

MATERIAL/SUBSTANCE FLOW ANALYSIS OF CARBON FLUX IN AN ORGANIC AND A CONVENTIONAL VEGETABLE FARM

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Organic input in agricultural farm system is thought to enhance carbon sequestration by increasing soil organic matter content. Yet, the findings on the soil carbon concentrations increment in organically managed soil still remain controversial. In this paper, carbon flow of the key processes in organic farm (OF) and conventional farm (CF) were modelled using material flow analysis (MFA) for evidence of carbon stock. Carbon flux modelling shows $363 \text{ tC h}^{-1} \text{ y}^{-1}$ of entry into farm system and signify the potential of OF as carbon sink. On the other hand, CF was identified as carbon source because the farm had $-34,724 \text{ tC h}^{-1} \text{ y}^{-1}$ carbon stock change. The carbon flux of OF system led to 29% increase in the soil carbon concentration, whereas at CF the carbon concentration decreased by 11.7%. High amount of carbon exit in OF and CF through surface runoff and leaching, hence, improvement of farm management is needed especially in water management. Lower water outflow was observed at OF than within CF; however, the high carbon concentration found in surface runoff and leaching indicates that carbon get washed off from the farm. Based on MFA results, the farm management for OF and CF system can be improved to ensure economic and environmental benefits.

Keywords: Greenhouse gases, carbon flux, organic farming, vegetable culture, carbon sequestration

INTRODUCTION

One-third of the global greenhouse gas emissions (GHG) come from agriculture sector (Gilbert, 2012). Proper land use management mitigate GHG emission and or even create carbon sink by encouraging carbon sequester practices (Vleeshouwers and Verhagen, 2002; Freibauer *et al.*, 2004; Ogle *et al.*, 2005; Luo *et al.*, 2010). IPCC has identified biomass application as the promising tool to capture and store carbon at terrestrial reservoir (Sims, 2007). Farming practices affect farm input which is the key factor for soil organic matter turnover rates that exert high influence over soil carbon content (Freibauer *et al.*, 2004). Organic farm (OF) is believed to be carbon (C) sequester because organic fertilizer application is the common practice in OF. While conventional farm's (CF) lack of organic input is viewed to be the contributor to GHG emission. Various reports tried to conclude the benefit of converting from CF to OF in regards to C sequestration. Evidence of higher soil C concentration in organically managed farm was found, yet some other studies have not agreed with such findings (Janzen, 2006; Leifeld and Fuhrer, 2010; Scialabba and Müller-Lindenlauf, 2010). Several modelling studies reveal that conversion of CF to OF increases soil C is only a temporary solution for C sequestration due to high GHG emission (Foereid and Høgh-Jensen, 2004). Carbon sequestration at tropics and subtropics region faced difficulties because of the high soil degradation rate (Lal, 2004). Thus, the restoration of degraded soil and ecosystems in tropics and subtropics is much needed. Extensive researches of carbon sequestration

have been done but few at tropical region (Foereid and Høgh-Jensen, 2004; Ogle *et al.*, 2005). The insufficient information of carbon storage on agricultural land is prevalent within developing world, tropics and subtropics region (Govaerts *et al.*, 2009). Data limitation is the main set back in meta-analysis of global soil carbon change (Leifeld and Fuhrer, 2010). This study discussed and provided an insight to carbon flux at tropical region and the variation from other studies.

Material flow analysis (MFA) is an integrated modelling and assessment tool to evaluate the environment sustainability, especially, waste management. However, it is not used in agri-environmental assessment. Therefore, this study utilized MFA for carbon modelling within the farm systems in order to have a comprehensive assessment of farm system sustainability. It is a practical analytical method to quantify flows and stocks of materials or substances in a defined spatial and system which provide vital information on farm system stability (Baccini and Brunner, 2012; Brunner and Rechberger, 2004). In addition, MFA highlights the existing and potential material stocks accumulating within a system which can cause environmental problems or a potential source of resources. Material flow emphasizes on the imminent resource and environmental issue without depending on indicators of environmental. This study evaluated the role of material flow modelling in understanding carbon flux dynamics of OF and CF system. The objectives were to identify the system differences between OF and CF, potential drivers for changes and differences between systems in carbon flow. It also aimed to

test whether the farming system results in enhancement or reduction of soil carbon stocks.

