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Research Paper

Material flow analysis in an integrated catfish farming system in Mekong Delta, Vietnam

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ABSTRACT

The purpose of this study is to conduct the material flow accounting (MFA) in the integrated catfish breeding system with purpose to evaluate the pollution reduction and the economic benefits gained from the system. An amount of 21.17% of water is evaporated into the air, 4.73% is accumulated in the compost and biomass of cultivation plants, and the larger part of 74.1% after being treated by using aquatic plant flowing in the water ponds is discharged into receiving canal. The pond bottom sludge after being mixed with other organic components in the system is used as compost for fertilizing the cultivation plants. The organic matters accumulated in cultivation plants and soil are 1.95% and 9.6% respectively, and the remaining amount is accumulated in the compost. A larger scale system is recommended for 9 catfish breeding families in the area. However, the wastewater generated from these 9 households is not totally reused for watering purpose due to the limited cultivation land area at these households, thus other households in the neighboring area need to be included in the system in order to form more effective integrated aquaculture system leading to pollution reduction and sustainable livelihood for the local farmers.

1. Introduction

Between two or more agricultural activities, of which at least one is aquaculture (Little and Edwards, 2003). The most integrated aquaculture systems are closely associated to the VAC model in Vietnam, an ecosystem production that 3 components: garden (V), pond (A) and livestock pen (C) are integrated. These VAC systems effectively use all the available land, air, water and solar energy resources, and also effectively recycle by-products and wastes for providing diversified agricultural products to meet the complex nutritional demands of rural communities (Huong et al., 2018). The garden can provide feed for fish and livestock, and water from the pond can be used for watering the plants in the garden, livestock manure can be used as fertilizer for plant growth in the garden.

Cultivation – pond - livestock – biogas system is more concerned because waste materials are effectively recycled by linking appropriate components, the minimization of environment pollution, and almost recycling of product and by-products for the sustainability of farming system. The garden can provide feed for fish and livestock, and water from the pond can be used for watering the plants in the garden. Livestock manure can be used as fertilizer for plant growth in the garden. Crop wastes from the garden and livestock manure can feed the fish in the pond (Engle, 1987; Yunlong and Smit,

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1994; Nhan et al., 2007). The manure from livestock supplies to bio-digester for producing biogas, and the biogas effluent is used as fertilizer for crops (Ngan et al., 2012). The agro-based zero emission system (AZES) with severe components including cultivation – pond - livestock – biogas – house – workshop – wastewater treatment is an advanced pollution reduction model/system based on optimal combination among the components in the system with purpose to reduce and treat the wastes for meeting the permitted standard, to lower the investment and operation cost of the waste treatment system, as well as to gain the additional income from the waste treatment work (Hai et al., 2016; Schnitzer et al., 2019).

Material flow analysis (MFA) have been widely used as a systematic assessment of the flows and supplies of material in the system (Brunner, 2004). MFA has attracted a lot of attention and is included in the official statistical reports of the EU (Eurostat, 2009). This is a typical analytical tool that is based on the material balance (Steubing, 2010). MFA captures the mass balances in an economy where inputs equal outputs according to Pincetl (2012). MFA is application for waste management and recycling (Moriguchi Y and Hashimoto S, 2016; Markic et al., 2019).

This study aims to apply MFA method as an analytical tool for material flow transformation in an integrated catfish farming system in Mekong Delta, Vietnam. More specifically, MFA is used to quantify the input sources such as water and feed, transformation in an integrated catfish farming system. Then, the result of the case study are used to evaluate the whole area, including 9 catfish ponds around there. The scaling up model for the whole area was applied to forward to sustainable development.

2. Methods

2.1 Background

The research area is located at Tan Phu District, An Giang province, in Mekong delta area, Vietnam, and this area belongs to one of the most concentrated areas for the catfish breeding activities in Mekong delta area, Vietnam. There are 9 households (families) having main livelihood of the catfish breeding. Total area of catfish ponds is about 69.180 m^2, with 9 ponds and each pond with an area from 5,294 to 13,900 m^2 (Fig. 3). The highest area is for the rice cultivation, around 42.2%, fruit cultivation takes about 12.3%, maize garden, around 18.5%, catfish area, around 25.1%. Based these features, this research has selected.

