, Na, and other micro nutrients (Fe, Mn, Zn, and Cu) were close to each other except that Cu in BSR which was 5-6 times lower than in composts and BLRs. Cow BLR had very low N, so the amount of application had to be large in order to meet crop requirement. This might resulted in too high amount of other nutrients and toxicity of high salinity.

Table 5.2 Nutrient content (kg/ha) in organic fertilizers based on the same amount of N application

Treatment	N	P	K	Ca	Mg	Na	Fe	Mn	Zn	Cu
BLR										
Pig	342	49.4	370	47.0	35.4	45.8	125.0	25.0	3.76	0.90
Chicken	342	13.9	384	27.8	14.0	56.8	62.2	11.2	2.24	1.15
Cow	342	151.0	752	686.0	256.0	328.0	880.0	139.0	16.80	6.30
Compost										
Pig	342	422	168	352	52.0	37.8	124.0	25.20	5.30	0.72
Chicken	342	450	246	1048	39.2	40.4	95.4	13.40	3.40	0.20
Cow	342	152	358	386	51.4	36.2	140.0	31.80	1.00	0.99
BSR										
Pig	342	356	84.8	348	55.6	29.4	136.0	16.1	5.14	0.14
Chicken	342	384	204.0	1974	84.6	44.0	43.0	8.1	6.04	0.23
Cow	342	222	200.0	356	74.6	44.4	34.4	44.4	0.89	0.28

5.3.3 Growth, yield, and yield components of morning glory Yield

Yield in chicken BLR and pig BLR was the highest (21.61 and 20.00 t/ha) (Table 5.3). The difference between pig and chicken BLR was not significant, because both of them had plenty of N for short-season vegetables. Even low P in both BLRs, the uptake of N could promote the P uptake from the soil, unlike the hydroponic experiment which did not have additional P in the solution. Both of chicken and pig BLRs were highly significantly different with other treatments (cow BLR, all composts and BSRs). There was no significant difference among chicken BSR and chicken compost, pig BSR, and pig compost (14.50, 14.50, 13.83, and 13.67 t/ha). But yield in both form of chicken were higher than in both forms of pig residues. Yield in cow BSR was better than other forms of cow manure (12.17 t/ha), since it was digested a little more completely than compost. In cow BLR and cow compost, the yield was the lowest among all the residues. It was due to low N in cow BLR, and N loss by leaching during the big amount of application of cow BLR. Also, with big amount of cow BLR application, other nutrients in cow manure BLR could be antagonistic and toxic for the morning glory. Therefore it may prohibit the nutrients uptake. Additionally, cow compost which had high fiber content needed longer time to digest in the soil, but the short-season crop could not uptake the nutrient before harvesting. Besides, cow compost during the composting was not uniformly and completely digested under the aerobic fermentation, compared with the anaerobic fermentation. The available nutrient release was not uniform even both compost and BSR had the same fermentation time under different fermentation techniques.

Stem height

Stem height in pig BLR was the highest (50.47 cm), followed by chicken BLR, pig and chicken compost, and chicken BSR (49.20, 45.77, 44.60, and 43.33 cm). In pig BSR it was shorter (39.83cm). In all forms of cow manure it was the shortest, most of them could not reach the standard height for selling, and most were stunt and not tender.

Fresh weight

Fresh weight had similar tendency as yield. It was the highest in chicken and pig BLR (31.60, 28.52 g/plant). It was close to pig and chicken compost and BSRs. It was 23.95, 23.59, 23.04, and 21.47 g/plant in chicken BSR, pig compost, chicken compost, and pig BSR, respectively. In all forms of cow manure it was the lowest. It was 10.73, 9.53, and 9.43 in cow BSR, cow BLR, and cow compost, respectively.

Dry weight

Dry weight showed the same trend as yield and fresh weight. Dry weight was the highest in chicken BLR (1.67 g/plant), followed by that in chicken BSR (1.56 g/plant). It was 1.50, 1.49, and 1.47 g/plant in chicken compost, pig BLR, and pig BSR, respectively. In pig compost, it was 1.40 g/plant. In cow BSR, cow compost and cow BLR, it was 0.54, 0.51, and 0.49 g/plant, respectively. There was quite low dry matter content accumulated for the fast growing vegetables. Due to the short growing season, water account for the bigger part.

It meant besides the BLRs, suitable amounts of BSRs and composts of pig and chicken manure also could be used for short-season vegetables, but they should be applied earlier in the soil as base fertilizer for digestion to release enough nutrients. Chicken and pig BLRs contained readily available essential plant nutrients for short-season vegetables. The available nutrients uptake in early growing stage promoted the differentiation and growth of plant tissues, and the establishment of rooting system, therefore, more nutrients in the surrounding soil could be exchanged and uptake by plants. The nutrient availability of BLRs in the soil also promoted the growth and activities of soil microorganisms, and organic substances in BLRs which had not been digested by anaerobic bacteria could continue to be digested by soil microorganisms, thereby improving the soil microenvironment. All the factors resulted in the fast growing of plants.

Cow BLR was not applicable to the short-season vegetables even in high application amounts because of low N content. To apply enough N, it needs large amount of application (136 kg/m^2). Additionally, this is not convenient for the application. Moreover, other nutrient such as K will be very high and can cause toxicity to the crops.

Table 5.3 Yield and yield components of morning glory in organic farming

Treatment	Yield (t/ha)	Stem height (cm)	Fresh weight (g/plant)	Dry weight (g/plant)
BLRs				
Pig	20.00a	50.47a	28.52a	1.495bc
Chicken	21.61a	49.20ab	31.60a	1.674a
Cow	9.17cd	32.93e	9.53c	0.489d
Composts				
Pig	13.67b	45.77abc	23.59b	1.402c
Chicken	14.50b	44.60abc	23.04b	1.502bc
Cow	8.50cd	33.70bcd	9.44c	0.510d
BSRs				
Pig	13.83b	39.83cd	21.47b	1.473bc
Chicken	14.50b	43.33bc	23.95b	1.560ab
Cow	12.17bc	33.77de	10.73c	0.540d
Control	6.17d	27.03d	3.95d	0.254e

Means in a column followed by the same letters are not significantly different at 5% level by DMRT

5.3.4 Growing period and times of harvesting

Beside the yield and yield components, growing period and time to market could be the critical indicators for organic vegetable.

For the organic vegetable grower, short growing and early time to market means more economic benefits. A short growing period could guarantee the tenderness, freshness, and taste of vegetables, while longer growing time resulted in more lignin and fiber accumulation. Lignin formulation and accumulation always happen to short-season vegetables if they are grown longer, the taste and quality of vegetables could be affected. Pig and chicken BLR could shorten the market time to 15-20 days, 20-30 days in BSR and compost of pig and chicken manure, while in all forms of cow manure the market time was normal, 30-40 days (Table 5.4).

Short growing period also could control the weed by the space, canopy, and fertility competition of high density of vegetables. Short growing period in the field could avoid the breakout of insect pests. The vegetables were harvested before the insect pest reached the highest population.

Furthermore, the nutrient availability could be seen by the harvest times, numbers and height of side shoots. Since the complete rooting system was set up, the shoots of morning glory could be regenerated by the cutting harvest method, which was found for Chinese Kale and also morning glory in hydroponic system.

It was observed that the morning glory in pig and chicken BLR treatments could harvest 4-5 times, and that BSR and compost of pig and chicken for 3-4 times, but only once in all forms of cow manure. As for site shoots, in pig and chicken BLR, 2 higher site shoots, 2 medium-high shoot BSR and composts of chicken and pig manure, and no side shoot in cow treatments were observed (Table 5.4).

Table 5.4 Growing period, shortest time to sell, and harvest times

Treatment	Shortest time to sell (days)	Normal growing period (days)	Maximum harvest time (time)	Side shoots or Branches
BLR				
Pig	15-20	30-40	4-5	2
Chicken	15-20	30-40	4-5	2
Cow	30-40	30-40	1	0
Compost				
Pig	20-30	30-40	3-4	2
Chicken	20-30	30-40	3-4	2
Cow	30-40	30-40	1	0
BSR				
Pig	20-30	30-40	3-4	2
Chicken	20-30	30-40	3-4	2
Cow	30-40	30-40	1	0
Control				
Control	30-40	30-40	1	0

5.3.5 Nutrient uptake of morning glory

Nutrient uptake of morning glory showed that N uptake in pig and chicken BLR was the highest (4.26, 4.02%), followed by chicken BSR (3.62%) (Table 5.5). Pig compost and chicken compost had the same level of N uptake (2.86, 2.82%). It was low in cow compost, cow BLR, and cow BSR (2.70, 2.52, and 2.14%). They were even lower than control. N in pig BSR was low. There might be antagonistic from P uptake in the BSRs.

P uptake in pig BSR was the highest (1.07%). Higher P uptake from pig

BSR might inhibit the N uptake. P uptake from cow compost and chicken compost was also higher (1.02, 1.01%), due to high P in both compost, and it was easily uptaken by plants. Unlike in the BLR mentioned in Chapter 3, there was less P dissolved in the BLR since they actively reacted with other nutrients such as Ca and precipitated in the BSR. For aerobic fermentation of the compost, there was no P loss, and all of it was still in the compost during the fermentation. P uptake in chicken BSR, cow BSR, and pig compost was at the same level (0.85, 0.85, and 0.84 %). In pig BLR and chicken BLR, P uptake was quite low, since plants uptake more N in pig BLR, and there was low P content in the chicken BLR applied (only 6.96 kg/ha). This experiment reflected with the nutrient analysis result, and confirmed the results of the hydroponic study. Since P was low in all BLRs, it needed to add extra P sources.

K uptake was the highest in chicken BLR (9.13%), the lowest in cow compost, cow BSR, and chicken BSR (7.80, 7.67, and 7.67%). In pig compost, pig BLR, pig BSR, cow BLR and chicken compost, P was at the same level (8.72, 8.55, 8.44, 8.20, and 8.18%, respectively). Since K had higher solubility, it dissolved in all the BLR during digestion. Results also showed that after K dissolved in the BLR, there was less K in the BSR (K in chicken and cow BSR was much less). Results also showed that, in terms of the digestibility of the compost, pig compost was the easiest one, and K was easy to release to the soil. It can be concluded that organic fertilizer application improved the K uptake for organic vegetables. While Ca, Mg, and other micro nutrients were in a certain low amount even when they showed some differences. They all showed the trend that higher application had higher amount of nutrient uptake.

