DOI: https://doi.org/10.4038/jdza.v9i1.69

Journal of Dry Zone Agriculture, 2023, 9(1): 45 – 65

Assessing environmental impacts of chemical fertilizers and organic fertilizers in Sri Lankan paddy fields through life cycle analysis

P.D. Kahandage[1,2*], C.P. Rupasinghe[3], K.T. Ariyawansha[1,4] and S.D.S. Piyathissa[1]

[1]Graduate School of Life and Environmental Sciences, University of Tsukuba, 1-1-1 Tennodai, Tsukuba, Ibaraki, 305-8572, Japan
[2]Department of Agricultural Engineering and Soil Science, Faculty of Agriculture, Rajarata University of Sri Lanka, Sri Lanka
[3]Department of Agricultural Engineering, Faculty of Agriculture, University of Ruhuna, Sri Lanka
[4]Department of Agricultural Technology, Faculty of Technology, University of Colombo, Sri Lanka

Received on June 25, 2023; Accepted on July 31, 2023

Abstract

The application of fertilizer is a very important activity in paddy cultivation as it is one of the yield-determining factors. But the use of chemical fertilizer is a matter of debate as it is suspected as a cause of many prevailing health problems and comparatively large amounts of environmental pollution. Therefore, the focus of this study was to carry out a proper life cycle analysis on the application of chemical and agricultural waste-based organic fertilizers considering all the important steps such as collection of raw material, manufacturing, transportation, and application fields. The integration application of chemical and organic fertilizers was considered with two different ratios. Characterized results reveal that chemical fertilizer application has the highest impact on all selected categories, while organic fertilizer application has lower impact.

Citation:
Kahandage, P., Rupasinghe, C., Ariyawansha, K., and Piyathissa, S. (2023). Assessing environmental impacts of chemical fertilizers and organic fertilizers in Sri Lankan paddy fields through life cycle analysis. *Journal of Dry Zone Agriculture*, *9*(1), 45-65.

*Corresponding author
Postal address: Department of Agricultural Engineering and Soil Science, Faculty of Agriculture, Rajarata University of Sri Lanka, Puliyankulama, Anuradhapura.
Email: pubudu2144@gmail.com, pubudu2144@agri.rjt.ac.lk

The combination of chemical and organic fertilizers shows that reducing the proportion of chemical fertilizers reduces environmental impacts. Additionally, the study identifies the processes that significantly contribute to each impact category, such as urea production for climate change and freshwater ecotoxicity, and composting and field application for human toxicity and terrestrial acidification. Normalized results show that switching to organic fertilizers could reduce up to 82.4% of the current environmental impact. Therefore, an integrated approach will give more benefits in many ways. These findings provide valuable insights for policymakers and farmers in making informed decisions regarding sustainable fertilizer management.

Keywords*:* Chemical fertilizer; Climate change; Environmental impacts; Organic fertilizer

Introduction

Agriculture plays a vital role in Sri Lankan economy by contributing 7% to the GDP with 0.7% from the paddy cultivation. The percentage of the population employed in agricultural sector of Sri Lanka is reported as 25.3 and the number of farmers engaging in paddy cultivation is about 1.8 million (Basnayake *et al.,* 2020). The average paddy yield of Sri Lanka in 2020 was reported as 4800 kg/ha and it is highly sensitive to the timely supply of water and fertilizer (Department of Census and Statistics of Sri Lanka, 2020). Therefore, the application of fertilizer is very important as it is one of the yield-determining factors. In Sri Lanka, most of the fertilizer use in paddy fields involves the application of chemical or inorganic fertilizer, accounting for 69.7% of the cultivated area. A combination of chemical and organic fertilizers is applied to 30% of the area, while only 0.1% of the cultivated land is treated solely with organic fertilizer (Department of Census and Statistics, 2020). Department of Agriculture, Sri Lanka has recommended a mixture of chemical fertilizers (Urea, Triple Super Phosphate (TSP), Muriate of Potash (MOP) and Zinc Sulphate) for paddy fields considering the climatic zones, duration of paddy variety and water supplying method. Nutrient balance in the soil is very important to have better quality and a higher yield from any crop.

Unlike natural forests, cultivation fields lose nutrients when the harvest is taken out. Intensive cultivation pattern leads to loss of the soil fertility very rapidly unless soil nutrients are provided with fertilizers. But the use of chemical fertilizer is a matter of debate as it is suspected as a cause of many prevailing health problems and comparatively large amounts of pollution. Even though fertilizers are beneficial, irresponsible use without effective management creates a variety of detrimental effects on the environment (United Nations, 2014). As 92% of chemical fertilizers are imported from leading producing countries, the country needs to bear a huge amount of direct transportation cost and indirect cost of environmental damage.