A demonstration site at the household (family) with typical character as for all other households in the area. At this household, agriculture system was demonstrated with a purpose to evaluate the potential for coupling different components in the same system, to reuse and recycle organic wastes, to effectively reuse the resources from wastes, and to reduce maximally the wastes discharging into environment. The success gained from this system will be multiplied and combined with other economic components in the research area leading to pollution reduction, increasing income and creating sustainable livelihood for the local farmers.

The function of the components in the system are described below:

- Catfish pond with the area of 5,294 m^2 contains around 7,200 m^3 of water. The water is replaced periodically every 3 days, thus, there are totally 50 times changes of water in the fishpond during 5 months of fish breeding. Quantity of water for 1 replacement is 300 m^3/h, and time for 1 replacement (emptying the fishpond) is 8 h. The fishpond is a place for consuming input materials (food for fishes), and also a place for generating wastewater, bottom sludge, and dead fishes.
- Garden includes cultivation plants and cultivation soil. Total garden area is 18.000 m^2 that is used for maize planting. The maize plant absorbes and transforms/converts the organic components in compost into living components for his body. The cultivation soil and microorganism system available in soil have function to transform further the organic components in compost into the organic nutrient sources which are directly uptaken by the cultivation plants. In the reverse way, the organic components in compost play role in soil quality improvement, increasing the physical and chemical property for cultivation soil. The use of bottom sludge for producing compost will help to supply nutrients for the cultivation plant, reduce the use of chemical fertilizer, save the investment cost, reduce Green House Gassess emission, and also to reduce the agent for degradation of cultivation soil.
- Cowshed (including the cows) is a place for consuming the products from planting the grass and maize body after harvesting. It is also a component generating manure and urine from cow. The cow manure after composting process is used as organic fertilizer for the grass. The cow urine together with cowshed cleaning wastewater are collected for further production of biogas.
- Biogas and compost are products from the bio-processes. Biogas is produced from wastewater from cowshed cleaning and blackwater from

household. This biogas is used as burning fuel instead of using natural gas for the cooking demand at the family. This will lead to reduce GHGs from burning industrial gas as before, and also to save badget for the family from the purchase of gas container (metal bottle). Compost is a product received from the biodegradation of fishpond sludge for producing organic fertilizer supplying organic nutrients for the cultivation plants.

- House: there are 3 people in the family. The house plays a central role in the system, a living place for the family's members, managing all the activities of the system, and a place getting direct impact from system operation. The human is a main agent playing important role in the system operation, and it is also a place consumimg products from Biogas and transforms it into heat energy. Moreover, it is a place receiving the economic and environmental benefits from the system achievement.
- Treatment of wastewater from fishpond: the wastewater discharged from fishpond is treated by using aquatic plant (*water morning glory*). Here a large part of the nutrient components in wastewater are uptaken by the *water morning glory* plant and converted into living components for plant itself, and another part is settled down to the pond bottom, and a rest part is discharged directly to the environment (canal).

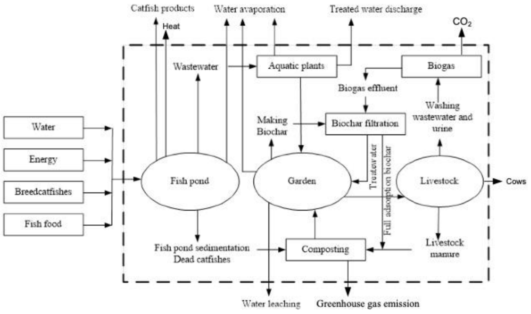

Fig. 1 Material flow transformation in an integrated catfish farming system.

The application of MFA techniques in the integrated fish farming system: the input material flows for a fishpond basically comprises of water, energy for the water pump, fish and food for fish. Thus, these components are quantified and calculated through their transformation processes within this closed integrated system:

