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Design and Evaluation of Biomass Residue Recycle System for Sustainable Crop Cultivation based on Material Flow Analysis

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Abstract

Analysis of material and elemental flow was performed in the farm land and crop processing mill of plantation. Elemental flow in the biomass residue and wastewater recycle process such as composting, methane fermentation and cattle fattening was analyzed as well. Procedure to design and to evaluate the biomass residue recycle system for carbon sequestration and for soil fertility improvement toward sustainable crop cultivation was proposed based on the experimental approach in the plantations of sugarcane, oil palm and cassava.

1. Introduction

Followings are the background and motivations of this research. 1) Serious deforestation and impact on ecosystem in tropical area brought by the expansion of plantation to meet the increased demand for the biomass materials and biomass energy. 2) Significant and serious mineralization of organic matter in soil of agriculture field after deforestation followed by reclamation works, which brings the huge emission of carbon dioxide from farm land, and then reduced content of organic matter in soil brings the decrease in soil fertility and thus the crop yield. 3) Discharge of greenhouse gas from the treatment and disposal of biomass wastes and wastewater discharged from crop processing mill. Biomass residue such as empty fruits bunch is not effectively utilized and huge greenhouse gas such methane and carbon dioxide are discharged from lagoon which is storing the mill wastewater for several months before discharging the effluent into water body.

The final objective of this research is to ensure the sustainability of agriculture and ecosystem services without compromising environmental integrity. Soil organic carbon sequestration will increase the soil fertility, and thus the yield of agricultural crops, while the greenhouse gas discharge is reduced. Biomass residues and wastewater discharged from biomass processing mill can be utilized as organic matter for agricultural field and the energy to operate the mill. Wise and effective use of the biomass residues and the wastewater can promote both the increase of crop yield and the reduction of greenhouse gas discharge. Energy self sufficiency is realized as well by utilize the biomass residues.

2. Experimental

Figure 1 shows the configuration of biomass residue recycle system under consideration by our research group. The following items have been done through this research; 1) optimal cultivation and fertilizer management of soil with biomass residue recycle was explored through the experimental practice in the sugarcane and cassava field. 2) Material and energy flow analyses both in the crop processing and in the biomass residue recycle system were done in the mills of sugarcane, tapioca and palm oil. 3) Procedure to design biomass residue recycle system was proposed based on the results obtained in the above.

Material flow analysis in mill of tapioca, palm oil and sugarcane has been carried out. The amount and property of wastes such as biomass residues and wastewater were clarified as well as the elemental flow of organic carbon and nitrogen. Elemental flow analysis was carried out in composting, methane fermentation, livestock fattening, and so on. Elemental flow of organic carbon and nitrogen was explored in cultivation field of sugarcane and cassava with different cultivation management such as tillage and fertilization to elucidate the appropriate management for the improvement of carbon sequestration and soil fertility. These experimental research have been carried out in the plantations with crop processing mill in Lampung province, Indonesia.

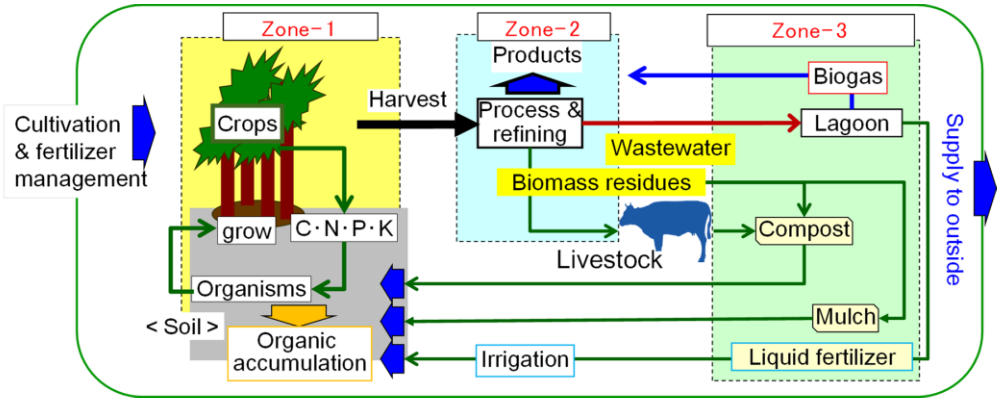

Fig. 1.Biomass residue recycle system for plantation.