MATERIALS AND METHODS

Material flow analysis: Material flow analysis is defined based on law of mass balance and comprises the following fundamental steps described in section 1, 2, 3 and 4 (Baccini and Brunner, 2012; Bauer *et al.*, 1997; Brunner and Rechberger, 2004).

1. Parameters selection: This study aims to determine any relationship between amount of carbon input and carbon flux within organic and conventional farm system.

2. Determination of system boundary: The system boundary is within two existing vegetable farms in Malaysia: conventional farm (3°25'52.66"N, 101°38'54.50"E) and organic farm (2°56'56.59"N, 101°53'25.69"E). The selected farms are complying with Malaysia agriculture certification: Scheme Organic Malaysia (SOM) and Malaysia Good Agriculture Practices (SALM).

3. Identifying key flows, processes, stocks and quantifying mass and carbon flow: Data were collected over a period of 24 months with integrated method of scientific field data collection, qualitative survey and site observation. Eight inputs (Bokashi compost, compost, vermi-compost, peat moss, chicken manure, chemical fertilizer, rainfall, and irrigation water) and five outputs (harvested crop, surface runoff and leaching, carbon emission, waste water, and organic waste) associated with carbon flow at the farms were identified. Mass inputs and outputs values were obtained in-situ. Samples were collected for chemical analysis to determine carbon concentration (see section 2.5 and 2.6).

The total water outflow volume through surface runoff and leaching was estimated from the water balance (Bengtsson *et al.*, 2003). Mean monthly evapotranspiration ranged from 1360mm year⁻¹ to 1490mm year⁻¹ (Lee *et al.*, 2004; Tukimat *et al.*, 2012). Daily rainfall and evaporation during the study period were obtained from meteorological station (03°07'N, 101°33'E) situated 50 km from both farms.

4. Mass balance calculation and carbon stock: The basic theory of mass balance is that output is derived from input (Baccini and Brunner, 2012; Brunner and Rechberger, 2004). The mass change over a period of time is used to classify a process whether it is "source" or "sink" of a particular substance within a system (Kellner *et al.*, 2011). The term 'sink' is defined as a process with a positive stock change, while negative stock change is considered a 'source'. Material flow modelling was performed based on the data collected from the field using STAN2.5 (subSTance flow ANalysis) which taking uncertainties into account (Cencic and Rechberger, 2008; Vyzinkarova and Brunner, 2013).

Field Sampling: Soil, vegetable, compost, fertilizer, manure, organic waste and water were sampled through random composite sampling method and analysed at the laboratory.

Chemical Analysis: The carbon content of samples were analysed with Perkin Elmer CHNS/O Series II 2400 and HACH DR/4000 (Pereira *et al.*, 2006; Wendling *et al.*, 2010).

Gaseous emission: Carbon dioxide and carbon monoxide emissions was measured with static chamber (32cm x 22cm x 22cm) and portable gas meter (Binder Combimass GA-m multi-element) (Rochette and Gregorich, 1998; Parkin and Venterea, 2010). The gas flux and total carbon mass were calculated based on Parkin and Venterea (2010).

RESULTS AND DISCUSSION

Material flow analysis and carbon flux: The MFA model demonstrates the material flow which directly influences the carbon flow of OF and CF (Fig. 1 and 2). Figure 3 displayed the carbon flux of OF. There were three primary outputs at OF which includes surface runoff that takes up 97% of total carbon output, harvested vegetables and gaseous emission which were 0.5% and 2.4%, respectively. Similar to OF, CF has three major carbon outputs; 28% was through surface runoff and leaching, 72% and 0.001% were attributed to harvested vegetable and gaseous emission, respectively.