- *Water resource accounting*: in this system, water in the pond is accounted and analyzed by using parameter such as the amounts of water accumulated in catfish, in maize plant, glory plant as well as the water amount evaporated into the air, absorbed into the soil, and/or discharged into the environment. The total evaporated water quantity in the system is defined from 4 main sources including: water mass evaporated from breeding ponds, from aquatic plant (*water morning glory*), from maize plant, and moisture content in the composting product. The water mass evaporated from breeding ponds is defined by measuring the water levels in the ponds among the pumping periods; the water mass evaporated from the maize and aquatic plants is defined by measuring the bio-parameters of these 2 plants. The water mass evaporated from pond bottom sludge is accounted through moisture contents after collecting the sludge from the pond and the remaining moisture in the composting product. The water masses accumulated in the maize, aquatic plants and the catfish products are defined by water contents in their bodies. The wastewater quantity discharging into the environment is defined as a difference between the total input supply water mass and evaporated and/or accumulated water masses.
- *Energy flow accounting*: The input energy flow is used mostly for water pump, and is almost converted into electricity and waste heat emitted into environment.
- *Input raw fish accounting*: the quantity of input raw fish is accounted through the quantity of final fish products (harvested) and the dead fish during the breeding time.
- *Accounting on the fish food quantity*: The quantity of food for fish is accounted through the mass accumulated in catfish product (the food transfer coefficient), in composting product, in maize plant, in aquatic plant, in soil as well as the mass accumulated in wastewater which is discharged directly into the environment (canals).

The other material flows from livestock activity and from garden products used as biochar material are also analyzed and accounted.

2.2 Material Flow Accounting

Total quantity of water used for catfish pond is calculated based on the pumping capacity and pumping time, and the water pump (BOYU GX4P-35000, 500W, capacity 35 m^3/h (Q) was used for that purpose.

The amount of water in the catfish pond which is evaporated into the air is calculated on the basis of “water level stage” method by measuring the water level on the first day (water level stage on day 1), and that level on day 3 (after pumping removing old water and pumping new water into the pond, the water level was then re-measured - water level stage on day 3). Thus, the evaporated water quantity during the catfish breeding is calculated by the total quantity of water avaporated during the whole 5 months of catfish breeding (Equation 1).

$$\Sigma W_{\text{pond evaporation}} = \Sigma(W_{\text{Water level stage on day 1}} - W_{\text{Water level stage on day 3}})*S_{\text{pond}} \qquad (1)$$

In which, $W_{\text{water in fish/sludge}}$ is amount of water in fish/sludge; $M_{\text{fresh(fish/sludge)}}$ is fresh amount of fish or wet sludge before drying; $M_{\text{dry(fish/sludge)}}$ is dried amount of fish or sludge after drying; $M_{\text{fish/sludge}}$ is total quantity of fishes after harvesting, or the total quantity of fishpond bottom sludge.

The water amount accumulated in compost and in cultivation plant are calculated by using formulas 3 and 4 (equation 3 and 4). The moisture of compost is directly measured by using equipment DM-13 *(Takemura electric work Ltd)*. The water amount evaporated from bottom sludge during composting process is calculated using formula 5 (equation 5). The moisture of cultivation plant is calculated by drying plant samples (vegetables and maize) at 105°C until the stable mass is reached.

$$W_{\text{water in compost}} = M_{\text{compost}} * A_{\text{compost moisture}}\ (\%) \qquad (3)$$

$$W_{\text{water in plants}} = ((M_{\text{freshplants}} - M_{\text{dryplants}})*100/M_{\text{freshplants}})*M_{\text{plants}} \qquad (4)$$

$$W_{\text{water in sludge evaporation}} = W_{\text{water in sludge}} - W_{\text{water in compost}} \qquad (5)$$

Where: $W_{\text{water in compost}}$ is water amount in compost; M_{compost} is total mass of compost product; $A_{\text{compost moisture}}$ is % moisture of compost; $W_{\text{water in plants}}$ is water amount in the plant; $M_{\text{freshplants}}$ is mass of fresh plant; $M_{\text{dryplants}}$ is dried mass of plant after drying; M_{plants} is total mass of cultivation plant after harvesting; $W_{\text{water in sludge evaporation}}$ is water amount evaporated during composting time.

The water amount discharging directly into the environment is calculated by equation 6:

$$W_{\text{wastewater}} = W_{\text{Total water use}} - (W_{\text{evaporation}} + W_{\text{accumulation in fish and plants}} + W_{\text{water in mud}}) \qquad (6)$$

Where: $W_{\text{wastewater}}$ is the total wastewater amount discharging into environment (canal); $W_{\text{evaporation}}$ is the total water evaporation; $W_{\text{accumulation in fish}}$ is the total water amount accumulated in fish body.