Table 5.5 Nutrient content of morning glory in organic farming

Treatment	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	Na (%)
BLR						
Pig	4.26a	0.768c	8.55abc	0.547b	0.351a	0.581ab
Chicken	4.02ab	0.715c	9.13a	0.897a	0.363a	0.503abc
Cow	2.52cd	0.868abc	8.20bcd	0.236c	0.294bc	0.471abc
Compost						
Pig	2.86bcd	0.840bc	8.71ab	0.268c	0.336ab	0.494abc
Chicken	2.82bcd	0.999ab	8.18bcd	0.350bc	0.334ab	0.470abc
Cow	2.70cd	1.020ab	7.80cd	0.227c	0.265c	0.409bc
BSR						
Pig	1.97d	1.067a	8.43abc	0.351bc	0.337ab	0.472abc
Chicken	3.62abc	0.849bc	7.67cd	0.368bc	0.338ab	0.587a
Cow	2.13d	0.846bc	7.66cd	0.288c	0.268c	0.394c
Control						
Control	2.81bcd	0.745c	7.40d	0.350bc	0.314abc	0.386c

Means in a column followed by the same letters are not significantly different at 5% level by DMRT

5.3.6 Soil analysis

Soil analysis showed that after the morning glory was harvested, all treatments had higher EC and higher OM (Table 5.6). N in chicken compost was the highest, which means most of it was still in organic form, not have been completely digested yet, and there was less in low dosage of pig BSR. It was lower in cow BLR (loss caused by leaching with big amounts of application). The statistical trends indicated that there was not much difference since the amount of N application was the same, and the amount taken up by plant depended on the availability and a balanced combination of other macro and micro nutrients. Anyhow, N is the nutrient that is most likely to get lost, and there might be some N loss caused by leaching during the rainfall, while soil micronutrients were kept at a certain level.

The BLR had low P but the experimental soil had very high P content (217 ppm) by many years of organic fertilizers' application. If the experiment conducted in the low P content soil, this might be a problem. Therefore, it was suggested that P sources should be added to the BLR, or BLR, BSR, and compost should be used in combination.

It could be concluded that the application of biogas residues especially pig and chicken BLRs not only have the same function of common using compost, but also can shorten the growing period, shorten the time to market, and build soil fertility.

Choudhary *et al*. (1996) assessed the effect of swine manure on yield and composition and on soil and water quality. They pointed out that use of swine manure as a soil amendment for crop production is a practical method to solve disposal problems. The composition and effectiveness of swine manure as a source of plant nutrients depend on several factors including type of ration fed, housing system, and method of manure collection, storage, and handling. They also found that manure application increased soil N, P, K, Ca, Mg and Na. However, heavy or excessive application of manure increased leaching of NO_3-N, P and Mg. Swine manure was reported to be effective in increasing the yields of cereals, legumes, oilseeds, vegetables and pastures, and in increasing plant nutrient concentration, especially N, P and K. The efficient use of swine manure can be an agronomically and economically viable management practice for sustainable crop production in temperate regions such as the Canadian prairies where the swine industry is expanding rapidly.

Hartz *et al*. (2000) studied the nitrogen and carbon mineralization dynamics of manures and composts. They found an average of 15-16%, 6-7%, and 1-2% of organic N was mineralized in 12-24 weeks in manure, manure compost, and plant residue compost, respectively. Mineralization of manure C averaged 35% of initial C content in 24 weeks, while compost C mineralization averaged only 14%. Within 4 (compost) or 16 weeks (manure), the rate of mineralization of amendment C had declined to a level similar to that of the soil organic C. Therefore, organic fertilizers to soil as amendment should be added regularly. The BLR alone could reduce the soil P. It is necessary to combine the BLRs with other organic residues.

Table 5.6 Soil nutrient content in each treatment

Treatment	**pH**	**EC (µS/cm)**	**OM (%)**	**N (%)**	**P (ppm)**	**K (ppm)**	**Ca (ppm)**	**Mg (ppm)**
BLR								
Pig	7.49	166	2.92	0.171abc	223cd	278b	2293ab	685abc
Chicken	7.42	231	3.01	0.171abc	242bcd	424a	2780a	735abc
Cow	7.59	208	2.61	0.141bc	201d	423a	2527a	572c
Compost								
Pig	7.39	193	2.58	0.139c	315ab	346ab	1727b	764ab
Chicken	7.51	203	3.65	0.217a	367a	418a	2750a	840a
Cow	7.47	213	2.8	0.162bc	194d	401ab	2457a	688abc
BSR								
Pig	7.43	192	2.95	0.189ab	359a	317ab	2353ab	766ab
Chicken	7.54	201	2.91	0.180abc	298abc	437a	2517a	769ab
Cow	7.45	215	2.95	0.169abc	231bcd	360ab	2700a	689abc
Control								
Control	7.57	167	2.96	0.139c	216cd	305ab	2240ab	636bc

Means in a column followed by the same letters are not significantly different at 5% level by DMRT

5.4 Conclusions

Based on results of this study, suitable amounts of pig and chicken BLRs application could be the successful and optimal choices for short period organic vegetable growers, since they contain readily available essential plant nutrients.

The application also could improve plant growth, shorten the time to market, avoid insects' breakout, generate economic income, and improve the soil condition.

Suitable amounts of BSR and composts from pig and chicken also had satisfactory results. Cow BLR was not applicable for short-season crops, but large amounts of cow BSR could be applied.

Therefore, it is suggested that BSR, BLRs, and compost should be used in combination. If BLR is applied alone, other P sources are needed to be added to the soil.

CHAPTER VI

EFFECTS OF BIOGAS RESIDUES AND COMPOST FROM PIG MANURE ON ORGANIC RICE PRODUCTION

6.1 Introduction

Rice is the staple food for almost half of the world's population and approximately 90% of the world's rice is produced in Asia. BRs are widely applied to rice production in China. Studies show that residues from biogas production can increase rice yield, but most studies combined biogas residues with chemical fertilizers due to the higher yield demand under population pressure. Few studies have reported the effect of biogas residues as organic fertilizer sfor organic rice production.

Apart from the common organic fertilizer compost, biogas solid residue and liquid residue from biogas production contain all plant nutrients not only readily available for short-season crops, but also applicable for long-season growing rice. Organic rice may have potential for higher yield because balanced nutrients in biogas residues can improve the yield and can also help the establishment and development of rice straw to avoid lodging.

The objective of this study was to compare the effects of pig liquid and solid residues from biogas production and pig compost as organic fertilizers on organic rice production.

6.2 Materials and methods

The experiment was aimed to study the effect of biogas residues and compost as organic fertilizers for rice production in the paddy field. It was conducted at the SUT organic farm, in Nakhon Rachasima.

6.2.1 Organic fertilizers

The experiment had 4 treatments in RCB design with 3 replications. The treatments were as follows:

(1) Pig compost

(2) Pig BSR

(3) Pig BLR

(4) Control (no organic fertilizer)

The amount of organic fertilizer was based on the same amount of N (171 kg/ha). This amount of N was used according to the recommended rate of compost for organic rice production (≅5 t/ha). Amounts of other organic fertilizers were accordingly calculated. Compost and sludge were dried and applied as base fertilizer, while in the BLR treatment, the BLR was added twice after transplanting. Single rice seedlings were transplanted by following the prescription of the system of rice intensification (SRI) technique.

6.2.2 Rice

Rice cultivar *Patum-1* was used in this study and the density of rice plant was 16,000 plants/ha (12×20 plants in each plot of 3×5 m^2). Field plots were regularly irrigated and weeded during the growing period.

6.2.3 Rice samples

Rice samples in 2×2 m^2 were harvested to measure the yield and yield component as follows .

Tillering, above ground biomass, grain yield, grains per panicle, weight per panicle, good grain percentage, and 100-grain weight.

Rice grains and straws of the samples were oven-dried and ground to analyze the nutrient content and to estimate nutrient uptake.

6.2.4 Soil analysis

Soil samples in each plot of the rice field were taken at the depth of 15 cm, air dried, and sieved to analyze soil nutrient content.

6.2.5 Statistical analysis

Analysis of variance was performed by using the Statistical Package for the Social Sciences (SPSS) for Windows (version 14.0). Differences among means were compared with each other by Duncan's New Multiple Range test at 5% level of significance.

6.3 Results and discussion

6.3.1 Nutrient content in organic fertilizers

Nutrient analysis results showed that based on the same amount of N in organic fertilizers, P from the liquid residue was 24.7 kg/ha, which was 7-8.5 times lower than that in the sludge and compost (Table 6.1). However, K was the highest in the liquid which was 2-4 times higher than that in the compost and sludge. This might be due to the fact that K had the highest solubility during the digestion process. Ca was also the lowest in the BLR, which was 6 times lower than that in both compost and sludge. Mg, Na, other micro nutrients Fe, Mn, Zn, and Cu were close to each other, except that Cu in sludge was 5-6 times lower than that in both compost and liquid.

Table 6.1 Nutrient content in all the organic fertilizers based on the same amount of N application (kg/ha)

Organic fertilizer	N	P	K	Ca	Mg	Na	Fe	Mn	Zn	Cu
Compost	171	211.0	84.2	176.0	26.0	18.9	62.2	12.6	2.65	0.36
BSR	171	178.0	42.4	174.0	27.8	14.7	68.0	8.0	2.57	0.07
BLR	171	24.7	185.0	23.5	17.7	22.9	62.6	12.5	1.88	0.45

6.3.2 Growth, yield, and yield components of rice

The analysis results showed that yield and yield component in all organic fertilizer treatments were significantly different from the control group, but were not significantly different among the organic fertilizers except for 100-grain weight in pig liquid (Table 6.2). Organic fertilizers could promote the numbers of rice tillering from 19.5 to 22.8 tillers from each single seedling. Tillering in pig compost treatment was the highest, followed by pig sludge and pig liquid. Biomass in pig compost treatment was the highest. Pig BLR could promote the yield and weight per panicle which might be due to the higher amount of K in it. However, it had lower 100-grain weight, which might be due to N leaching, the small amount of P, and Zn in the pig BLR. In the BLR, even P was much less, but K was the highest among organic fertilizers. Higher amount of N and K application could stimulate the P uptake from soil, which might be the reason for the improvement of grains and weight of panicle.

