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Life cycle analysis of monocrop and multicrop in conventional and organic vegetable production systems in Tayabas, Quezon, Philippines

Life cycle analysis of monocrop and multicrop in conventional and organic vegetable production systems in Tayabas, Quezon, Philippines

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Abstract. Attaining food security is directly linked to increasing agricultural production to meet the needs of the exponentially increasing population. Extensive efforts in the past to improve crop production resulted to massive land conversion, deforestation and inappropriate use of modern technologies among others. Comparative assessment of the potential impacts of conventional and organic vegetable production systems is valuable because agriculture is one of the major contributors to environmental degradation. This study assessed and compared the environmental burdens of conventional and organic vegetable production systems in both monocrop and multi-cropping using the environmental Life Cycle Analysis (LCA) approach. The data gathered from in-depth interviews with farmers and farm surveys in Tayabas, Quezon, were used to determine the cropping system that has significant potential contributions to Global Warming Potential (GWP), Acidification Potential (AP), Eutrophication Potential (EP) and Human Toxicity Potential (HTP) with land area and kg^{-1} of vegetable as functional units. The conventional vegetable multi-cropping system contributed 4.10E-02 kg CO_2-eq kg^{-1} to GWP higher than the monocrop with only 3.69E-02 kg CO_2-eq kg^{-1} potential contribution. Organic multicrop contributed less to GWP with only 2.48E-02 kg CO_2-eq kg^{-1}. AP of conventional multicrop is also higher with 6.79E-03 g SO_2 -eq kg^{-1} as compared to the combined AP of organic monocrop and multicrop. Further, conventional vegetable production contributed higher HTP with 6.22E+06 g 1,4 DCB -eq kg^{-1} than organic. This study shows that organic production system has lower environmental burdens and a better alternative to improve food crop production while protecting the environment.

1. Introduction

Food production issues exacerbated the food security challenges faced by the current increasing population. In the Philippines, the total land area devoted to agricultural crops is 13 M hectares distributed among food grains (31% or 4.01 million ha), food crops (52% or 8.33 million ha) and non-food crops (17% or 2.2 million ha) [1]. Of the land area allotted for food crops, only 270 thousand hectares is allotted for vegetables and root crops, which is only 3.2% of 8.33 M ha [1]. Feeding the current Philippine population of 103.3 M as of 2016 [2] has been the greatest challenge and is directly linked to increasing agricultural food production. The issues of land conversion also played important disabling factor as agricultural production were intensified even in a small piece of agricultural land. This is an evident practice of the vegetable farmers in Tayabas in the province of Quezon in the Philippines.

Agriculture is a significant contributor to land degradation, anthropogenic global greenhouse gas emissions [3, 4] and negatively affect agro-ecosystem services [5]. Producing vegetables in both conventional and organic could provide the needed food requirements of the local municipality and its nearby provinces but could also potentially contribute significantly to environmental degradation of the area. Unsustainable agricultural practices can put a greater pressure and may threaten the capability of the natural resource base to provide basic needs to people in the long run [6] since increasing productivity has been the primary concern rather than long term sustainability [4].

The conventional agriculture characterized by extensive application of inorganic fertilizers and spraying of harmful chemical pesticides has been associated with many environmental stresses and serious impact to human health [7]. Alternatively, organic agriculture has been the most discussed appropriate technology which promised environmentally sound and economic viability to farmers [4, 8-9].

Comparing conventional and organic farming has been one of the most important themes in conducting Life Cycle Analysis (LCA) [4, 10]. These were done in various issues including olive production [3]; arable crop rotations with clover grass [4]; cereal and rape seed production [4]; greenhouse tomato production [7]; milk production [10]; grassland farming and pig production [11]. This study, on the other hand, assessed the potential environmental burdens of conventional and organic vegetable production systems. It specifically compared the mono-cropping and multi-cropping practices of both conventional and organic using the LCA approach.

The results of this comparative analysis, albeit very focused on cropping system, can contribute and guide the decision makers in drafting policies and build awareness and will guide the farmers identify and decide which cropping and vegetable production system to adopt considering the potential contributions to emissions, environmental protection and economic gains.

2. Materials and Methods

This study evaluates the potential environmental burdens of both conventional and organic vegetable practices in the municipality of Tayabas. Specifically compared using the LCA, are the mono-cropping and multi-cropping practices in combination with other environmental research methods. The data used in this study were gathered through in-depth formal household interview with 23 conventional and 23 organic farmers selected from across six barangays of Tayabas as well as members of SAMA PO KATA, an organic farmer organization, respectively. Focused group discussions (FGD) and key informant interviews (KII) were done and relevant secondary data were gathered from existing profiles and published studies.