3. Results and discussion

3.1Material flow in crop processing mill

Figure 2 shows the material and carbon flow observed in palm oil mill with the processing capacity of 40 ton fresh fruit bunch (FFB, hereafter) per one hour. The result shows 60% of organic carbon in FFB was recovered as products such as crude palm oil (CPO, hereafter) and kernel oil, while the other 40% organic carbon was discharged as biomass residues such as mesocarp fiber, empty fruit bunch (EFB, hereafter), palm kernel shell, and wastewater. It is noted that mesocarp fiber and palm kernel shell are effectively used as an only fuel of boiler to supply steam and electricity for the mill operation.

Figure 3 shows the observed results of material, organic carbon and nitrogen flows in small scale tapioca mill. One ton of raw cassava contains 164kg organic carbon and 1.26kg nitrogen in it. It is noted only 44% of organic carbon is recovered as tapioca, a product of cassava, while the other 56% of organic carbon in the raw cassava appeared in the biomass residues, such as onggok (cassava fiber) and elot, and the wastewater evenly. It can be known that the wastewater of tapioca mill will be suitable for the methane fermentation to recover energy and for the reduction of GHG discharge.

Figure 4 shows the material and energy flow observed in a sugarcane mill. The data shows the quantity per one hectare of farm land in the plantation. Dead leaves of cane are burned in the farm land before the harvesting by manpower. 26 tons of head part, raw leaf and litter of sugarcane is plowed into the soil of one hectare sugarcane field after harvesting. Almost all bagasse is used as the fuel of boiler for the electric power and steam generation.