Table 6.2 Yield and yield components of organic rice by using different organic fertilizers

Treatment	Tillering	Biomass (t/ha)	Grain yield (t/ha)	Grains per panicle (grain)	Weight per panicle (g)	Percent good grain (%)	100-grain weight (g)
Pig compost	22.8a	22.1a	4.16a	128ab	2.85ab	80.0	2.66a
Pig BSR	19.9ab	20.4ab	4.00ab	126ab	2.98ab	84.6	2.69a
Pig BLR	19.5ab	19.3ab	4.22a	141a	3.08a	85.8	2.51b
Control	16.1b	17.2b	3.72b	108b	2.01b	79.2	2.46b

Means in a column followed by the same letters are not significantly different at 5% level by DMRT

6.3.3 Nutrient uptake of rice

Nutrient uptake data showed that N and P in rice grain were 2 times higher than that in rice straw since N and P were components of starch, carbohydrate, and protein (Table 6.3). While K, Ca, Mg, Na, Mn, and Cu in rice grain were lower than that in rice straw as they were the components to build the strong straw tissue structures to support the gravity of rice grain. Fe in rice grain was higher than in rice straw. Zn in rice grain was also higher than that in rice straw. Zn can improve the transformation of carbohydrate by photosynthesis improvement in chlorophyll, and it can improve the formation of plant growth hormone such as auxin. It is also an enzyme activator.

Rice grain nutrient content indicated that there was no significant difference among the treatments except for Fe in pig sludge and pig liquid which was higher than that in compost and control, and 68 kg/ha of Fe application in the sludge was slightly higher than the other treatments. N and Na in compost treatment was higher than the other treatments. Zn in pig liquid treatment was the lowest.

Table 6.3 Nutrient content of organic rice grain

Treatment	N (%)	P (%)	K (%)	Ca (ppm)	Mg (ppm)	Na (ppm)
Pig compost	1.32	0.303	0.263	24.4	1460	252
Pig BSR	1.24	0.299	0.315	24.2	1500	226
Pig BLR	1.25	0.338	0.323	24.6	1520	221
Control	1.23	0.281	0.275	32.7	1340	220

Means in a column followed by the same letters are not significantly different at 5% level by DMRT

Table 6.3 Nutrient content of organic rice grain (Continue)

Treatment	Fe (ppm)	Mn (ppm)	Zn (ppm)	Cu (ppm)
Pig compost	6500b	119	522	105b
Pig BSR	8020a	137	372	225ab
Pig BLR	8930a	122	20.9	264a
Control	3960c	88.9	398	211ab

Means in a column followed by the same letters are not significantly different at 5% level by DMRT

In rice straw, N, P, and Zn were significantly different among the treatments, but K, Ca, Mg, Na, Fe, Mn, and Cu were not different among the treatments (Table 6.4). N in pig compost treatment was higher than other treatments. Straw N in BLR was lower because N in liquid form is readily available. It was easy to be used, but also easy to be lost by leaching in the open rice paddy field due to water movement, flooding, etc. Therefore, liquid residue should be applied continuously and separately in different stages to avoid leaching. P in pig compost and pig BSR were significantly higher than the control, but it was less in pig liquid treatment. These results were in agreement with the P analysis results in pig BLR that had relatively low P. K, Ca, Mg, Na, Fe, Mn, and Cu did not show any significant difference among the treatments. Only Zn in liquid treatment was lower than that in other treatments.

Table 6.4 Nutrient content of organic rice straw

Treatment	N (%)	P (%)	K (%)	Ca (ppm)	Mg (ppm)	Na (ppm)
Pig compost	0.840a	0.167a	2.85	3120	1760	942
Pig BSR	0.756ab	0.172a	2.76	2350	2160	979
Pig BLR	0.708b	0.100b	2.76	2900	1900	991
Control	0.725ab	0.092b	3.12	2510	2110	818

Means in a column followed by the same letters are not significantly different at 5% level by DMRT

Table 6.4 Nutrient content of organic rice straw (Continued)

Treatment	Fe (%)	Mn (ppm)	Zn (ppm)	Cu (ppm)
Pig compost	0.319	246	193a	408
Pig BSR	0.318	286	157a	279
Pig BLR	0.328	309	94.7b	553
Control	0.298	287	192a	512

Means in a column followed by the same letters are not significantly different at 5% level by DMRT

6.3.4 Soil nutrient content

Analysis of soil after the rice harvest showed that organic fertilization could improve soil fertility (Table 6.5). Soil pH reduced from 7.73 to 7.76 in all organic fertilizer treatments, but in the control it was the highest (7.87). Soil electrical conductivity (EC) in all treatments was lower than the control.

Soil organic matter (OM) in all organic fertilizers was higher than that in the control. It was the highest in pig compost treatment with 1.65%, followed by pig liquid (1.55%) and pig sludge (1.44%).

N was not significantly different among treatments. N was the highest in pig compost treatment (0.159%), followed by pig sludge and pig liquid. One reason could be the un-uniformity of pig compost during the composting. It was not completely digested under the aerobic fermentation. All of it was digested again in the paddy field under anaerobic conditions. Its digestion might be slower than the pig sludge which had been digested more completely during the biogas production process. The biogas generation experiment showed that pig manure could be digested in a period of 150 days. N in biogas liquid was readily to be used after the digestion. Due to less N uptake and less productivity in the control, N in the control was still high. It seemed that there had still potential to increase the rice yield, and the application of N (171 kg/ha) could increase since the yield of rice was still not very high. Higher application amount and balanced fertilization could help to reach the maximum yield if the rice lodging could be avoided.

P was significantly different among all treatments. P in paddy field plots was much lower than that in the upland, due to the continuous anaerobic digestion since the paddy filed was always submerged by irrigation water, and there might be nutrient loss due to water movement and flooding during the raining season. Since P in pig BLR was low, P in soil of pig BLR treatment was also low, it was the lowest in the control. P in pig compost and pig BSR treatment was 30 and 20 times higher than that in pig BLR treatment and the control, respectively. Therefore, P fertilizer might be the most critical deficient nutrient in organic rice production. It is suggested that suitable P be applied into organic rice, or P sources be found when applying pig BLR alone as an organic fertilizer. K, Ca, Mg, Na, and other micronutrients (Fe, Mn, Zn, and Cu) were not significantly different among all treatments.

Table 6.4 Soil nutrient content in organic rice field after harvesting

Treatment	pH	EC (µS/cm)	OM (%)	N (%)	P (ppm)	K (ppm)	Ca (%)
Pig compost	7.73	279	1.65	0.159	31.2a	124	0.507
Pig BSR	7.75	265	1.44	0.113	20.9ab	122	0.500
Pig BLR	7.76	265	1.55	0.104	1.34b	130	0.506
Control	7.87	343	1.12	0.159	1.13b	133	0.523

Means in a column followed by the same letters are not significantly different at 5% level by DMRT

Table 6.5 Soil nutrient content in organic rice field after harvesting (Continued)

Treatment	Mg (ppm)	Na (ppm)	Fe (ppm)	Mn (ppm)	Zn (ppm)	Cu (ppm)
Pig compost	416	197	75.4	89.6	3.69	0.828
Pig BSR	436	220	94.4	115	6.45	1.380
Pig BLR	408	173	63.4	76.5	3.02	0.658
Control	430	200	48.1	56.3	2.67	0.799

Means in a column followed by the same letters are not significantly different at 5% level by DMRT

6.4 Conclusions

It can be concluded that all the organic fertilizers (compost, BSR, and BLR) are suitable for organic rice production.

Apart from the compost which is a common organic fertilizer, solid and liquid residues from biogas production contained all plant nutrients were not only readily available for short-season crops, but were also applicable for long-season crops such as rice. BLR application, in particular, did not show much significant difference compared with compost and BSR.

BLR could also provide nutrients for long-season crops. It contained enough N and large amounts of K. The only concern was P and Zn shortages in the liquid.

Therefore, it is suggested that using of BLR should be combined with other organic fertilizers, or added with other organic P fertilizer sources such as P mine.

Based on the nutrient content analyzed in the organic fertilizers, balanced fertilization can be applied by the combination of different forms. According to the maximum nutrient requirement, the highest yield of organic rice can be achieved. Organic rice production still has a potential to increase the yield. Balanced nutrients uptake can also help the establishment and development of rice straw to avoid lodging.

CHAPTER VII

COMBINED EFFECTS OF *Azolla cristata* AND BIOGAS RESIDUES ON ORGANIC RICE PRODUCTION

7.1 Introduction

Azolla is a genus of water floating fern that can fix atmospheric nitrogen in association with the cyanobacterium *Anabaena azolla*. It is worldwide distributed in the rice growing regions of the tropical and temperate zones, and it has been used as a green manure in rice cultivation. The potential benefits of *Azolla* with symbiotic N_2-fixation cyanobacteria to enrich and maintain soil fertility have been aware of for centuries. In an organic system, *Azolla* is good for organic rice production. However, the growth of *Azolla* has to rely on the nutrient supply from organic fertilizers. Biogas residues have readily available nutrients that could be efficiently applied to *Azolla* in the organic rice field.

The objectives of this study were to compare the effects of BLR and BSR from biogas production, and the effects of *A. cristata* as a green manure combined with the BRs on organic rice production.

7.2 Materials and methods

7.2.1 *A. cristata*

The experiment was conducted at the SUT organic farm, in Nakhon Rachasima. *A. cristata* was used in this study as a green manure to combine with biogas residues in organic rice production.

7.2.2 Biogas residues

The experiment was conducted in a 2×3 factorial in CRD design with 3 replications. The experimental design was as follows:

Control= no fertilizer application

Factor 1 = green manure (*A. cristata*)

Factor 2 =2 forms of biogas residues (BSR, BLR)

The treatments were:

(1) *A. cristata* + BSR

(2) *A. cristata* + BLR

(3) *A. cristata* + control

(4) BSR

(5) BLR

(6) Control

The amount of organic fertilizer was based on the same amount of N (171 kg/ha). This amount of N was used according to the recommended rate of compost for organic rice production (≌5 t/ha). The amounts of other organic fertilizers were calculated accordingly. BSR was dried and applied as a base fertilizer, while in BLR treatment, BLR was added twice after transplanting. Single rice seedlings were transplanted followed by the prescription of the system of rice intensification (SRI) technique.

7.2.3 Rice

Rice cultivar *Patum-1* was used in this study and the density of rice plant was 18,000 plants/ha (9 plants in each tank with 0.5 m^2). *A. cristata* in the treatments were buried to the soil 4 times after they had the highest population, and around 10 g of new *A. cristata* population were added when the one in the tank was too old to propagate. The water level was maintained during the growing period.

7.2.4 *A. cristata* samples

A. cristata samples were taken to estimate the yield and nutrient uptake to study the interaction of *A. cristata* and biogas residues.