Total quantity of pond bottom sludge is defined by collecting the sludge into a rectangle storage area having 13 m long and 4 m width, the height of sludge pile was then measured, and the volume of collected sludge pile is defined by formula $V_{\text{sludge}} = 13 * 4 * h$ (h: height of sludge pile) (m^3). The specific mass of sludge is defined by taking a sludge sample and putting it into a glass beaker/container (volume: 1 litter); weighting the mass of glass container before and after adding sludge. The sludge amount in 1 litter is defined by equation 7, the specific mass of sludge - equation 8, and total quantity of pond bottom sludge - equation 9.

$$M_{\text{sludge in 1 lit}} = M_{\text{sludge and glass beaker}} - M_{\text{glass beaker}} \qquad (7)$$

$$d_{\text{sludge}} = M_{\text{sludge in 1 lit}}/V_{\text{1 lit sludge}}\ (kg/m^3) \qquad (8)$$

$$\text{Therefore;}\ M_{\text{total sludge}} = d_{\text{sludge}} * V_{\text{sludge}}\ (ton/m^3) \qquad (9)$$

Where: $M_{\text{sludge in 1 lit}}$ is sludge amount in 1 litter; $M_{\text{sludge and glass beaker}}$ is total mass of sludge and glass beaber; $M_{\text{glass beaker}}$ is mass of glass beaker; d_{sludge} is specific mass of sludge; $V_{\text{1 litter sludge}}$ is volume of glass beaker (0.001 m^3); $M_{\text{total sludge}}$ is total mass of pond bottom sludge.

The nutrient content from compost uptake by the maize plant is calculated by equation 10. The organic content which is absorbed into the pond after passing through 5 ponds having *water morning glory* plant is calculated by equation 11.

$$M_{\text{plant adsorption from compost}} = M_{\text{maize plant}} * 30\% \qquad (10)$$

$$M_{\text{organic materials adsorption by water glory morning}}$$

Where: $M_{\text{plant adsorption from compost}}$ is nutrient amount uptaken by the plant from the compost; $M_{\text{maize plant}}$ is fresh mass of maize plant; 30% is proposed nutrient uptake rate of the maize plant.

The FCR (Feed Conversion Rate) of catfish or maize plant is ratio between input feed mass or organic fertilizer and total mass of catfish or fresh mass of maize plant after harvesting. FCR is calculated by equation 11.

$$FCR = M_{\text{fishfood/compost}}/M_{\text{yield(Fish/maize plants)}} \qquad (11)$$

Where: FCR is Feed Conversion Rate; $M_{\text{fishfood/compost}}$ is amount of food for catfish or amount of composting fertilizer for the maize garden; $M_{\text{yeild(fish/maize plants)}}$ is productivity of catfish or maize after harvesting.

The density of maize cultivation is 7.000 plants/ha. The water quantity used for watering the maize garden during the whole growth time is 4,805 m^3/ha, and 3,054 m^3 is proposed volume/quantity of water which was evaporated during one harvest in one hectare (1 – 2 litters water is released from one maize plant in one day averagely, Du et al., 2011). An electrometer is installed for the experimental fishpond for measuring the electricity used at the pond.

3. Result and Discussion

Figure 3 represents the material accounting flow for catfish pond after 1 harvest. There are 4 major material flows for accounting purpose including: water, raw catfish, food for fish, and electricity flows. Total quantity of water used for catfish breeding is estimated to be 72,000 m^3 water, in which, 7,200 m^3 is the initial water quantity in the pond, the rest is an increase due to the changes (replacements) of water during 5 months of catfish breeding. The water in the ponds is changed in every 3 days, and about 20% of water in the ponds is changed in each time. Total quantity of catfish harvested is 127.06 tons, total biomass of maize plant harvested is 90 tons, total biomass of *spinach water morning glory* harvested is 2.68 tons, and total composting fertilizer produced from the system is 207.8 tons.

In this integrated system, the water mass evaporated into the environment is estimated to be about 15,258 m^3, in which, the water evaporated directly from the ponds is 9,120 m^3, from the composting process is 640.8 m^3, and from the maize plants is 5,497.2 m^3. The water mass accumulated in fish (final) products is about 108 m^3, in dead fish is 10.62 m^3, in maize plant biomass is about 76.5 m^3, in *spinach water morning glory* plant biomass is about 2.38 m^3, and accumulated in composting product is about 64.33 m^3, as well as the one accumulated in the maize cultivation soil is about 3,147.98 m^3 (from the watering is 3,141 m^3 and from the water in compost is 6.98 m^3). Total wastewater from fishponds which is treated by/in the ponds having *spinach water morning glory* plants is 62,064 m^3, in which the water reused for watering the maize plants is 8,650 m^3, and the quantity of wastewater discharging directly into the environment, around 53,411.62 m^3.