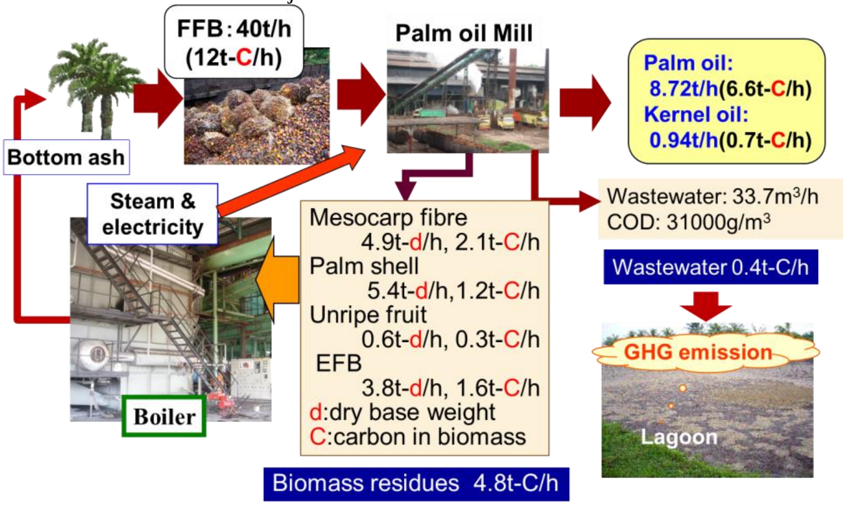

Fig.2 Material and organic carbon flow observed in palm oil mill

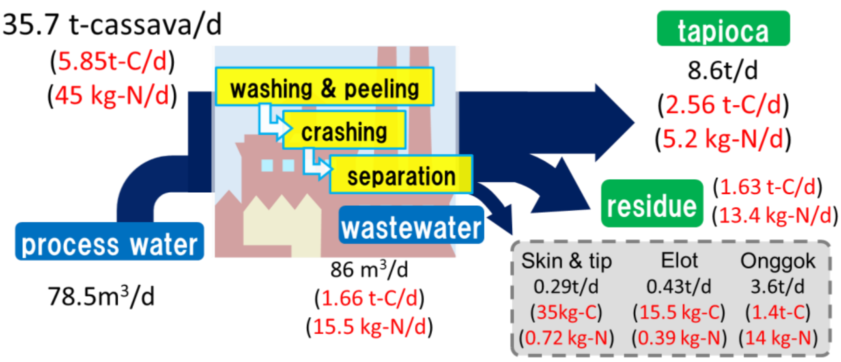

Fig.3 Material and organic carbon flow observed in palm oil mill

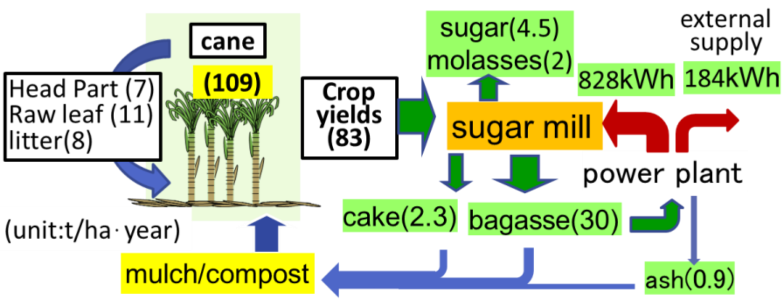

Fig.4 Material and energy flow observed in sugar mill

Based on the material flow data observed in the crop processing mill, the amount of organic carbon discharged into the wastewater has been clarified. Figure 5 shows the amount of organic carbon discharged from each processing mill of cassava, sugarcane and oil palm per unit amount of each product, respectively. It should be noted that huge organic carbon discharged from tapioca production. Self-sufficiency ratio in the primary energy supply is almost 100% in the sugar mill and palm oil mill, while the almost all energy to operate the mill is supplied from external source in tapioca mill. There is a small demand for the additional energy brought by methane fermentation of wastewater in sugar mill and palm oil mill. Biogas production from the cassava processing wastewater through the methane fermentation can contribute the sufficient energy supply to the mill, the pollutants removal from the wastewater and thus the reduction of greenhouse gas discharge from the lagoon storing the mill effluent. Researchers and engineers should pay their attention to develop suitable technologies and systems to actualize the above mentioned tasks.

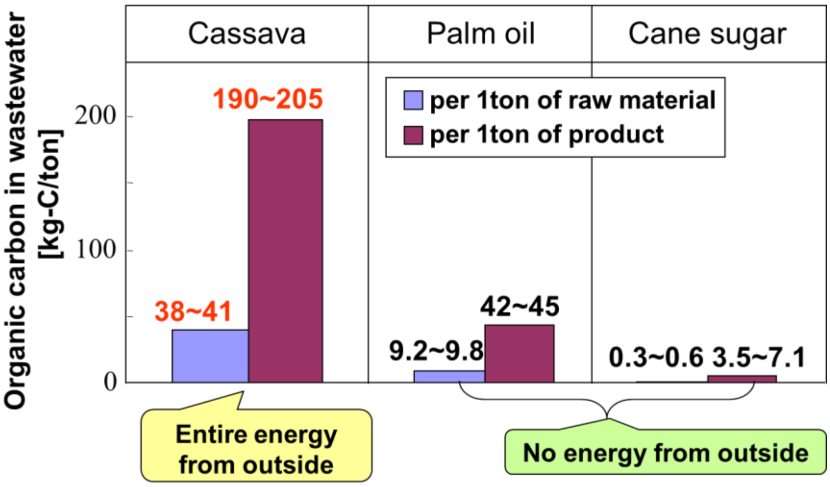

Fig.5 Discharge of organic carbon into wastewater from processing mill of crops

3.2Material flow in recycle process of biomass residue and wastewater

The effluent of crop processing mill is usually stored in the lagoon for long time. Tropical climate and the long retention time in the lagoon as long as two to three months is a suitable condition for the anaerobic digestion of effluent to produce methane and carbon dioxide. It can be readily understood that huge greenhouse gas is discharged from the lagoon and thus the biogas can be effectively utilized for the energy of the mill or for the outside of plantation.