7.2.5 Rice samples

All the rice developing from the 9 plants in each cement tank ($0.5m^2$) was harvested and sampled to measure the yield and yield component.

Tillering, above ground biomass, grain yield, grains per panicle, weight per panicle, good grain rate, and 100-grain weight were measured.

Rice grains and straws of the samples were oven-dried and ground to analyze the nutrient content.

7.2.6 Soil analysis

Soil samples in the cement tanks were taken, air-dried, and sieved to analyze soil nutrient content.

7.2.7 Statistical analysis

Analysis of variance was performed by using the Statistical Package for the Social Sciences (SPSS) for Windows (version 14.0). Differences among means were compared by Duncan's New Multiple Range test at 5% level of significance.

7.3 Results and discussion

7.3.1 Nutrient content of biogas residues

Nutrient analysis results showed that based on the same amount of N in biogas sludge, P (24.7 kg/ha) was quite low in the BLR, which was 7-8.5 times lower than that in the BSR and compost. However, K was the highest in the BLR which was 2-4 times higher than that in the compost and sludge. This might be due to its higher solubility during the digestion process. Ca was also the lowest in the BLR, which was 6 times lower than that in both compost and sludge. Mg, Na, and other micro nutrients (Fe, Mn, Zn, and Cu) were close to each other except for Cu in BSR which was 5-6 times lower than that in both compost and BLR (Table 7.1)

Table 7.1 Nutrient content in all the biogas residues based on the same amount of N application (kg/ha)

Biogas residues	N	P	K	Ca	Mg	Na	Fe	Mn	Zn	Cu
Pig BSR	171	178	42.4	174.0	27.8	14.7	68.0	8.04	2.57	0.071
Pig BLR	171	24.7	185	23.5	17.7	22.9	62.6	12.5	1.88	0.451

7.3.2 Biomass and nutrient content in *A. cristata*

Biomass measurement and nutrient analysis results showed that based on the same amount of N application, fresh and dry biomass of *A. cristata* inoculated in pig BSR was the highest (50.9/1.89 t/ha) (Table 7.2).

N, K of *A. cristata* combined with both biogas residues was significantly higher than that in the control, indicating that the biogas residues not only improved the biomass of *A. cristata*, but also stimulated the nutrient uptake of *A. cristata* from the soil. N in the pig BSR was the highest, indicating that pig BSR could provide more nutrients and promote *A. cristata* growth and consequently stimulate the N fixation. As Lumpkin and Plucknett (1982) mentioned that *Azolla* can accumulate 2-4 or more kg of N/ha/day (equivalent to 10-20 kg of ammonium sulfate).

Again, P confirmed the results in all previous experiments that P in BLR treatment was very low. P is recommended to be added to the biogas BLR in order to meet the balanced fertilization if BLR is used. As in the previous chapter, K was high in both BLR and BSR, both of them were highly significantly different from the control.

Ca and Mg content might be affected by the shell of snail larva (as pests of *A. cristata*) since plenty of them were observed during the sample collection. Both of the BLR and control had higher Ca and Mg than that in the BSR. It might be also due to the uptake of other nutrients which inhibit the uptake of Ca and Mg.

Micro nutrients (Fe, Mn, Zn, and Cu) content in *A. cristata* combined with different treatments were not different. Singh (1981) found that every 100 kg of live *Azolla* contributes 0.5 kg N, 0.4 kg Ca, 0.5 kg Mg, and 0.6 kg Fe.

The N and other nutrients content in *Azolla* were the same as some organic fertilizers. It could also be uptaken by plants again when used as a green manure. Therefore, *Azolla* could replace organic fertilizers to a certain extent. Generally 6 tons of *Azolla* is comparable to 50 kg N. In Hazarika's study (2007), *Azolla* compost contains 1.51-3.50% N apart from other macro and micronutrients. N content was even higher in this study which was 2.92% in *A. cristata* alone, and 3.39% to 4.16% in BLR and BSR with *A. cristata* combination.

Table 7.2 Biomass and nutrient content of *A. cristata*

Treatment	Biomass fresh/dry (t/ha)	N (%)	P (%)	K (%)	Ca (%)	Mg (%)
A. cristata + Pig BSR	50.9/1.89	4.16a	0.641a	4.15a	2.45b	0.533b
A. cristata + Pig BLR	42.6/1.66	3.39bc	0.386b	3.98a	7.31a	0.580ab
A. cristata + Control	36.8/1.63	2.92c	0.163b	2.07b	6.77ab	0.671a

Means in a column followed by the same letters are not significantly different at 5% level by DMRT

Table 7.2 Biomass and nutrient content of *A. cristata* (Continued)

Treatment	Na (%)	Fe (%)	Mn (%)	Zn (ppm)	Cu (ppm)
A. cristata + Pig BSR	0.861ab	0.466	0.249	322	83.9
A. cristata + Pig BLR	0.689b	0.657	0.304	222	166
A. cristata + Control	0.935a	0.435	0.468	17.4	66.4

Means in a column followed by the same letters are not significantly different at 5% level by DMRT

7.3.3 Growth, yield, and yield components of rice

As Singh (1981) mentioned, *Azolla* could be used as dual cropping or as a green manure by using biomass at 5-10 ton/ha incorporated into the soil. Hazarika (2007) also mentioned that *Azolla* green biomass can be converted into *Azolla* compost by transferring them into an *Azolla* pit for a period of 15-20 days and thereafter can be used as a compost fertilizer in upland crops.

This study used it directly as a green manure with the rice. It was found that all biogas residues could promote the generation of rice tillering, the number from each single plant to 15.1-17.4 plants. All the tillering in biogas residues treatment was significantly different from that in the control, but no significance among the fertilizers was found (Fig. 7.1).

Biomass in both biogas residues was significantly different from that in the control (Fig. 7.2). Grain yield in BLR was lower than that in BSR (Fig. 7.3). It might be due to the nutrient imbalance (low P) in the BLR. As Pillai (1980) reported, an additional increase in rice to 200-500 kg/ha is due to *Azolla* alone. Singh *et al.* (1981) also found that during the dry season, incorporating green *Azolla* biomass at the rate of 20 t/ha in soil along with 50 kg N/ha before transplanting increased grain yield of rice by 98% over the control.

Grains per panicle, weight per panicle, and 100-grain weight were also significantly different with the control but no significance was found among the biogas residues (Fig. 7.4). In pig BLR, even P was less, but K was the highest among the BSRs. Higher K was the main cause for the improvement in the grains and the weight of panicle. When *A. cristata* was combined with biogas residues, more N uptake in the rice plant occurred during the tillering stage.

Similar to the BRs, *A. cristata* combined with biogas residues had effects on biomass, grain yield, grains per panicle, weight per panicle, and 100-grain weight. All of them in *A. cristata* combined with BRs were significantly different from treatment of *A. cristata* without any biogas residues application (Fig. 7.5-7.7).

It can be concluded that both biogas residues (BLR and BSR) are suitable for organic rice production. They can provide available nutrients to *Azolla*. Growth and N-fixation of *Azolla* were stimulated by biogas residues application. Consequently, rice growth and yield were mostly benefited by the combination of biogas residues and *Azolla* application.

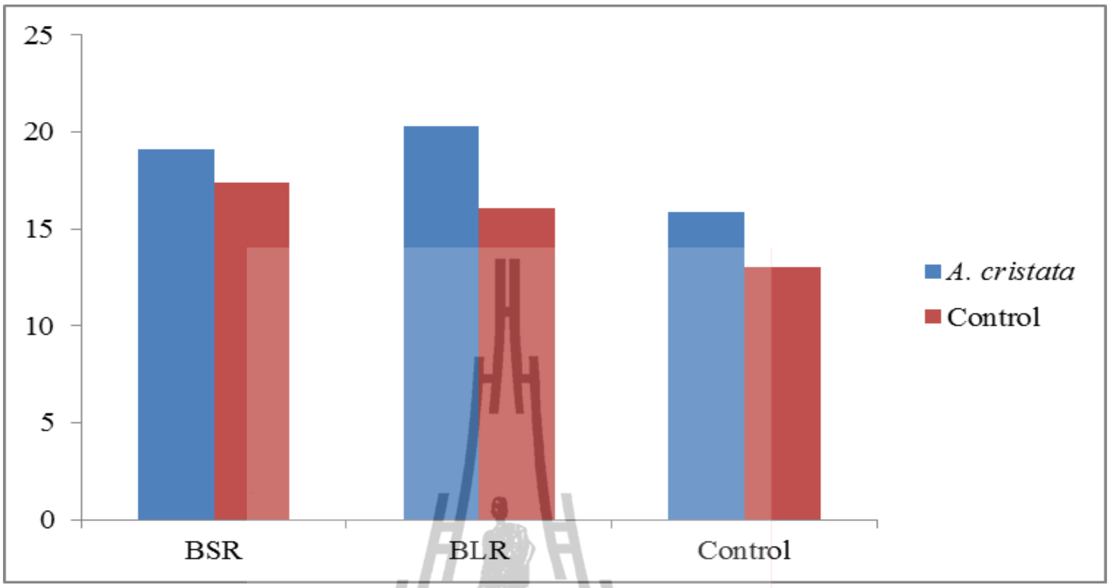

Figure 7.1 Tillering number in different treatments with and without *A. cristata*

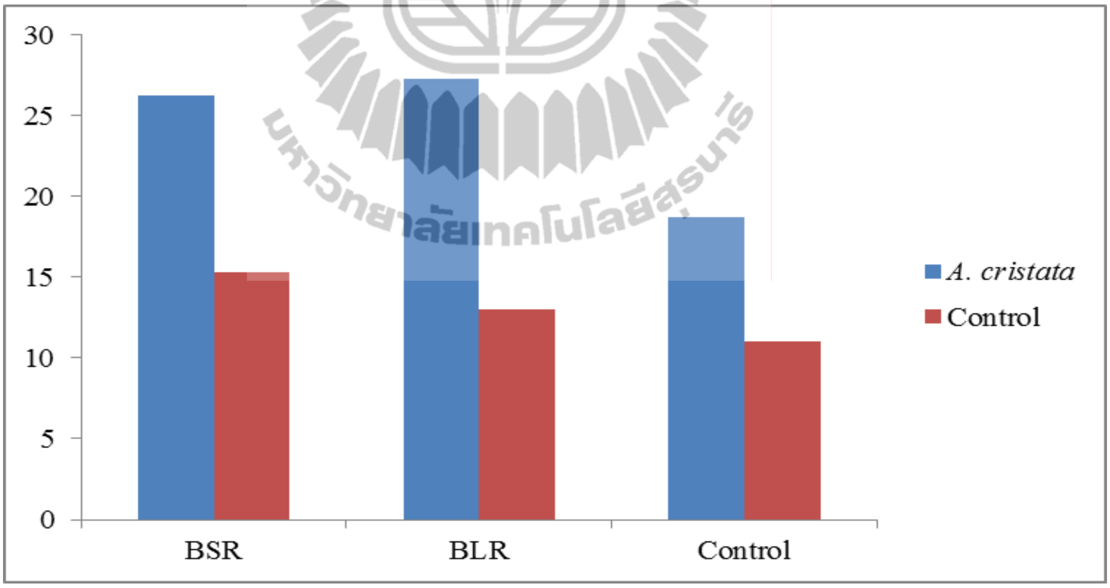

Figure 7.2 Biomass (ton/ha) in different treatments with and without *A. cristata*