The inventory analysis were done by quantifying all material inputs and outputs at each stage from planting to transport to the market of both conventional and organic farmers. Material inputs include seeds, trellis, fuel, organic and inorganic fertilizers, chemical pesticides and herbicides applied by farmers. Inputs such as water and electricity were excluded in the study since during the data gathering activities farmers rely on rainfall as source of irrigation for their crops and hence do not use electricity for water pump and other machines. The functional unit used in the analysis is 1 kg of packed vegetable and 1 ha of farm area.

Results of inventory analysis were translated to environmental impacts of the studied system [12] by identifying and determining the result of each impact category and by multiplying both the aggregated resources used and the aggregated emissions of a substance with a characterisation factor [13]. This study considered four (4) different types of impact categories (Table 1), the Global Warming Potential (GWP), Acidification Potential (AP), Eutrophication Potential (EP) and Human Toxicity Potential (HTP). The CO_2 emissions were considered for the GWP with the assumption that the soil organic carbon stocks remained unchanged. Indirect N_2O emissions induced by leaching of

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NO_3^{-1} or NH_3 volatilization were not considered due to data limitation. Also, part of the limitation is the analysis of the soil organic carbon as affected by tillage practices.

The energy consumed e.g., diesel in liters during crop production and transportation were considered to obtain the AP. Eutrophication potential were determined by obtaining the nutrient nitrogen (N) and phosphorus (P) applied, N and P available less corresponding crop uptake and by multiplying with the eutrophication factor of 0.1 and 1 to determine the NO_3 and PO_4 [13] expressed as kg $(PO_4)^{3-}$ equivalent [14]. Pesticide application (active ingredient, volume and frequency of use) of conventional farmers were considered to determine the human toxicity potential measured in kg of 1,4 Dichloro Benzene (DCB) equivalents [14].

Interpretation of results was done to effectively communicate the results of inventory and impact assessment. Improvement options, recommendations, policy formulations in consideration with the systems under study were covered.

Table 1. Formula used in determining the Global Warming Potential (GWP), Acidification Potential (AP), Eutrophication Potential (EP) and Human Toxicity Potential (HTP) of conventional and organic vegetable production systems in Tayabas, Quezon, Philippines.

Impact Categories	Formula	References
Global Warming Potential (GWP)	Carbon dioxide emission (kg) = diesel used (L) * (2778 g carbon/3.74 L diesel) * 99 (CO_2C^{-1}) Global Warming Potential of CO_2= Emission of CO_2 * GWP_{100} characterisation factor	[4, 12, 14]
Acidification Potential (AP)	SO_2 kg^{-1} = L * (Density of Diesel, kg L^{-1}) * (Sulphur content in diesel, SO_2/S) Wherein: L is the liters of diesel used Density of diesel = 85g $L-^{1}$ Sulphur content of diesel = 0.5% ~ 0.05 Atmospheric Acidification Potential of a substance = Emission of the substance * Atmospheric Acidification Potency factor of a substance	[4, 12, 14-15]
Eutrophication Potential (EP)	Eutrophication factor of a substance = Emission of a substance * Eutrophication potency factor of a substance	[4, 13-14, 16]
Human Toxicity Potential (HTP)	Amt. of pesticides Applied (g) = = Active ingredient L^{-1} * Vol. of pesticides used * Frequency of use Human toxicity of a substance = ∑ {emission of the substance * Human toxicity potency factor for the substance} $_{\text{air, water, agri-soil}}$	[4, 14]

3. Results and Discussion

3.1. Study area

The study area is in Tayabas, Quezon in Luzon, Philippines. Tayabas is a land-locked municipality geographically located at 14^0 50' Latitude East-Southeast of Mt. Banahaw and positioned between 14^0 01' 40.3" North Latitude and 121^0 36' 54.5" East Longitude [4]. The total land area of 23,095 ha is politically subdivided into 66 barangays, 36 of which are classified as rural areas where major types of vegetables are produced [4]. Agriculture, especially vegetable farming is an important livelihood source in Tayabas. In 2015, a total of one hundred ten (110) conventional and organic vegetable farming households were randomly surveyed and interviewed. Of the total farming household interviewed, forty-six (46) vegetable farmers who are into monocropping and multi-cropping for both conventional and organic vegetables were purposively selected as representative sample of this study.