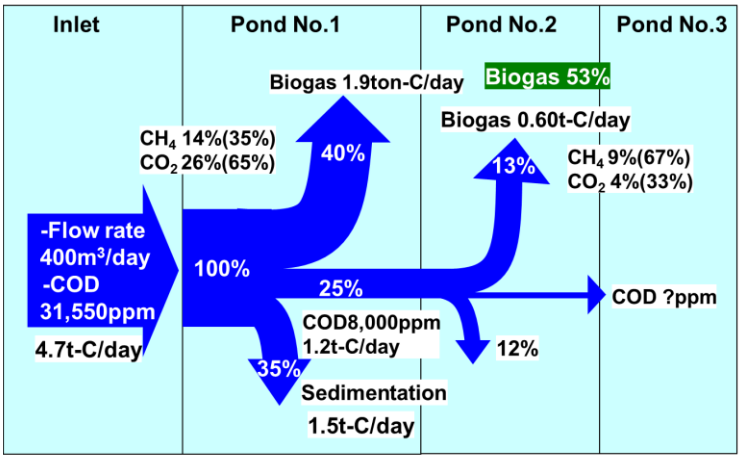

Fig.6 Observed carbon flow in the lagoon of palm oil mill

Figure 6 shows the carbon flow in the lagoon of palm oil mill. Observed results shows 53% of organic carbon in the wastewater of palm oil mill was converted to methane and carbon dioxide in the lagoon.

Figure 7 shows that processing of one ton cassava to produce tapioca in the mill discharges 2.4 m^3 wastewater with COD of 9400mg/L and Ttotal-Nitrogen (T-N hereafter) of 180 mg/L. 5.02m^3 carbon dioxide and 6.93 m^3 methane are produced respectively from the lagoon with 45 days of hydraulic retention time (HRT, hereafter). COD and T-N in the effluent of the lagoon is 500 mg/L and 162 mg/L. Removal efficiency of COD in the lagoon 95%, while that of T-N is as low as 10%.

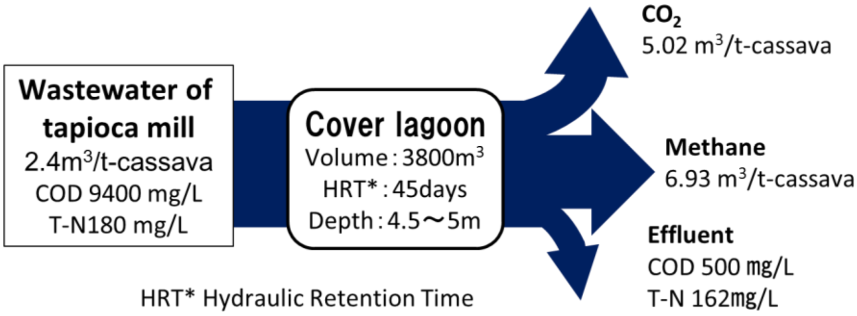

Fig.7 Material flow and operating condition of lagoon in tapioca mill.

Material and elemental flow analysis has been performed on the composting of EFB mixed with palm oil mill effluent (POME, hereafter) and cattle fattening using biomass residues of tapioca mill as feedstuff. Composting of EFB and POME under aerobic condition was consumed about 79.1% of POME and reduce GHG emission about 60.5% compared to open lagoon system. Utilization of onggok and elot for cattle feed is common uses as carbohydrate sources in several cattle fatteing company in Lampung province.