The MFA analysis indicated that water was the major input and output in the farm system and carbon analysis shows that the water discharged did transport the carbon away from the farm system. Even though the carbon concentration of surface runoff and leaching water samples at CF was lower compared to OF, but the high water outflow volume leads to higher total carbon output at CF (Fig. 4). About 81% of the water outflow at CF was from rainfall and this signified that the carbon lost through surface runoff and leaching at CF is highly variable. This indicates the carbon balance is particularly sensitive to the amount and timing of precipitation; hence the results only reflect the condition during the study period (Chou *et al.*, 2008). Higher carbon concentration in runoff at OF implied that the farm possess higher rates of soil erosion and microbial decomposition activity (Table 1). It suggests that the high organic matter inputs at OF increases the microbial activity and decomposition rate which is the principal cause of soil erosion that directly contributed to soil organic carbon depletion (Freibauer *et al.*, 2004; Tu *et al.*, 2006; Luo *et al.*, 2010). Despite the fact that carbon is lost from farm system, the carbon that leaches away may enter the water table and surface water which indirectly contribute to carbon sequestration (Nordt *et al.*, 2000). However, there is a possibility that increase in carbon concentration in aquatic system has detrimental effect on ecosystem.

Carbon flux in vegetable farms

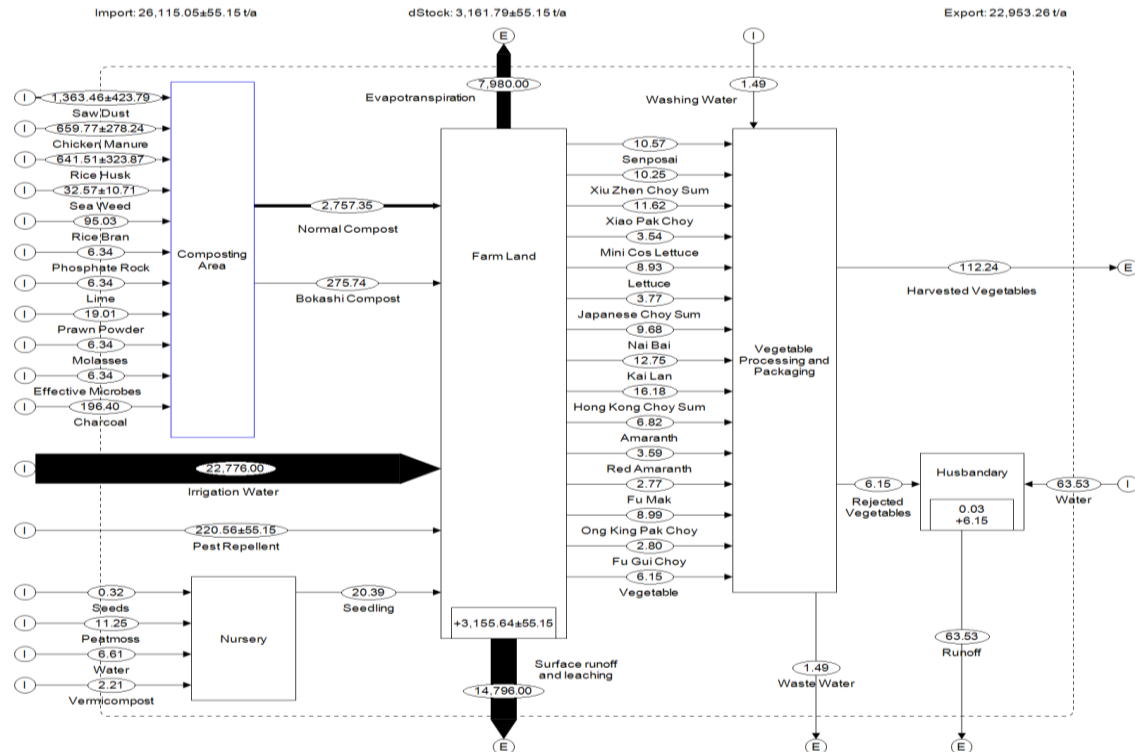


Figure 1. Material flow model of organic farm ($\text{t ha}^{-1} \text{y}^{-1}$)