Conventional vegetable farmers (15 farms) who are into monocropping planted bitter gourd (*Momordica charantia*), string beans (*Phaseolus lunatus*), eggplant (*Solanum melongena*), spring onion (*Allium sp*.), chayote (*Sechium edule*), tomato (*Solanum lycopersicum*), and pechay (*Brassica chinensis*). Multi-cropping is practiced mostly through intercropping of two or more types of vegetables as observed during the field visits. Intercropped vegetables commonly observed in conventional farms (8 farms) are eggplant and bell pepper (*Capsicum*); bitter gourd and string beans; pechay, spring onion and mustard (*Brassica sinapis*); and farmers also intercropped celery (*Apium graveolens*), spinach (*Spinacea oleracea*) and mustard. Organic farmers cultivate crops that are different from those of conventional farmers. During the interviews, organic farmers planted single crop in the farm due mainly to scarcity of water. Organic farmers mostly rely on rainfall to irrigate their farms. Common crops planted in organic farms (15 farms) are baguio beans (*Phaseolus vulgaris*), lettuce (*Lactuca sativa*), squash (*Cucurbita maxima*), tomato, string beans, bitter gourd, eggplant and intercropped crops in eight (8) organic farms are string beans and baguio beans; string beans, eggplant and bitter gourd; cucumber, string beans, squash and tomato among others.

3.2. Life cycle inventory analysis (LCI)

Conventional and organic farms are both cleared manually. Since vegetable farms in Tayabas are considered small-scale (90% of the respondents cultivate less than 0.5 ha), farmers mostly rely on manual labors and tools e.g. *bolo*, rake, shovel during land preparation [4]. Some (20%) conventional farmers apply herbicides to kill persistent weeds and to save on hired labors prior to clearing. Additional land preparation step for conventional farmers is making their raised beds/plots to ensure good drainage in between plots. Before planting, organic farmers apply vermicompost at about 190 g (N, P, K) kg^{-1} of vegetables and animal manure at 123 g (N, P, K) kg^{-1} of vegetables. Farmers follow standard seedling preparations e.g., direct seeding (string beans, bitter gourd, and squash) and transplanted (pechay, mustard) and required spacing depending on the types of vegetables planted. Management practices such as weeding, trellising (mostly for organic farmers), application of inorganic fertilizers e.g. urea, complete at about 133 g N, P, K are the common practice especially for conventional farmers. Harvesting and preparation e.g. washing, packaging of harvested vegetables prior to marketing is done mostly in the field to immediately deliver it to the market. For organic farmers, post–harvesting activities e.g. washing of vegetables, packaging using native biodegradable materials, etc. are being done in their trading or *bagsakan* center in Tayabas proper. Harvested organic vegetables (80%) are marketed mostly in Lucena and 20% are marketed in Sariaya, Quezon. Almost 90% of conventionally produced vegetables are being sold in Sariaya Quezon.

3.3. Life Cycle Impact Assessment (LCIA)

The calculated GWP, AP and HTP were all higher in conventional vegetable production systems. The global warming potential contribution of conventional multi-cropping and mono-cropping are 4.1E-02 kg CO_2-eq kg^{-1} and 3.69E-02 kg CO_2-eq kg^{-1}, respectively (Table 2). Organic multicrop has the lowest GWP with 2.48E-02 kg CO_2-eq kg^{-1} followed by organic monocrop (3.15E-02 kg CO_2-eq kg^{-1}). Conventional farms have higher GWP than organic due to higher usage of fuel (diesel in Li) during crop production, purchasing of inputs, and marketing. Organic farms are highly organized in terms of marketing their produce because of the presence of a farmers' organization which lessen fuel expenses especially during marketing and hence, the lower GWP and AP of organic monocrop and multicrop.

Acidification is caused by release of acid gases, mostly from the burning of fossil fuels and has a wide variety of impacts on soil, ground water, surface waters, and biological organisms among others [12]. Acidification potential of conventional vegetables is 6.79E-03 g SO_2 -eq kg^{-1} for multicrop and 1.83E-03 g SO_2 -eq kg^{-1} for monocrop, which are higher than organic system with only 9.62E-04 g SO_2 -eq kg^{-1} for multicrop and 1.23E-03 g SO_2 -eq kg^{-1} for monocrop. High acidification potential, specifically for conventional multicrop system is attributed to lower yield than monocropping and higher usage of fuel.

Table 2. The computed impact categories of conventional and organic vegetable production systems in Tayabas, Quezon, Philippines.

Impact Categories	Units	Conventional		Organic	
		Monocrop	Multicrop	Monocrop	Multicrop
1) GWP	kg CO_2-eq kg^{-1}	3.69E-02	4.10E-02	3.15E-02	2.48E-02
2) AP	g SO_2 -eq kg^{-1}	1.83E-03	6.79E-03	1.23E-03	9.62E-04
3) EP	NO_3 kg PO_4 -eq kg^{-1}	2.88E-01	2.04E+00	3.00E+00	2.84E+00
	PO_4 kg PO_4 -eq kg^{-1}	5.65E-02	1.27E+00	2.78E+00	5.41E-01
4) HTP	g 1,4 DCB -eq kg^{-1}	1.58E+05	6.06E+06		