The breeding density is 25 fishes/m^2, average weight of raw fish is 40 g/fish. Thus, total quantity of raw catfish used at the beginning of the breeding time for a pond system of 5,000 m^2 is about 5.29 tons. Total amount of food for fish during the whole breeding time is 209.65 tons. The FCR (Feed convention ratio) is 1.65, and the percentages of transformation and accumulation of the food in product (final) fish is 12.13%. The remaining food as well as the convention of most of this food into the waste product from the fish is accumulated into the pond bottom sludge, into the *spinach water morning glory* plant, and a rest part is gone into the environment.

After fish harvesting, the pond bottom sludge collected is about 833 tons, in which the dried sludge is 125 tons (15%) and the water mass in sludge is 708 tons (85%). The components contained in the bottom sludge include the surplus of fish food, the excretion product from the fish, corpse of microorganism in the pond, lime and chemicals used for treating the pond bottom, the soil/sludge from erosion at the pond bottom, and the suspended solids having in the input water entering the pond. After composting process, the water mass remained in the compost is 63.24 m^3, and the rest is evaporated into the environment. Total quantity of organic fertilizer used for the experiment with maize plant is 24 tons. It is proposed that the 30% of organic fertilizer is absorbed into the soil, thus the dried matter from the compost which is absorbed in and accumulated by the maize plant biomass is 4.05 tons, the remaining 19.95 tons is then accumulated into the soil. The compost remained in the storage place is 183.8 tons. Total quantity of organic matter from the pond waste which is not settled down in the pond bottom is 7.04 tons. Organic matter are settled down and accumulated in the *spinach water morning glory* ponds is 1.79 tons. Another part is gone into maize cultivation soil is 0.69 tons, and a remaining part, around 4.26 tons is discharged directly into the environment. About 0.3 tons is absorbed and accumulated into the biomass of the *spinach water morning glory* plant.

The cow manure from 3 cows during 5 months is estimated to be about 8.1 tons and 15 kg of biochar is produced from dried leaves after being used for the treatment of wastewater leaving biogas digester. The water mass evaporated from the cow manure is 5.1 tons during the composting process together with pond bottom sludge. The amount of dried cow manure remained in compost is 3 tons, in which 0.346 tons is used for fertilizing the maize plant and 2.654 tons is stored together with pond bottom sludge in the compost.

In general, the material flow accounting and analysis in the system indicated that if the traditional fish breeding is applied, the wastewater quantity discharging directly into the environment is 62,064 m^3, and the sludge is about 833 tons, and in the meantime, the integrated fish breeding system under study could reduce 8,563 m^3 wastewater discharging into the environment (being pre-treated by using *spinach water morning glory* plant). This water amount is recycled in the system and accumulated into the biomass of the cultivation plants, evaporated and/or absorbed into the cultivation soil. All the waste sludge is collected and reused with purpose to contribute to be converted into the biomass of the cultivation plants or accumulated into the soil which condition the growth of soil microorganism and thus, improve the quality of cultivation soil.

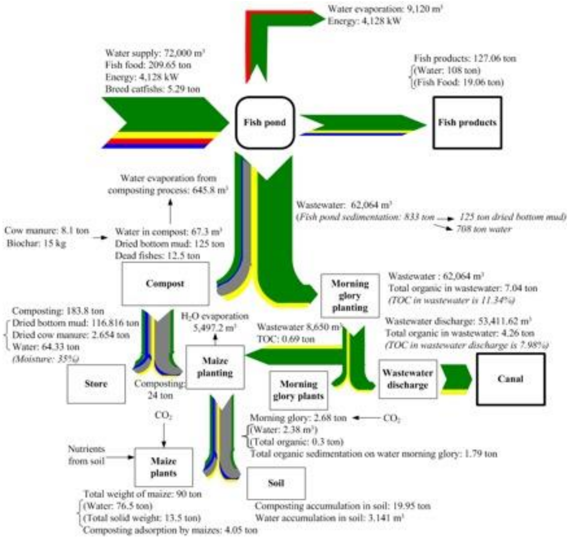

Fig. 2. Material flow accounting in the pond

3.2 Up scaling system

By evaluating the effectiveness of the material conversion within the demonstration system under study, an integrated up scaling system is recommended based on the existing conditions at these 9 households (families). Total area for these 9 households is 27.48 ha, in which 11.63 ha is for rice cultivation, 0.52 ha for fruits and vegetables, 5.09 ha for maize plant, 6.9 ha for fish breeding, and 3.39 ha for livestock. In this system, on the basis of the favor geographical condition, the households will participate in an integrated closed self-supply fish breeding system. The cost for building up new internal canals (flowing among the households) will be shared among the households themselves, and the benefits gained by the system will also be shared on the basis of the respective contribution.