Although previously all the paddy farmers of Sri Lanka had a subsidy for chemical fertilizers, recently a ban on using them in agriculture was imposed by the government to popularize organic fertilizers in farming to prevent the adverse effects of chemical fertilizers. Among organic fertilizers, compost is widely used as a nutrient source for crops. According to the starting material and composting method, several types of compost are available. Adding compost to the soil is beneficial in several ways such as improving overall fertility by giving readily available nutrients, providing organic matter, vitamins, hormones, and plant enzymes, and acting as a buffer for soil pH. Municipal Solid Waste (MSW) in Sri Lanka is generated at the rate of 7,210 t/day and it consists of both biodegradable and non-biodegradable waste (Saja *et al.,* 2021).

The agricultural sector of the country also produces considerable amounts of biodegradable waste that can be easily used in composting. Crop residues such as green leaves, banana leaves, banana trunks, rice straw and rice husk, weeds, sawdust, food waste such as food and vegetable peelings, animal manure such as cow-dung and poultry manure, farmyard waste, and slaughterhouse waste are some of the cheap and abundantly available raw materials from agricultural sector for compost production in Sri Lanka. In medium-scale commercial level production of compost, windrows, semi-aerobic trenches, and in-vessel composting methods are currently being practiced (Dandeniya and Serena, 2020; MOA, 2022a).

The government has planned to implement a long-term policy to gradually reduce the use of chemical fertilizers by systematically solving the barriers to organic fertilizers. Therefore, the effect of chemical fertilizers and organic fertilizers on the environment should be judged comprehensively to support the future development policies of the country. Life Cycle Assessment (LCA) is an international standard methodology that considers all the inputs and outputs involved in the entire life cycle of a product or a system to estimate their potential environmental impacts (Mohammadi *et al.*, 2017). Therefore, this study aimed to carry out a proper life cycle analysis on the application of chemical and agricultural waste-based organic fertilizers considering all the important steps such as collection of raw material, manufacturing, transportation, and application to fields.

Material and methods

Goal and scope definition

The goal of this LCA was to comparatively assess the environmental impacts of Chemical Fertilizer Application (CFA), Organic Fertilizer Application (OFA), and two different ratios of them 70% of chemical fertilizer with 30% of organic fertilizers (COA1) and 50% of chemical fertilizer with 50% of organic fertilizers (COA2) with the functional unit of application for one hectare as recommended by the Department of Agriculture, Sri Lanka. Fig. 1 shows the selected boundary for the study. In a comparative LCA study, the emissions from similar processes can be excluded. Therefore, the impacts of the processes of land preparation, cultivation, and harvesting operations were excluded as they make similar effects on all the systems. Production of both chemical and organic fertilizers, transportation to one of the major paddy growing areas called Anuradhapura, application to the field, and all the emissions to air, water and soil were considered in this study.