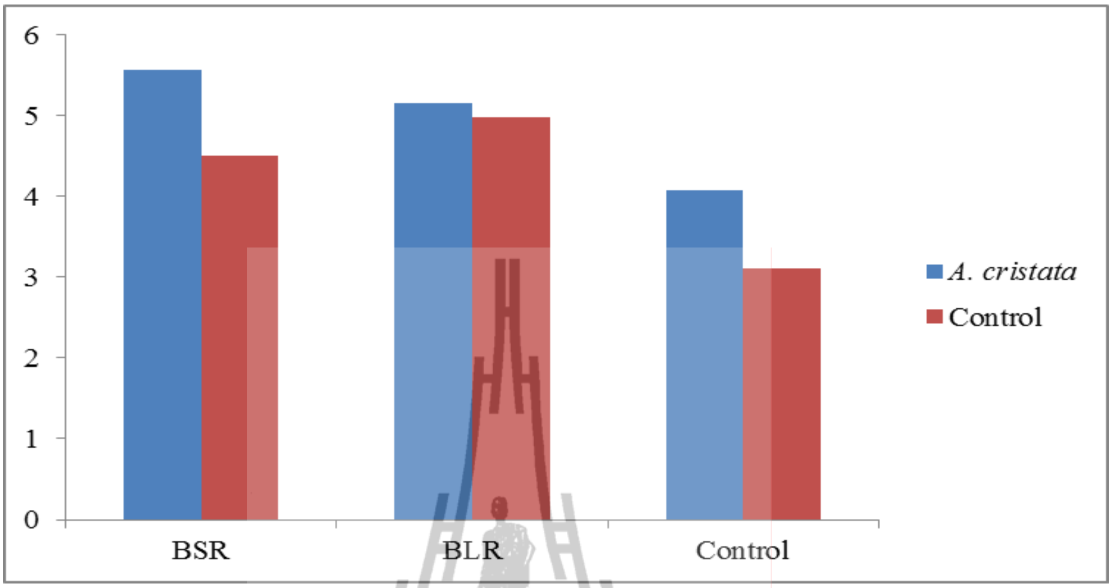

Figure 7.3 Grain yield (ton/ha) in different treatments with and without *A. cristata*

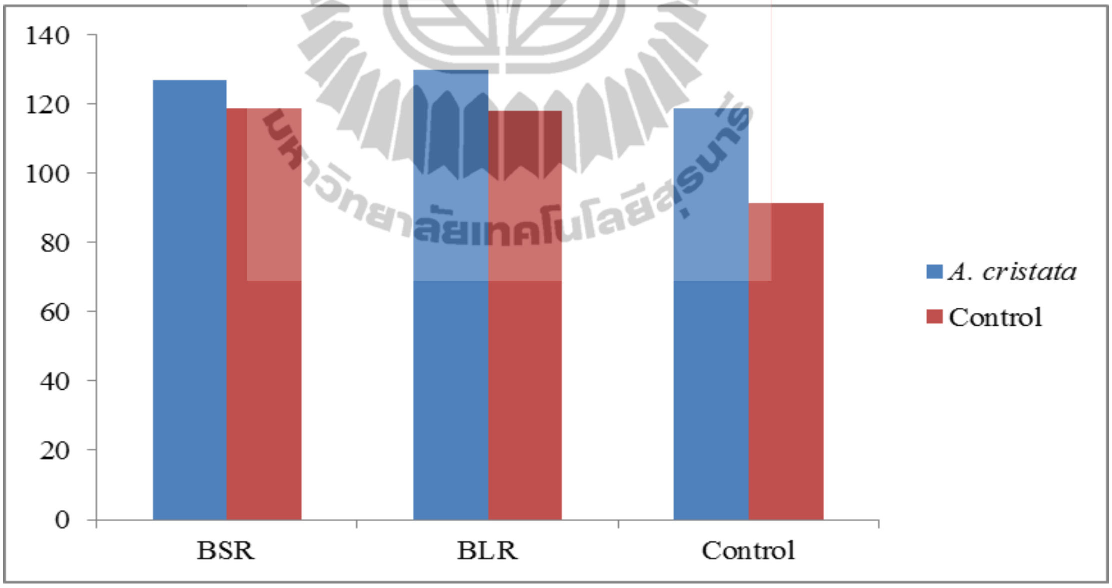

Figure 7.4 Grains per panicle in different treatments with and without *A. cristata*

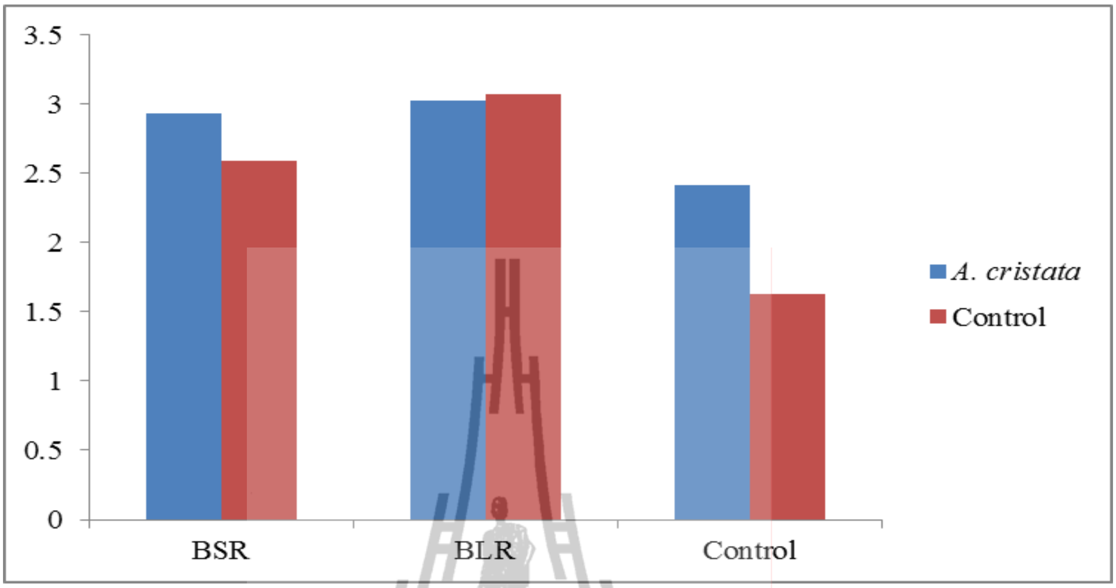

Figure 7.5 Weight per panicle (g) in different treatments with and without *A. cristata*

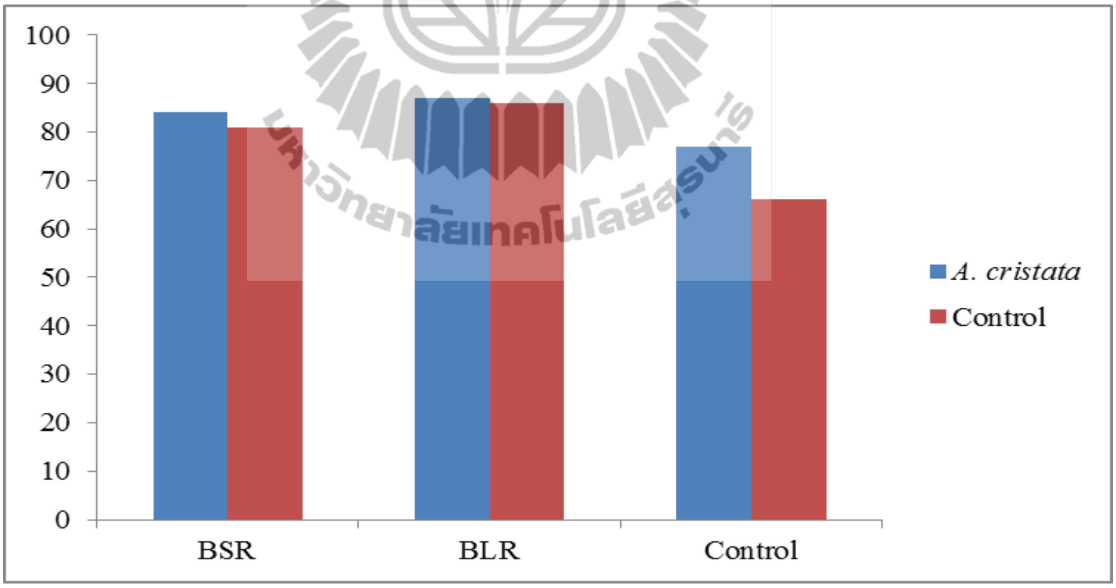

Figure 7.6 Percentage of good (%) grain in different treatments with and without *A. cristata*