With the total area for breeding catfish of 69,180 m^2, it is estimated that total wastewater generated during 1 breeding time is about 996,192 m^3, and 11,525 tons wet sludge or 1,729 tons compost. The family of Mr. Nguyen Van Giau has agreed to use his 7000 m^2 pond for plating the spinach water morning glory for further use in treating the wastewater from 9 fish breeding ponds. Thus, with this are the family of Mr. Giau will continue to receive and treat about 217,000 m^3 for 1 fish breeding time. The wastewater quantity being treated by this aquatic pond will be used for watering for the maize cultivation area (1.3 ha) (a neighboring family). Thus, the total quantity of wastewater for watering for the maize cultivation after 2 breeding times is estimated to be about 22,490 m^3. A rice cultivation area of 32,500 m^3 is able to receive an amount of wastewater of 29,138.7 m^3 from fish ponds for his watering purpose during 2 rice cultivation crops (1 rice cultivation crop lasts for 3 months), in which the watering demand for the rice plant is 4,489.8m^3/ha/crop (Tuan, et al., 2019). A rice cultivation area of 5 ha can receive an amount of water after 2 rice crops of about 44,898 m^3. Thus, total wastewater quantity which is collected and treated from 9 fish breeding ponds at 9 households is 291,036.7 m^3. The wastewater discharging into the environment after being treated by/at the spinach water morning glory plant pond is 194,510 m^3. Untreated wastewater of 705,155.3 m^3 must be treated before being discharged into the environment. The other households have no cultivation land closed to the fish breeding pond area, then they cannot receive this surplus of wastewater. Due to that reason, the household should integrate with the households in the surroundings of the breeding area in order to receive all the wastewater from 9 breeding ponds. The total rice cultivation area in the surroundings of the fish breeding area is 75 ha. Thus, it can receive a water amount of 734,820 m^3 for 1 fish breeding time in about 5 – 6 months (equally to 2 rice cultivation crops). Thus, if these 9 households in the catfish breeding area can combine all the cultivation land in the surrounding area, then they are able to receive all the wastewater from fish breeding ponds and use later for watering purposes.

For the pond bottom sludge, an empty area of about 1,500 m^3 will receive all the waste sludge from 9 fishponds with purpose to produce compost for later use at the rice cultivation of these 9 households. A part of produced compost may be sold as organic fertilizer to the other surrounding families. The amount of compost supplies to 9 fish breeding households is about 400 tons for 1 breeding time (20 tons/ha), thus, after 5 - 6 months (2 breeding times), the total quantity of compost used for these 9 households is 800 tons/20.06 ha of cultivation. Thus, the remaining compost part (about 1 ton) will be supplied to the other surrounding households.

The total number of cows and pigs of 9 fish breeding families is 68 (12 cows, 54 pigs), in which 3 families have no livestock activity (fish breeding only). These 9 households are located not very closed to each other, thus each household has to invest 1 biogas digester. The biogas from biogas digester will be delivered to the other families (which have no livestock activity) through the gas line pipe connecting the neighboring households. The wastewater after leaving biogas digester at each household will be collected and treated by using biochar material, and this biochar material will also be used later as fertilizer for gardening purposes. The livestock manure at each separate household will be collected for producing compost and it will be used again for the gardening purpose at home. The quantity of maize plant body collected from the garden of 11.63 ha of all 9 fish breeding households will be supplied back as food for 12 cows in the system. Thus, the collaboration among the catfish breeding households and other households to form a unique system will help to decrease the pollution and recycle the valuable materials in the system. Moreover, the integrated system at the larger scale will generate new jobs which help to maintain sustainable livelihood for the local farmers.