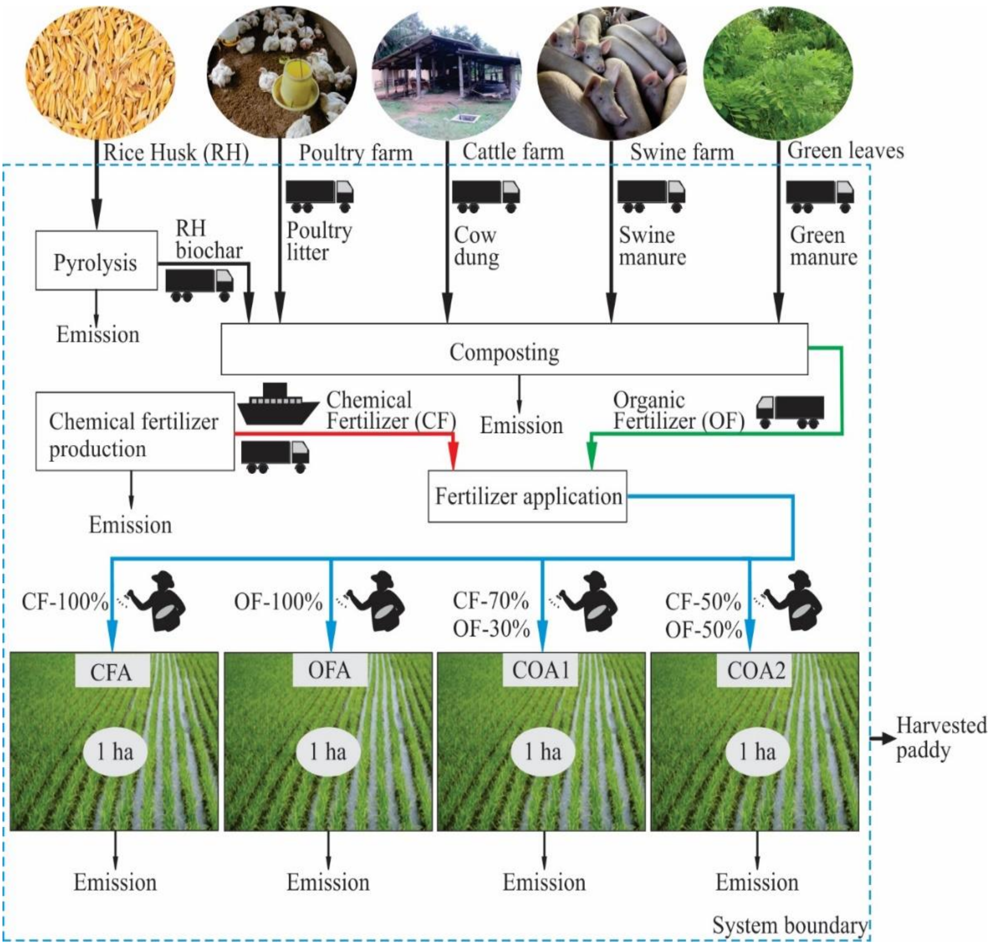

Fig. 1: Simplified flow chart for the boundaries of the selected systems CFA, OFA, COA1 and COA2 for fertilizer application in paddy fields.

Systems description

Paddy cultivation consists of several steps starting from land preparation to harvesting. Application of fertilizers and agrochemicals, weeding and irrigation are some of the inter-cultivation operations of paddy cultivation. Providing the essential nutrients, which are lacking in the natural soil, for healthy growth and a higher yield is the objective of fertilization. In the present study, the cultivation of paddy in the Anuradhapura area, which belongs to the dry zone of the country was considered. The chemical fertilizer recommendation for one hectare (ha) of paddy cultivated under irrigated conditions in the Intermediate zone and dry zone of Sri Lanka is 225 kg of Urea (N-46%), 55 kg of TSP (P_2O_5 - 45%), 60 kg of MOP (K_2O-40%), and 5 kg of Zinc Sulphate (DOA, 2022). The organic fertilizer is recommended as a blanket recommendation for any field of the country and for 1 ha of paddy, 500 kg of organic fertilizer (N⩾1%, P_2O_5⩾0.5%, K_2O⩾1%, MgO⩾0.5%, CaO⩾0.7% and Organic C⩾20%), 5 kg of plant nutrient Ammonium Acid (liquid nitrogen fertilizer), 35 kg of potash and 10 kg of bio-fertilizer have been recommended (MOA, 2022b; SLSI, 2019).

As compost is the most practicable type of organic fertilizer in Sri Lanka, the production and application of compost made from raw materials of agricultural origin was considered in this study. Considering the availability throughout the year and the suitability, rice husk, green leaves, cow dung, poultry manure with litter, and swine manure were considered as the agricultural origin raw material for the production of compost. Table 1 shows the availability of livestock manure in Sri Lanka. Therefore, the composition of the raw material for the compost was considered as 10% (W/W) of rice husk biochar, 30% (W/W) of green leaves, 20% (W/W) of cow dung, 20% (W/W) of poultry manure with litter and 20% (W/W) of swine manure.

Table 1. Availability of livestock manure in Sri Lanka

Type of livestock	Population in 2020 (heads)	Daily manure production/ head (kg/day)	Total daily manure production (kg)	Total Solid (%)
Poultry	41,970,000	0.10	4,197,000.0	10 – 29
Cattle	1,628,771	22.50	36,647,347.5	25 – 30
Buffalo	497,316	22.50	11,189,610.0	25 – 30
Swine	163,681	4.93	806,947.3	6 – 11

(Ali *et al.,* 2020; Chastain *et al.,* 1999; DAPH, 2020; Manogaran *et al.,* 2022)

Rice husk biochar collected from household-level rice husk pyrolytic cook stoves, which is an alternative to unbearable demand for cooking gas (LP gas) in the country, was considered in the production of compost. These stoves are popular in rural paddy growing areas for domestic-level rice parboiling, sterilization of grow bags in mushroom production, and cooking. As animal manure is a waste product of the livestock industry, the production process of manure was not considered. The windrow method was taken as the composting method. As mechanical application of fertilizer is not widely practiced in Sri Lanka, manual application for both chemical and organic fertilizer was considered.