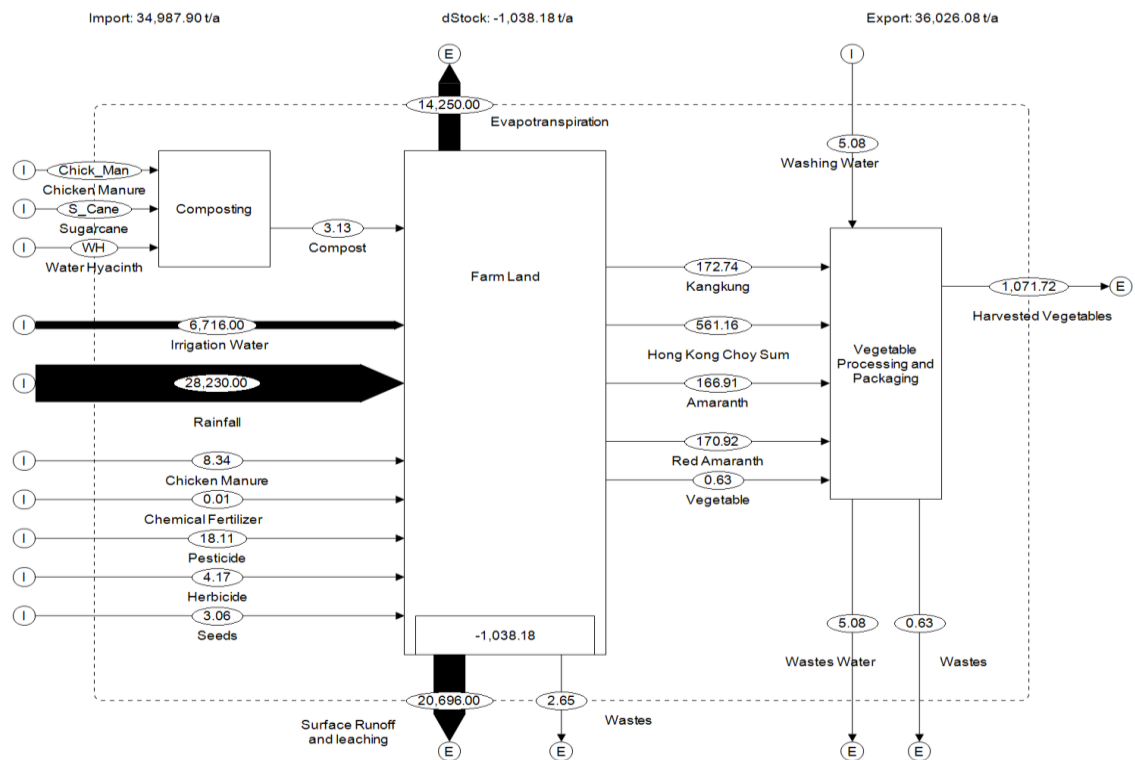


Figure 2. Material flow model of conventional farm ($\text{t ha}^{-1} \text{y}^{-1}$)