Figure 8 shows an example of cassava yield obtained through cultivation test in a plot using cattle manure compost as the sole fertilizer. The application rate of cattle manure compost on the plot was 20t-wet/ha. The result shows the cassava yield has been gradually increased with the continuous cultivation of cassava with application of compost.

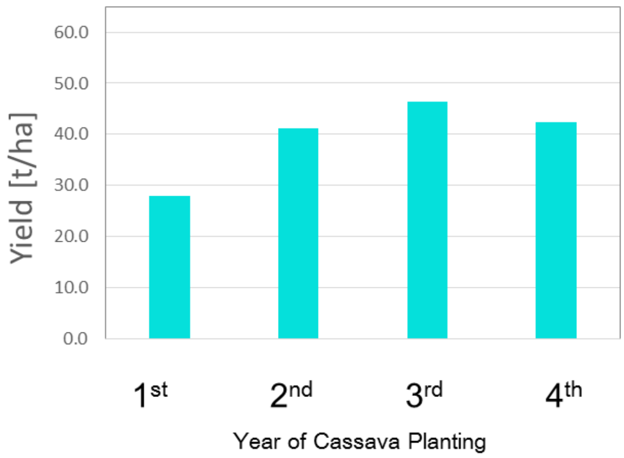

Fig.8 Cassava yield observed in the plot of experimental field applied with cattle manure compost

3.2Design and evaluation of biomass residue recycle in plantation

Figure 9 shows an example of supposed biomass residue recycle system for tapioca mill. The system is requested to satisfy the reduction of environmental loading and the sustainable cultivation of cassava and thus tapioca production. To design the suitable recycle system the following information and data are necessary; 1) quantity and property of biomass residue and wastewater from tapioca mill, 2) effect of liquid fertilizer application on cassava yield, 3) biogas production in lagoon or fermentation system, 4) quantity and quality of feed for the cattle fattening, 5) effect of cattle manure compost and liquid fertilizer on the cultivation of cassava and pasture, and so on. Quantitative information and data obtained through the present research can be effectively utilized to design and evaluate the biomass residue recycle system as shown in Fig.9.

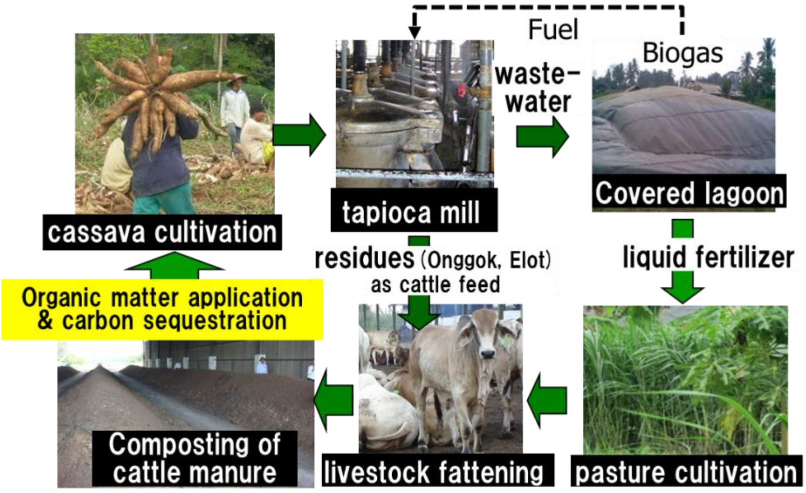

Fig.9 Supposed biomass residue recycle system for tapioca production from cassava.

4. Conclusions

Material and elemental flow analyses were performed in the farm land and crop processing mill of plantation as well as on the composting, methane fermentation and cattle fattening. Based on the results, procedure to design and to evaluate the biomass residue recycle system for carbon sequestration and for soil fertility improvement toward sustainable crop cultivation was proposed based on the experimental observed results.

Acknowledgments

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