The nitrogen and phosphorus inputs, uptakes and yield of farmers are the parameters considered in determining the eutrophication potential for both organic and conventional systems. Organic monocrop has higher NO_3 potential contribution with 3.00E+00 kg PO_4 -eq kg^{-1}, followed by organic multicrop with 2.84E+00 kg PO_4 -eq kg^{-1} (Figure 1). Highest PO_4 was recorded in organic monocrop, slightly higher than conventional multicrop. Conventional monocrop, on the other hand, has the lowest PO_4 among others with only 5.65E-02 kg PO_4 -eq kg^{-1}. Higher EP contribution for the organic system is attributed to higher and repeated application of organic fertilizers e.g. compost, vermicompost and animal manure every cropping season for more than 7 years and lower yield. The amount of nutrients (nitrogen and phosphorus) tend to accumulate into the soil and is prone to natural losses [17] which include leaching of soil nitrate to groundwater, excess nitrogen runoff and losses of nitrous oxide [4].

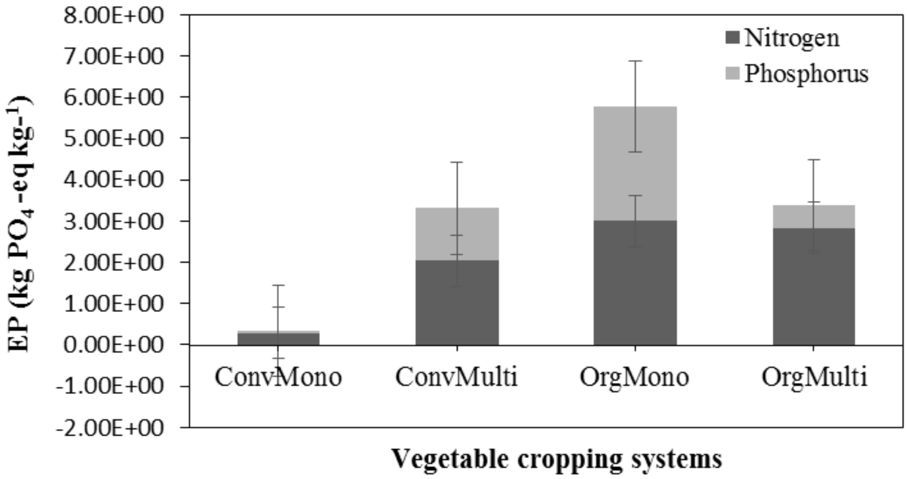

Figure 1. Eutrophication potential of monocrop and multicrop in conventional and organic vegetable production systems in Tayabas, Quezon, Philippines.

Conventional vegetable system both monocrop and multicrop contributed to human toxicity potential both in the air and soil compartments due to application of chemical pesticides e.g. Methomyl (*Lannate*), Cypermethrin (*Super M*), Chlorpyriphos (*Brodan*) and Carbofuran (*Furadan*) throughout the cropping season. The HTP for multicrop is 6.06E+06 g 1,4 DCB -eq kg^{-1}, which is higher than the monocrop with 1.58E+05 g 1,4 DCB -eq kg^{-1}. Of the active ingredients used (Table 3). Carbofuran has the highest potential HTP contribution with 6.00E+06 g 1,4 DCB -eq kg^{-1}, followed by the combined HTP of Cypermethrin, both in monocrop and multicrop with 2.09E+06 g 1,4 DCB -eq kg^{-1}.

Table 3. Human toxicity emission in the soil and air compartments of the common pesticides used in conventional monocrop and multicrop vegetable production systems in Tayabas, Quezon, Philippines.

Active Ingredient	Pesticides	Human Toxicity Potential (HTP)	
		Monocrop	Multicrop
Methomyl	*Lannate*	7.30E+01	6.28E+03
Cypermethrin	*SuperM*	1.58E+05	5.14E+04
Chlorpyriphos	*Brodan*	3.31E+01	1.50E+02
Carbofuran	*Furadan*		6.00E+06

The conventional vegetable farmers apply chemical pesticides to control pests and diseases at a faster rate. However, application of synthetic pesticides is alarming considering its possible impact in destroying the balanced natural ecosystem and biodiversity [4]. Most of these chemical pesticides are already banned, thus, proper interventions and policies to control the usage are deemed necessary. In this study, organic farmers do not apply chemical pesticides, hence without computed HTP.

4. Conclusion

The challenge of feeding the increasing population must be attained but without further degradation of non-renewable agricultural resources. Crop diversification is being encouraged because of its documented advantages i.e., reduce pests, higher land use efficiency, increase crop production, increase yield, etc. In the present study, obtaining optimum benefits of crop diversification and reducing potential environmental burdens can be best achieved through the practice of organic vegetable production system.

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