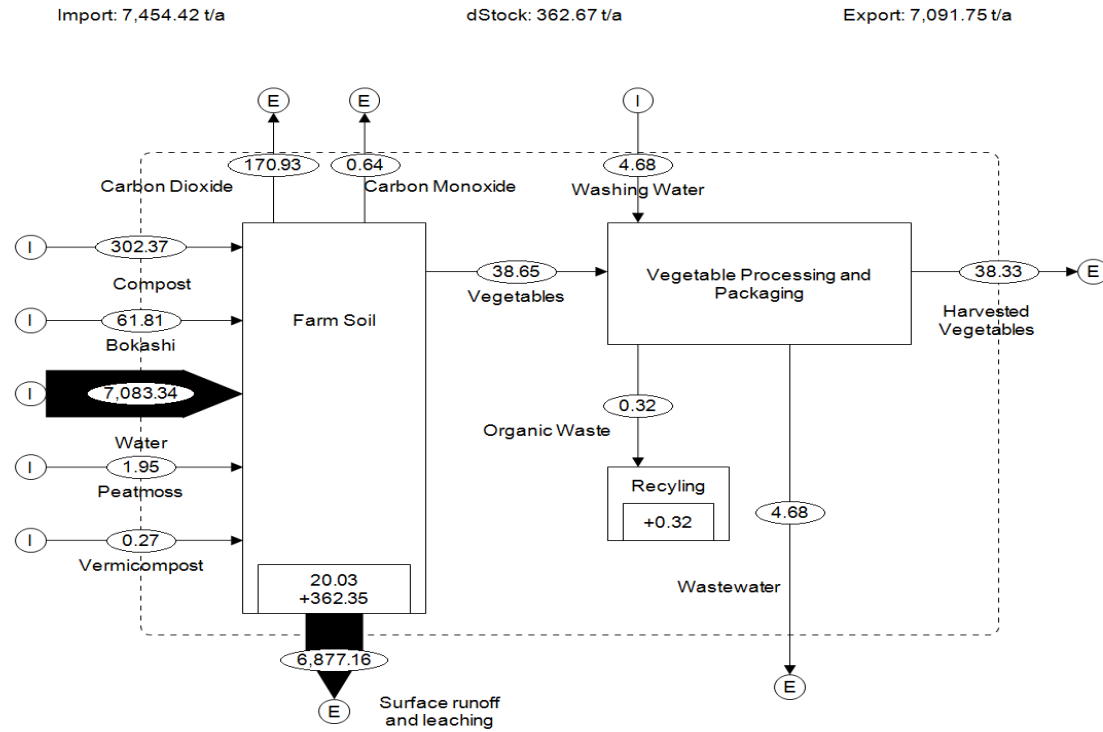


Figure 3. Carbon flow of organic farm (tCha⁻¹ y⁻¹)

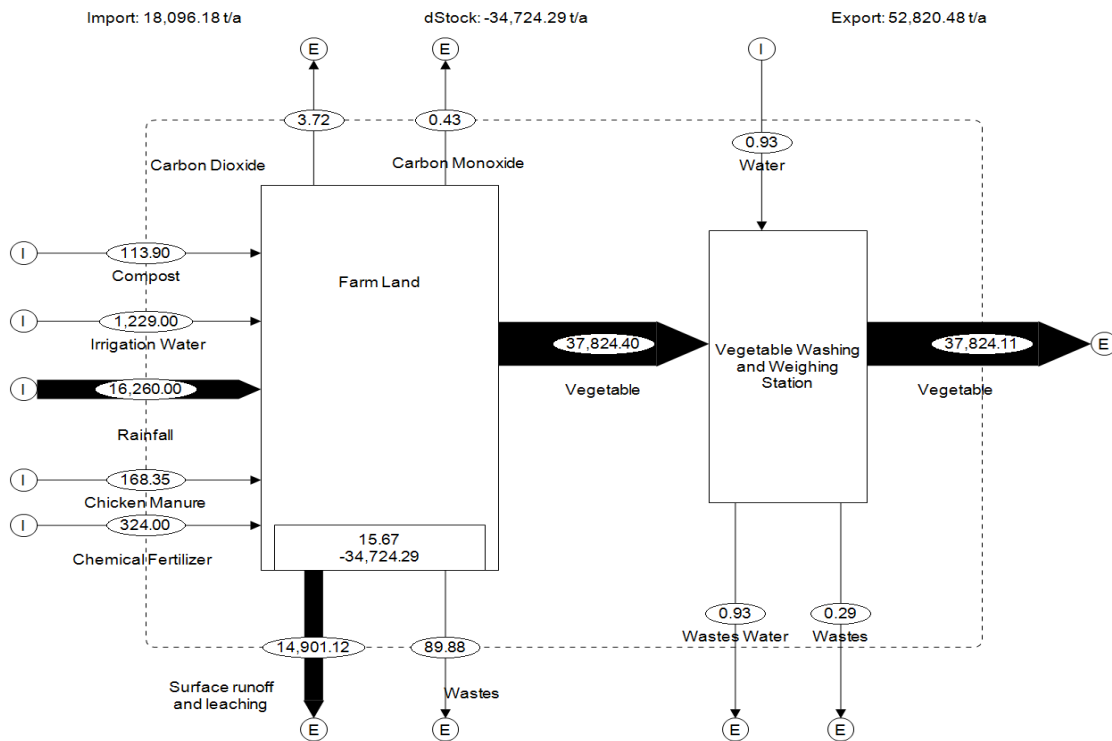


Figure 4. Carbon flow of conventional farm (tCha⁻¹ y⁻¹)

Table 1. Carbon concentration of water samples

	Total Organic Carbon (mg/L)		Total Dissolved Inorganic Carbon (mg/L)	
	Organic Farm	Conventional Farm	Organic Farm	Conventional Farm
Rain	2.37	5.71	5.61	0.05
Irrigation	3.10	1.55	0.01	0.28
Leachate	203.00	12.00	0.11	0.24
Runoff	1410.00	1.91	0.11	0.25