Data sources and assessment

The fertilizer recommendations issued by the Department of Agriculture, Sri Lanka were taken into account in the application of chemical and organic fertilizers. As commercial-level organic fertilizer production with agricultural waste and rice husk biochar is not popular in Sri Lanka, the data available in published scientific studies were used in this study. Data on emissions from production of chemical fertilizers and emission from transportation were obtained from life cycle databases available in SimaPro software. The emission factors for composting and field application were collected from the available literature, so some of them may not be hundred percent fit for the Sri Lankan conditions making it a limitation of the study. The impact assessments were computed with SimaPro (version 8.4.0.0) software by using the ReCiPe 2008, Heirarchist perspective (H), version 1.12, with midpoint indicators and world normalization factors.

As the heirarchist perspective of the ReCiPe method is based on the most common policy principles, value choices made by it are scientifically and politically accepted (SimaPro, 2022). The impact categories of Climate Change (CC), Terrestrial Acidification (TA), Freshwater Eutrophication (FEP), Human Toxicity (HT), and Freshwater Ecotoxicity (FE) were selected out of 18 different impact categories included in ReCiPe method for the comparison of this study as all these issues are associated with the fertilizer production, supply chain and application to the field (Hasler *et al.,* 2015).

Life Cycle Inventory Analysis (LCIA)

This study focused on the raw material collection and transportation, production processes of chemical fertilizers and organic fertilizers, transportation of fertilizers to the field, and fertilizer application to the field. Table 2 summarizes the transportation information considered in the study.

Table 2. Transportation of materials

Material	Transport mode	Distance (km)	Remarks
Urea/ Plant nutrient Ammino acid	Sea	2077.9	From Port of Paradip, India to Colombo port
	Road	200.0	From Colombo port to Anuradhapura
MOP	Sea	11026.8	From Grodno FEZ Belarus to Colombo port
	Road	200.0	From Colombo port to Anuradhapura
TSP	Road	50.0	From Eppawala to Anuradhapura
Material for compost	Road	20.0	From different areas to Kurunegala
Compost	Road	110	From Kurunegala to Anuradhapura

The pyrolysis process of rice husk to produce biochar was considered as biochar amended compost gives many advantages. During the pyrolysis process of producing 1 kg of rice husk biochar, 168 g of CO, 15.62 g of CH_4, 1.67 g of NO_x and 2.11 g of PM_{10} are emitted (Mohammadi *et al.,* 2017; Sparrevik *et al.,* 2015). Greenhouse gas emission factors for dairy manure composting are 625 – 720 g of CO_2, 0.72 – 0.76 g of CH_4, and 0.2 – 0.37 g of N_2O for 1 kg of compost (Mulbry and Ahn, 2014). Therefore, in this study, 672.5 g of CO_2, 0.74 g of CH_4 and 0.28 g of N_2O emission from 1 kg of compost production were considered. The emission factors for CH_4 and N_2O during swine manure composting are 4.51 kg /t of dry solids and 0.00626 kg/t of dry solids, respectively (Zhong *et al.,* 2013). As shown by Agyarko-Mintah (2017), 0.01 g of CH_4 and 0.213 g of N_2O are emitted during the composting of 1 kg of poultry litter (Agyarko-Mintah *et al.,* 2017). The considered emission factors for green leaf composting were 6.2 g of CH_4 and 0.03 g of N_2O as suggested by Zhu-Barker *et al.*(2017). Several studies indicate that, 10% of biochar in composting mixtures can reduce CH_4 emission considerably as 53% from manure and 80% from poultry litter (Agegnehu *et al.,* 2016; Mohammadi *et al.,* 2017; Sonoki *et al.,* 2013). In this study, CH_4 emission reduction was taken as 25% as taking a higher value into account may be biased for the organic fertilizer as the country-specific data are not available.