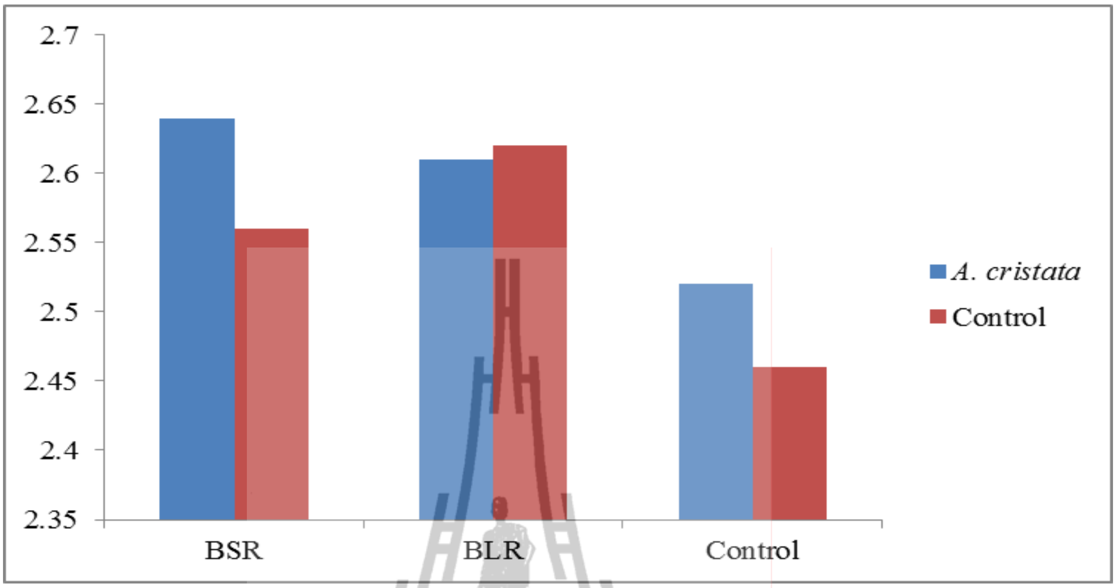

Figure 7.7 100-grain weight (g) in different treatment with and without *A. cristata*

7.3.4 Nutrient uptake of rice

Nutrient uptake in the rice grain was significantly different among the BRs and the control (Table 7.3). N was the highest in pig BLR without *A.cristata*. It was followed by pig BSR without *A.cristata*. In other treatments N was lower. N fixed by *A.cristata* and uptake by rice stimulated the uptake of P and K. They were higher in both pig BLR and pig BSR with *A.cristata* combination. In pig BLR they were the highest. Not only were P and K stimulated by N fixed from *A.cristata*, Ca and Mg were also higher in both BSR and BLR with *A.cristata* combination. They were significantly higher than that in the control. Na was highest in pig BSR and BLR. Fe, Mn, Zn, and Cu were also stimulated by *A.cristata*. All of them were higher in the BLR and BSR with *A.cristata* combination. In the treatment of *A.cristata* combined with biogas residues, N, K, Ca, Mg, and Na were not different in grain. P in all BRs was significantly higher than that in the control. Fe and Zn in BLR were the highest, and in all biogas residues they were significantly higher than in control.

P in rice straw from the biogas residues treatments was significantly higher than that in the control. Mg also was significantly higher than that in the control. Fe in BSR and BLR was higher than in compost and the control. Mn in the control and compost was significantly higher than in BSR and BLR. Similar to biogas residues without *A.cristata*. N in rice straw was significantly different, while P, K, and Ca were not significantly different. Mg in BSR was the highest and Na in the control was the highest, Fe in compost was the lowest, no difference in Mn, Zn, and Cu (Table 7.4).

Table 7.3 Nutrient content of organic rice grain without and with *A. cristata*

Treatment	N (%)	P (%)	K (%)	Ca (ppm)	Mg (%)	Na (ppm)
A. cristata + Pig BSR	1.08b	0.363ab	0.317ab	24.7ab	0.145a	272bc
A. cristata + Pig BLR	1.08b	0.384a	0.342a	24.8ab	0.116bc	206cd
A+ Control	1.10b	0.255cd	0.281bc	25.0a	0.135abc	225bcd
Pig BSR	1.19ab	0.278bcd	0.274bc	24.8ab	0.131abc	409a
Pig BLR	1.43a	0.282bcd	0.290abc	24.6b	0.136abc	349a
Control	0.990b	0.221d	0.309abc	24.6b	0.113c	176d

Means in a column followed by the same letters are not significantly different at 5% level by DMRT

Table 7.3 Nutrient content of organic rice grain without and with *A.cristata* (Continued)

Treatment	Fe (%)	Mn (ppm)	Zn (ppm)	Cu (ppm)
A. cristata + Pig BSR	0.202b	138.0ab	161b	553ab
A. cristata + Pig BLR	0.238a	150.0ab	261a	698a
A+ Control	0.140c	97.2b	117b	338b
Pig BSR	0.066d	136.0ab	197ab	505ab
Pig BLR	0.078d	148.0ab	166b	438ab
Control	0.048d	123.0ab	120b	433ab

Means in a column followed by the same letters are not significantly different at 5% level by DMRT

Table 7.4 Nutrient content of organic rice straw without and with *A.cristata*

Treatment	N (%)	P (%)	K (%)	Ca (%)	Mg (%)	Na (%)
A. cristata + Pig BSR	0.484c	0.137abc	3.14a	0.162	0.298a	0.111abc
A. cristata + Pig BLR	0.481c	0.158a	3.07ab	0.166	0.249cd	0.093c
A. cristata + Control	0.677ab	0.152ab	2.78abc	0.153	0.226d	0.157a
Pig BSR	0.634ab	0.173a	2.48c	0.198	0.262bc	0.085c
Pig BLR	0.596bc	0.101bc	2.84abc	0.141	0.242cd	0.159a
Control	0.727a	0.092c	2.63bc	0.150	0.238cd	0.155ab

Means in a column followed by the same letters are not significantly different at 5% level by DMRT

Table 7.4 Nutrient content of organic rice straw without and with *A.cristata* (Continued)

Treatment	Fe (%)	Mn (ppm)	Zn (ppm)	Cu (ppm)
A. cristata + Pig BSR	0.462ab	97.4b	205b	537ab
A. cristata + Pig BLR	0.498a	135.0b	320a	470ab
A. cristata + Control	0.432bc	74.4b	204b	413b
Pig BSR	0.395cd	167.0ab	239ab	455ab
Pig BLR	0.402cd	99.2b	242ab	605a
Control	0.350e	270.0a	190b	451ab

Means in a column followed by the same letters are not significantly different at 5% level by DMRT

7.3.5 Soil nutrient content

After the rice was harvested, the soil analysis results showed that N in the soil was not different among the treatments. P was relatively low in pig BLR treatment and the control, K and Ca in the compost was low, Mg in the compost and control was low, other nutrients (Na, Fe, Mn, Zn, and Cu) were low in the control, and Fe and Zn was also low in the BLR treatment.

With *A.cristata* inoculation, soil OM was lower and most nutrients content were lower than the treatments without *A.cristata* indicating that the uptake of N promoted the uptake of other nutrients, and it even could improve the soil microorganisms, accelerate the digestion process for organic matters during the rice growing (Table 7.5).

Table 7.5 Soil nutrient content in each treatment without and with *A.cristata*

Treatment	pH	EC (µS/cm)	OM (%)	N (%)	P (ppm)	K (ppm)	Ca (%)
A. cristata + Pig BSR	7.89	299	1.75	0.076a	94.90a	260e	0.477b
A. cristata + Pig BLR	7.98	290	1.38	0.021b	5.40b	299bcd	0.493b
A. cristata + Control	7.97	262	1.34	0.058ab	1.64b	269de	0.471b
Pig BSR	7.85	337	1.88	0.104a	94.50a	312b	0.617a
Pig BLR	7.95	352	1.46	0.081a	4.94b	348a	0.654a
Control	8.00	273	1.25	0.085a	0.98b	313b	0.624a

Means in a column followed by the same letters are not significantly different at 5% level by DMRT

Table 7.5 Soil nutrient content in each treatment without and with *A.cristata* (Continued)

Treatment	Mg (ppm)	Na (ppm)	Fe (ppm)	Mn (ppm)	Zn (ppm)	Cu (ppm)
A. cristata + Pig BSR	0.128a	180cd	94.4a	55.6ab	7.54ab	2.24a
A. cristata + Pig BLR	0.125a	191bc	63.4ab	55.4ab	3.73cd	1.37ab
A. cristata + Control	0.126a	159d	48.1b	52.7ab	2.08d	1.30ab
Pig BSR	0.116a	206ab	49.2b	47.7ab	7.91a	1.95a
Pig BLR	0.125a	216a	37.0b	63.3a	3.52cd	1.52ab
Control	0.082b	188bc	42.3b	58.0a	1.93d	1.32ab

Means in a column followed by the same letters are not significantly different at 5% level by DMRT

7.4 Conclusions

7.4.1 Effects of BRs on growth and yield of *A. cristata*

Biogas residues could provide nutrients to *A.cristata*. The *Azolla* population and biomass in pig BSR were the highest, followed by BLR, indicating that biogas residues could provide available nutrients to *Azolla* and promote N-fixation.

7.4.2 Effects of BLRs on rice yield

BLRs from biogas production contained all plant nutrients not only readily available for short-season crops, but also be applicable for long-season rice. According to the experiment results, it contains enough N, big amount of K. The only concern is the P shortage in the BLR. Therefore, it is suggested that it should be used with other BRs or other organic P fertilizer sources such as P mine.

7.4.3 Effects of combination *A. cristata* with biogas residues on rice yield

N fixed by *A.cristata* as a green manure from the atmosphere could be taken by rice, and the N uptake promoted the uptake of other nutrients from the biogas residues and soil, thus could increase the rice yield. Propagation of *Azolla* could reduce the cost for organic fertilizers. Other nutrients should be provided for *A.cristata* to propagate and accumulate the population.

7.4.4 Balanced fertilization, and combination of *A. cristata* with BRs on organic rice production

Based on the data analyzed for nutrient content and experimental data, it can be calculated that the optimal balanced fertilization of biogas residues combination with *A.cristata* instead of any single biogas residues, the highest yield could be achieved for organic rice production. Balanced nutrients uptake for rice also could help the development of rice straw to avoid lodging. The results also showed that *A.cristata* and biogas residues combination could reduce the cost for organic fertilizers.

CHAPTER VIII

CONCLUSION AND RECOMMENDATION

This study links the biogas production and organic farming. The main objectives of the BRs as organic fertilizers application on organic crops have already been accomplished. The characteristics and the innovation of the important results of the study are as follows :

1. The study of biogas generation from pig, chicken, and cow manure experiment found that the Chinese fixed dome digester could be successfully applied in tropical conditions for manures treatment and organic fertilizers production. Pig manure was the best manure material in gas generation duration and in terms of the amount of biogas, chicken manure had the highest methane composition, but lasted shorter than the pig manure. Cow manure was not good as pig and chicken manure. It is suggested that the chicken manure and cow manure be mixed to simulate the C/N as the pig manure or that other materials with high N content be added. All nutrients had dynamics in all the manures. BLRs from pig and chicken manures contained a large amount of available N. Most N was in NH_4^+ form. NH_4^+ increased, while NO_3^- decreased after hydrolysis phase. P, K, Ca, Mg, and other micronutrients also increased in the BLRs. Among them, P was found relatively low in all BLR due to the active P reacting with other nutrients and precipitated in the BLR. Therefore, the shortage of P in BLR should be taken into consideration when appling BLRs as an organic fertilizer alone. In the BSR, more than 10% of organic matter was digested by

the anaerobic bacteria, and all nutrients decreased due to the digestion, degradation, dissolving, and releasing into the BLR.