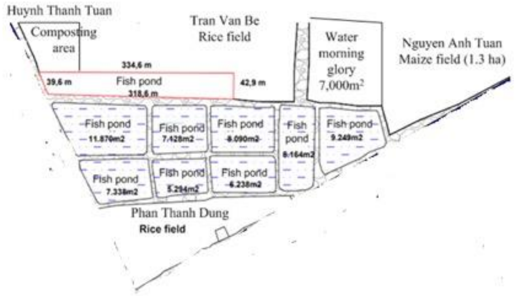

Fig. 3. Scaling up model for 9 households in this area

4. Conclusion

This study focuses on understanding the material flows through an integration among catfish farming, maize yield, and cowshed, as well as morning water glory pond in MeKong Delta, Vietnam. MFA was found to be a valuable tool for understanding the materials transformation in an integrated catfish farming system. A large amount of catfish sediment accumulated in composting and supply nutrients for plants. Amount of organic matters in wastewater of catfish pond also accumulated in morning water glory plants. The demonstration system in this research has shown that the ability to multiply this system to a larger scale of catfish breeding reduce pollution, create an organic compost for cultivation, and maintain sustainable income to the local farmers. Thus, the integrated catfish farming system has become the key mission for decision makers to develop and implement efficient strategies to facilitate organic recycling in Mekong Delta, Vietnam.

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References

Brunner, P.H., 2004. Materials flow analysis and the ultimate sink. Journal of Industrial Ecology, 8 (3), 4, 2004

Du, T.V., Lan, D.T.H., Binh, T.T.T., Hai, L.V., Ngoc, N.D., Thoa, L.T.M., and Hung, N.V., 2011. Biological characteristics of Maize plants. Ministry of Agriculture and Rural Development.

Engle, C.R., 1987. Optimal Product Mix for Integrated Livestock-Fish Culture Systems on Limited Resource Farms, Journal of the World Aquaculture Society, 18(3), 11.

Hai, L. T., Hans, S., Thanh, T. V., Thao, N. T. P., & Gerhart, B., 2016. An integrated eco-model of agriculture and small-scale industry in craft villages toward cleaner production and sustainable development in rural areas - A case study from Mekong Delta of Vietnam, Journal of Cleaner Production, 137(20), 274-282

Huong, N.V., Cuong, T.H, Thu, T.T.N., and Lebailly, P., 2018. Efficiency of Different Integrated Agriculture Aquaculture Systems in the Red River Delta of Vietnam, Sustainability, 10, 493

Little, D.C., Edwards, P., 2003. Integrated livestock-fish farming systems, FAO Inland Water Resources and Aquaculture Service Animal Production Service, Rome

Markic, D.N., Carapina, H.S., Bjelic, D., Bjelic, L.B., Ilic, P., Pesic, Z.S., Kikanovicz, O., 2017. Using Material Flow Analysis for Waste Management Planning. Pol. J. Environ. Stud. 28 (1) (2019), 255-265.

Moriguchi, Y., Hashimoto, S., 2016. Material Flow Analysis and Waste Management. In: Clift R., Druckman A. (eds) Taking Stock of Industrial Ecology. Springer, Cham. doi.org/10.1007/978-3-319-20571-7_12,

Ngan, N. V. C., Thanh, N. T., Loc, N. H., Nguon, N. T., Phuc, L. N., and Tan, N. T. N., 2012. Potential use of water hyacinth and rice straw as additional loading materials for biogas digester. [Potential use of water hyacinth and rice straw as additional loading materials for biogas digester], Can Tho University, Natural Science, Technology and Environment, 22, 9.

Nhan, D. K., Phong, L. T., Verdegem, M. J. C., Duong, L. T., Bosma, R. H. and Little, D. (2017), Integrated freshwater aquaculture, crop and livestock production in the Mekong delta, Vietnam: Determinants and the role of the pond, Agricultural Systems, 94(2), 14.

Pincetl, S., 2012. A living city: using urban metabolism analysis to view cities as life forms. Metropolitan Sustainability. pp 3-25

Steubing B., Böni H., Schluep M., Silva U., Ludwig C., 2010. Assessing computer waste generation in Chile using material flow analysis. Waste Management, 30 (3), 473, 2010

Tuan, D.D., Dat, T.V., Dung, T.V., 2019. Water demand, appropriate irrigation regimes for rice grown under traditional and improved methods in the Northern Delta. Vietnam Academy for Water Resources.

Yunlong, C., and Smit, B., 1994. Sustainability in Chinese agriculture: challenge and hope, Agriculture, Ecosystems & Environment, 49(3), 10.