Accumulation of heavy metals in the human food chain is a highly concerning issue and the application of fertilizer is one of the possible avenues for this. Although there are many heavy metals such as Cadmium (Cd), Arsenic (As), Chromium (Cr), Lead (Pb), Mercury (Hg), Nickel (Ni), and Vanadium (V) that could potentially have significant impacts, Cadmium (Cd) is considered as the most harmful one to human health. Commercial phosphate fertilizers are a source of Cadmium and other heavy metals while biofertilizers also contain small amounts of heavy metals. The Cadmium contained in phosphate fertilizers varies from country to country and an average value of 175 mg/kg was considered in this study and 10 mg/kg of average value was considered for animal manure.

Arsenic, Lead , and Mercury contained in phosphorus fertilizers are 71, 66, and 0.29 mg/kg of P, respectively and corresponding values in animal manure are 10,50, and 6 mg/kg, respectively (Mortvedt, 1995). The emission factor given by IPCC 2006 guidelines (0.2) was considered in the carbon emission of urea applications (Cecile De Klein *et al.,* 2006). The carbon emission factor for compost was considered as 0.2% based on the recommended minimum organic carbon content of compost (Dandeniya and Serena, 2020). The methane emission factor for poultry manure was taken as 0.94 kg/ kg N (Walling and Vaneeckhaute, 2020). The raw material to compost ratio considered in this study was 3:1. Table 3 gives the N_2O, NO and NH_3 emission factors considered in this study.

Table 3. Emission factors for N_2O, NO and NH_3

Type of fertilizer	**Emission factor (%)**		
	N_2O	**NO**	**NH_3**
Urea	1.1	0.6	25
N solutions	0.9	0.6	2.5
Organic fertilizers	0.6	0.4	20

(Bouwman and Van Der Hoek, 1997; Davis and Haglund, 1999)

The prepared inventories for the composting and field application of fertilizers in CFA, OFA, COA1, and COA2 are shown in Table 4.

Table 4. Life cycle inventory of CFA, OFA, COA1, and COA2 for 1 ha of paddy field

	Unit	CFA	OFA	COA1	COA2
Input					
Urea	kg	225	-	157.5	112.5
MOP	kg	60	-	42	30
TSP	kg	55	-	38.5	27.5
Zinc sulphate	kg	5	-	3.5	2.5
Liquid nitrogen fertilizer	kg	-	5	1.5	2.5
Cow dung	kg	-	300	90	150
Poultry litter	kg	-	300	90	150
Swine manure	kg	-	300	90	150
Green leaves	kg	-	450	135	225
RH biochar	kg	-	50	15	25
Bio liquid fertilizer	kg	-	10	3	5
Potash	kg	-	35	10.5	17.5
Transport (Sea)	tkm	1139.5	10.4	793.5	569.8
Transport (Road)	tkm	58	65	79.7	63.4
Output					
Direct emission to air					
Ammonia	kg	25.875	1.010	18.416	13.443
Carbon monoxide	kg	-	8.400	2.520	4.200
Carbon dioxide	kg	45.000	67.250	51.675	56.125
Methane	kg	-	1.124	0.337	0.562
Nitrous oxide	kg	1.139	0.053	0.016	0.026
PM_{10}	kg	-	0.106	0.032	0.053
Direct emission to water					
Nitrate	kg	5.175	0.253	3.698	2.714
Direct emission to soil					
Cadmium	kg	0.0096	0.003	0.0076	0.0063
Arsenic	kg	0.0039	0.003	0.0036	0.0035
Lead	kg	0.0036	0.015	0.0070	0.0093
Mercury	kg	0.000016	0.0018	0.0006	0.000908

Results and discussion

Comparison of the characterized results

The characterized midpoint environmental impact assessment results of the CFA, OFA, COA1, and COA2 for one hectare of paddy field are given in Table 5.

Table 5. Characterized LCIA results of CFA, OFA, COA1, and COA2 for 1 ha of paddy field.

Impact category	Unit	CFA	OFA	COA1	COA2
Climate Change (CC)	$kgCO_2eq$	1002.0711	135.1308	746.2248	568.9607
Terrestrial Acidification (TA)	$kgSO_2eq$	71.3672	2.6307	50.5246	36.8273
Freshwater Eutrophication (FEP)	kgPeq	0.1276	0.0003	0.0894	0.0639
Human Toxicity (HT)	kg1,4-DBeq	1065.7159	327.3303	844.8285	697.0787
Freshwater Ecotoxicity (FE)	kg1,4-DBeq	2.2226	0.0182	1.5637	1.1206

The highest impact in all the selected impact categories are exhibited by the chemical fertilizer application (CFA) while the lowest impact was recorded by the organic fertilizer application (OFA). It can be observed that the environmental impacts are reduced when the proportion of chemical fertilizer is reduced in the integrated application of chemical and organic fertilizers. Considering all the possible emissions such as emissions during the raw material production, transportation, and field application, the climate change potential of chemical fertilizer application is 1002.07 $kgCO_2eq$ and it is 7.4 times higher than the organic fertilizer application (Table 5).