2. The nutrient availability evaluation results of BLR in hydroponics showed that BLRs could be applied in organic hydroponics. It is found that pig BLR with EC 2.5 and chicken BLR with EC 1.5 were applicable for both resistant crop morning glory and sensitive crop lettuce, while cow BLR was not applicable. Morning glory showed higher resistance to higher EC. Among the BLR, pig manure BLR was the best material for organic hydroponic vegetable production, chicken BLR needed a big amount of water to dilute due to its higher salinity, and other nutrients i.e. P could be sufficient at high dilution levels. EC is the critical indicator instead of water dilution level for BLRs in organic hydroponics. However, issues of alkalinity, dominant NH_4^+ nitrogen form, lower dissolved O_2 level in the BLR, pathogen, and algae growing have to be aware. Further studies to solve these problems are recommended.

3. The results of biogas residues application as organic fertilizer showed the importance of both biogas BLR and BSR for short-season vegetables, and the results also indicated that suitable amounts of pig and chicken BLRs with readily available essential plant nutrients application could be successfully applied. The application could also improve plant growth, shorten the time to market, avoid insects' breakout, generate economic income, and improve soil conditions. Suitable amounts of BSR and composts from pig and chicken led to satisfactory results. Cow BLR was not applicable for short-season crops, but a large amount of cow BSR could be applied. Therefore, it is suggested that BSRs, compost, and BLRs be combined. BSRs and composts can be used as basal organic fertilizers, and BLRs can be sprayed to improve the growth of vegetables. If BLR is used alone, P sources should be considered to be added to the soil.

4. The evaluation of the BRs as organic fertilizers for organic rice a long-season crop showed that all the organic fertilizers were suitable for organic rice production. Besides the compost (common organic fertilizer), BSR and BLR contained all plant nutrients not only readily available for short-season crops, but also applicable for long-season rice. BLR could also provide enough nutrients for long-season crops. The only concern was the P and Zn shortage in the BLR. Therefore, it is suggested that it be conbined with other organic fertilizers, or other organic P fertilizer sources.

5. The interaction between green manure *Azolla* and biogas resisudes on organic rice in cement tanks were examined. Interaction effcts were found between green manure (*Azolla*) and organic fertilizers (BLRs and BSRs) on organic rice production. Organic fertilizers could provide nutrients for *Azolla*, propagate and accumulate the population. *Azolla* could harness atmospheric N, both of which improved with each other, and consequently improved the organic rice production.

Overall, the results of the study indicated the importance of BRs as organic fertilizers on organic crops and the benefit of biogas generation from anaerobic fermentation of animal manures in the Chinese fixed dome digester.

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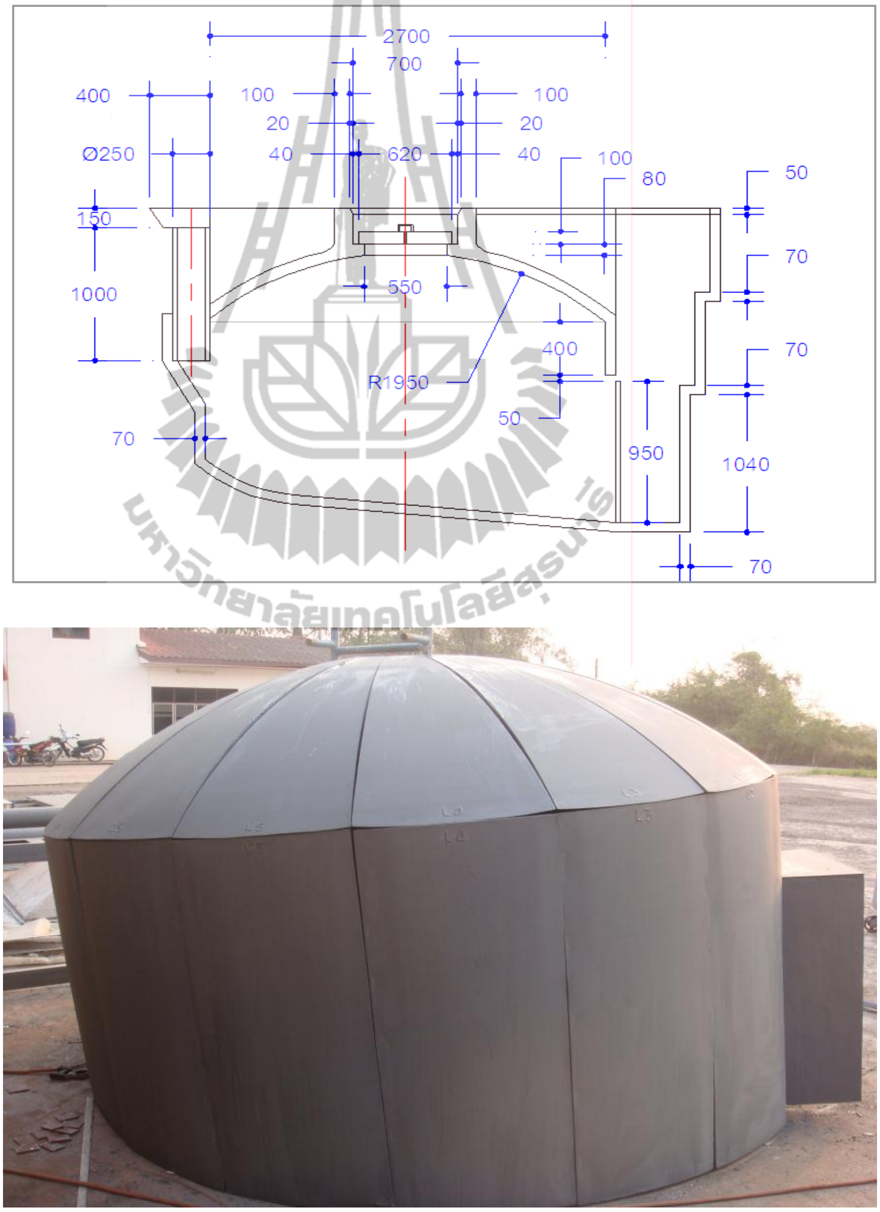
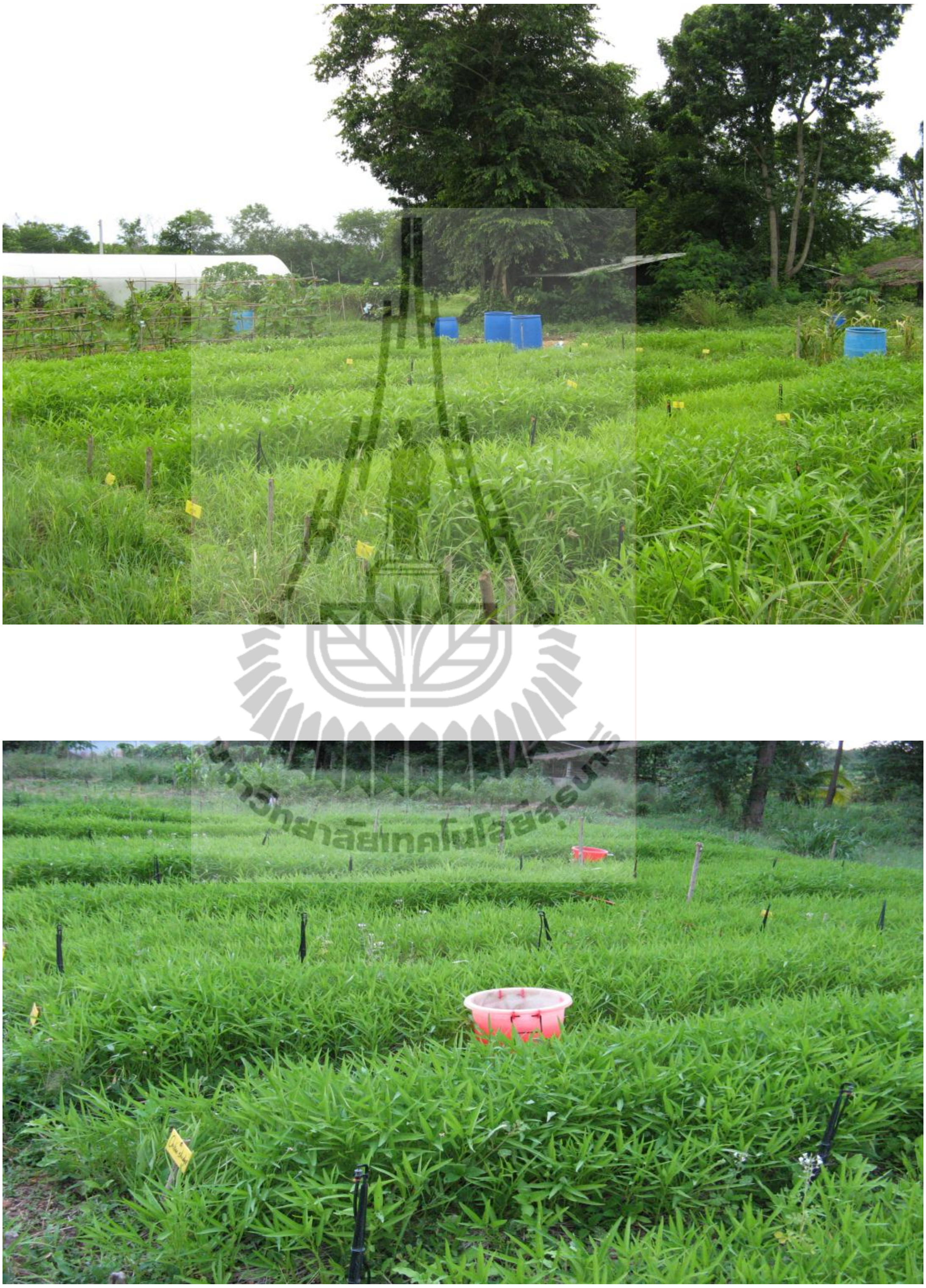
APPENDICES