Mass balance: The net input of carbon of mass balance suggested that OF portrays the potential to be a carbon sink (Fig. 3). The reason is that large amount of organic matters such as compost and Bokashi compost are used as fertilizer and in the same time, the farm is characterized of low carbon output as the results of low vegetable yield has shown. Vleeshouwers and Verhagen (2002) has estimated that usage of organic matter input increases carbon input and resulted to $1.50\text{tC ha}^{-1} \text{y}^{-1}$ of carbon flux. On the other hand, CF in this study has shown it is the source of carbon where carbon stream out from the system (Fig 4). Conventional farm in this study showed high carbon flux compared to research done by Vleeshouwers and Verhagen (2002) where $0.84 \text{tC ha}^{-1} \text{y}^{-1}$ of carbon exits conventional managed arable land. The differences may be due to higher temperature and precipitation (tropical climate) at the study farm system where it is suggested that temperature rise of 1°C resulted in a $-0.05 \text{tC ha}^{-1} \text{y}^{-1}$ (Vleeshouwers and Verhagen, 2002).

The carbon flux into OF system increased 29% of the soil carbon concentration during the study period. The increment is higher than Leifeld and Fuhrer (2010) where 2.2% increase in soil carbon concentration was reported. The soil carbon stock of OF increased from 20025kg ha^{-1} to 25922kg ha^{-1} . In contrast, the soil carbon concentration at CF decreases 11.7%. During the study period CF shows reduction of carbon stocks from 15670kg ha^{-1} to 13837kg ha^{-1} . However, another study shows CF system increases soil carbon in a lower rate (2.0%) compared to organically managed system (2.4%) (Pimentel, 2005).

The carbon flux model shows there is still need for improvement within the OF and CF systems through proper water management to minimize carbon outflow. Organic manures and compost improves soil carbon pool more than inorganic fertilizer for the same amount of nutrients (Gregorich *et al.*, 2001). Therefore, organic matter input of CF need to be increased in order to enhance soil carbon stock. Conventional farm managers should opt for practices that increase organic fertilizer use and reduce chemical use, without jeopardizing farm yield. It is crucial to achieve balance between food security and environment sustainability, and MFA model provides fundamental information for farm manager to evaluate the farm's stability.

Gaseous Flux: The carbon monoxide and carbon dioxide emission at OF was higher than CF (Table 2), but no statistical significant difference was detected ($P > 0.05$). Organic farm application of high organic matter input

(Fig. 1) was the main factor for higher carbon gaseous emission (Mielnick and Dugas, 2000). Results from Tu *et al.* (2006) demonstrated that carbon inputs can significantly impact microbial biomass and carbon decomposition. Therefore, Janzen (2006) questioned the benefit of organic input in effort for carbon sequestration when biological and decay activities releases carbon into atmosphere. The author also mentioned the need to suppress decay activity in order to increase soil carbon concentration. Decomposition is an important process in providing nutrient for plant growth, thus suppressing decay activity may have direct effect to farm yield. Therefore, the question is how to increase carbon input while ensuring sustainable carbon gaseous emission that will no compromise farm yield.

Nonetheless, the carbon flow model implies that OF has the potential to be carbon sink even when carbon emissions were taken into account for the carbon flow analysis. This research has high temperature at tropical region is often considered not suitable for carbon sequestration due to high soil respiration and decomposition activity. However, this study shows otherwise as OF proved to have potential to be carbon sequester even at tropics region.

Table 2. Gaseous flux of organic and conventional vegetable farm

($\mu\text{L gas L}^{-1}\text{m}^{-2}$)	Organic Farm	Conventional Farm
Carbon Monoxide	23.22	15.392
Carbon Dioxide	6187.23	133.33

In this study, material/substance flow analysis using STAN software is proved to be capable of providing an integrated and holistic analysis of the farm systems which provides database to facilitate national/regional/global scale forecast. The different input in the farm systems has influence the material flow in the systems. In addition, water flow was identified as an important driver in carbon lost in the farm systems. C flux modelling signify the potential of OF as C sink while CF was identified as C source. Further study is required to understand whether the impact of C lost through gaseous emission and water outflow can be 'overwrite' with the benefit of increased soil C stock.

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