I. ATTACHED FIGURES



Attached figure 1 : the biogas digester and steel frame

Attached figure 2 : Organic hydroponics for morning glory and lettuce



Attached figure 3 : Organic vegetable in the field

Attached figure 4 : Organic rice in the field and in cement pot

II. Chemicals and steps for NH_4^+ and NO_3^- analysis in liquid organic fertilizer were as follows

1. Put 75 ml of sample in distillation tube and add 1 g of MgO 5 ml. and put in the distillator

2. Pipette 25 ml of 4 % boric acid in 125 ml E-flask, add Mixed indicator 5 drops (the solution turn red-purple), put the E-flask in the distillator to receive 150 ml of the solution from the distillator (about 2 min) the solution will turn green (contain ammonium)

3. Take the distillation tube from the distillator and add 1 g of Davarda's Alloy and put the tube in the distillator again

4. Distill the sample again and add 25 ml of 4% boric acid in the 125 ml E-flask add 5 drops of Mixed indicator (the solution will turn red-purple), put the E-flask in the distillator to receive 150 ml of the solution from the distillator (about 2 min) the solution will turn green (nitrate to ammonium)

5. Titrate the solution in no 2 and 4 with 0.01 N HCL, at the end point the solution will turn to red-purple

6. At the same time prepare blank and follow the same procedure of the sample

7. Calculation

$$NH_4^+ \text{ and } NO_3^- \text{ (ppm)} = \frac{N(T-B)\times 14\times 1000}{A}$$

A= ml. of sample

B= ml. of HCl titrated with blank

T= ml.of HCL titrated with sample

N= normality of HCl

III. Chemicals for NH_4^+ and NO_3^- analysis in dry organic fertilizer were as follows

1. Weight 10 g of sample and put in 125 ml E-flask

2. Add 2 N 50 ml. KCl and shake for 1 h and filtrate with filter paper No 5

3. Pipette the solution in no 2 and put in distillation tube, add 5 ml of 12% MgO, put the tube in the distillatory

4. Pipette 4 % boric acid 5 ml and put in 125 ml E-flask and add Mixed indicator 2-3 drops the solution turn red-purple, put the E-flask in the distillatory to receive 30 ml of the solution from the distillator (about 2 min) the solution will turn green (ammonium)

5. Take the distillation tube from the distillator and add 2 g of Davarda's Alloy and put the tube in the distillator again

6. Pipette 5 ml of 4 % boric acid in the 125 ml E-flask add 2-3 drops of Mixed indicator the solution will turn red-purple, put the E-flask in the distillatory to receive 30 ml of the solution from the distillator (about 2 min) the solution will turn green (nitrate to ammonium)

7. Titrate the solution in no 4 and 6 with 0.05 N HCL, at the end point the solution will turn to red-purple

8. At the same time, prepare blank and follow the same procedure as the sample

9. Calculation

$$NH_4^+ \text{ and } NO_3^- \text{ (ppm)} = \frac{N(A-B)\times D\times 0.014\times 10^6}{C\times E}$$

A= ml. of HCl titrated with sample

B= ml. of HCl titrated with blank

N= normality of HCl

C= ml. of sample

D= ml. of the distilled solution

E= weight of sample (g)

IV. Chemicals for N analysis in organic fertilizers (both liquid and dry) and plants samples were as follows

Digestion (wet digestion) : digest organic substrate and converted to inorganic substrate

(For N analysis) : H_2SO_4 + mix catalyst (Na_2SO_4 + $CuSO_4$ + Se)

(For P K Ca Mg S Fe Mn Zn Cu analysis) : HNO3/HClO4 (5:3)

Chemicals

1. Analytical balance
2. Muffle furnace
3. Digestion block
4. Hot plate
5. Digestion tube
6. Volumetric flask 50, 100, 1000, 2000 ml.
7. Pipette 5, 10 ml.
8. Filter paper No. 42
9. H_2SO_4 98% (for N analysis)
10. Mixed acid : HNO_3 + $HClO_4$ (Conc.) (5:3) (for P K Ca Mg S Fe Mn Zn Cu analysis)
11. Mix catalyst : weight Na_2SO_4 500 gm. + $CuSO_4$ 5 gm. + Se 2.5 gm. blend and mix

Steps of wet digestion for N analysis

1. Weight organic fertilizers and plant samples 0.2000-0.3000 gm. put in digestion tube (5 ml. for liquid)

2. Add mixed catalyst 0.2-1.0 gm. and concentrated H_2SO4 10 ml predigest 1 night in digestion block

3. Adjust temperature to 100°C and gradually increased to 380°C (380°C for liquid), until solution clear.

4. After finish digestion, leave the solution cool down to room temperature.

5. Add distill water, mix, and adjust volume to 50 ml., keep the solution in plastic bottle for N analysis (also can directly analysis in the digestion tube).

Steps of wet digestion for P K Ca Mg S Fe Mn Zn Cu analysis

1. Weight organic fertilizers and plant samples 0.2000-0.3000 gm. put in digestion tube (5 ml. for liquid)

2. Add mixed acid (HNO_3 + $HClO_4$ (Conc.) (5:3)) 5 ml predigest 1 night in digestion block

3. Adjust temperature to 100°C and gradually increased to 200°C.

4. After finish digestion, leave the solution cool down to room temperature.

5. Add distill water, filtrate, and adjust volume to 50 ml., keep the solution in plastic bottle for P K Ca Mg S Fe Mn Zn Cu analysis.

N analysis (distillation)

1. Pipette 20 ml (or directly use digested solution) samples solution put in digestion tube

2. Add 10 ml 32% NaOH (320 gm + water = 1000 ml.) and distill (5 ml for plants samples solution) (The $(NH_4)_2SO_4$ will be converted to NH_3)

3. Collect the distilled solution with 20 ml 4% H_3BO_3 (40 g + water =1000 ml.) and 3-4 drops of mixed indicator (turn to green) until get 20 ml of distilled solution (about 5 min) (plants samples could be 3 min).

4. Titrate the distilled sample with 0.1N HCl (8.8 ml HCl + RO = 1000 ml) until the end point (turn to pink).

5. Also make a reagent blank from stem 1.

6. Calculation

$$N (\%) = \frac{(A - B) \times C \times D \times (14/1000) * \times T \times 100}{W \times D}$$

A= ml. of HCl titrated with sample

B= ml. of HCl titrated with blank

C= normality of HCl

D= ml. of the distilled solution sample

W= weight of sample (gm)

*= gm equivalent weight of nitrogen

P analysis for organic fertilizers and plant samples

1. Baton's reagent

    1.1 Ammonium molybdate ($(NH_4)_6MO_7O_{24} \cdot 4H_2O$) (25 gm + RO 400 ml.)

    1.2 Ammonium meta-vanadate (B-NH_4VO_3 1.25 gm + hot water 300 ml.), cool down, then add HNO_3 250 ml.

    1.3 Ammonium molybdate + Ammonium meta-vanadate to1,000 ml.

2. Prepare standard P (50 ml.) (1000 ppm 5 ml + DI =50 ml.)

    0 ppm (DI water)

2 ppm (100 ppm 1 ml. + DI)

4 ppm (100 ppm 2 ml. + DI)

6 ppm (100 ppm 3 ml. + DI)

8 ppm (100 ppm 4 ml. + DI)

3. Analyze

Take 5 ml. sample solution to test tube, add Baton's reagent 5 ml., add RO 15 ml., wait for 30 min., analyze by spectrophotometer in 420 nm.

4. Calculation

$$P(\%) = \frac{I \times 100 \times \mathrm{df} \times 100}{10^6 \times S}$$

I= ppm reading converted (= slope × absorbance)

df= dilution factor

S= weight of organic fertilizers or plant samples digested (gm)

K, Ca, Na analysis for organic fertilizers and plant samples

1. Prepare standard K (50 ml.) (1000 ppm 5 ml + DI =50 ml.)

0 ppm (DI water)

100 ppm (1000 ppm 5 ml. + DI)

200 ppm (1000 ppm 10 ml. + DI)

300 ppm (100 ppm 15 ml. + DI)

400 ppm (100 ppm 20 ml. + DI)

2. Prepare standard Ca (50 ml.) (1000 ppm 5 ml + DI =50 ml.)

0 ppm (DI water)

100 ppm (1000 ppm 5 ml. + DI)

200 ppm (1000 ppm 10 ml. + DI)

3. Prepare standard Na (50 ml.) (1000 ppm 5 ml + DI =50 ml.)

   0 ppm (DI water)

   100 ppm (1000 ppm 5 ml. + DI)

4. Analyze

   Analyze the 50 ml. sample solution directly under spectrophotometer.

5. Calculation

   K, Ca, Na (%) = $\frac{\text{Re}\,ading \times originalsolution \times \text{df} \times 100}{10^6 \times Weight(gm.)}$

   df= dilution factor

Mg, Fe, Mn, Zn, Cu analysis for organic fertilizers and plant samples

Same as K, Ca, Na, analyze under AAS

Mg, Fe, Mn, Zn, Cu (ppm) = $\frac{\text{Re}\,ading \times originalsolution \times \text{df} \times 10^6}{10^6 \times Weight(gm.)}$

BIOGRAPHY

Mr. Li Yurong was born on July 03, 1972 in Guizhou province, P. R. China. He received his Bachelor's degree from the Department of Biology, Guizhou Normal University in 1994. He started his career in Guizhou Academy of Agricultural Science (GAAS), joined in projects on soil and fertilizer, balanced fertilization, soil erosion protection projects funded by the Canadian International Development Agency (CIDA), the Phosphate Institute/Potash and Phosphate Institute of Canada (PPI/PPIC), the International Development Research Center, Canada (IDRC), and International Board for Soil Research and Management (IBSRAM) in Thailand.

In 2001, he won a scholarship from the Ford Foundation, cooperated by Winrock International to pursue a Master's Degree in Environmental Science in the School of Environment Science and Management (SESAM), University of Philippines, Los Baños (UPLB), the Philippines.

He continued working on the IBSRAM project after graduation from UPLB in 2003, and joined the International Water Management Institute (IWMI) network, also carried out soil loss protection and rural development projects financed by the International Crop Research Institute for Semi-Arid Tropics (ICRISAT). In 2004-2007, he was invited to work as an agricultural consultant with a French NGO, Initiative Development (ID), for rural development in the remote Weining County, Guizhou.

In 2006 and 2007, he was interviewed by Assoc. Prof. Dr. Jutharat Attajarushit and Dr. Sopone Wongkaew, and was accepted to the Ph.D. program under the supervision of Dr. Sodchol Wonprasaid at the School of Crop Production Technology, SUT, Thailand.