Additionally, the terrestrial acidification (TA), freshwater eutrophication (FEP), human toxicity (HT), and freshwater ecotoxicity (FE) potentials of chemical fertilizer application were 27.14, 425.33, 3.26, and 122.12 times those of organic fertilizer application. Although organic fertilizer application in paddy fields brings many environmental benefits, one study conducted in Japan has shown that complete organic paddy cultivation including, organic fertilizer, and organic pests and weeds management makes comparatively higher environmental impacts (Hokazono and Hayashi, 2012). But, now higher attention is paid to low-carbon mechanization to reduce the emission by a higher degree of machinery use in organic farming (Kahandage *et al.*, 2023).

Contribution of unit processes to the characterized values in CFA

Fig. 2 displays the contributions of each process involved in CFA indicating that urea production accounts for 77.2% of climate change and 80.5% of freshwater ecotoxicity impact categories, while field application contributes 89.0% of terrestrial acidification and 87.0% of human toxicity. Furthermore, TSP production was identified as responsible for 76% of freshwater eutrophication. Surprisingly, contributions of MOP production, as well as transportation by road and sea, demonstrated lower values (less than 5%) for all impact categories in investigating CFA.

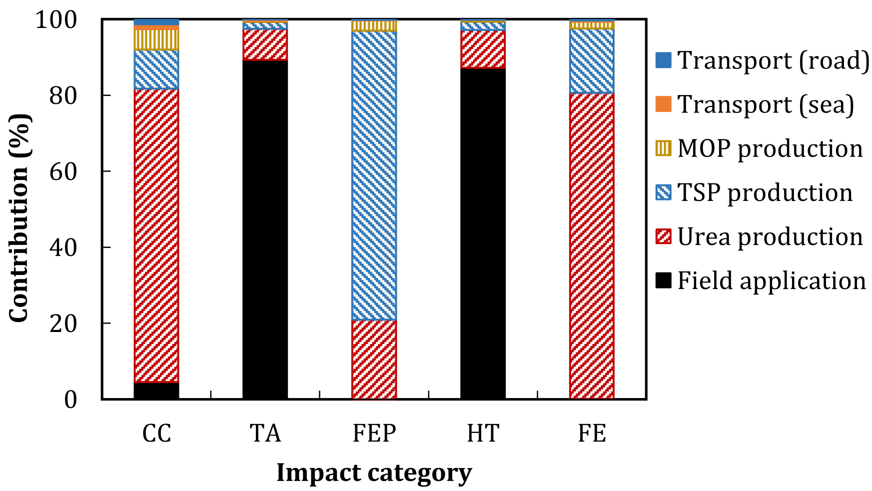

Fig. 2: Contribution of components for each impact category in chemical fertilizer application (CFA)

Climate change or global warming is caused by the emission of greenhouse gasses such as carbon dioxide, methane, nitrous oxide, carbon monoxide, hydrofluorocarbons, perfluorocarbons, sulfur hexafluoride, and nitrogen trifluoride. The production process of urea accounts for a considerable emission of these greenhouse gasses during production and transportation. According to the International Fertilizer Association (IFA), the greenhouse gas emission from global N fertilizer production is 470,000 ktCO_2eq (Menegat *et al.,* 2022).

SOx, NOx, CO, As, Cd, Pb, Hg, and PM10, have been identified as human toxic substances (Li and Qian, 2012), and the field application process of CFA contributes significantly to emitting As, Cd, Pb, and Hg. Eutrophication is mainly due to excessive levels of macronutrients such as phosphate in water caused by emissions of chemicals to the air, water, and soil (SimaPro Database Manual, 2021). The production process of triple super phosphate (TSP) contributes significantly to releasing phosphate into water bodies.

Contribution of unit processes to the characterized values in OFA

The impact categories of organic fertilizer application (OFA) were evaluated in eight processes, including the production of rice husk biochar, transportation by road and sea, liquid nitrogen fertilizer production, and composting of poultry litter, swine manure, green leaves, and cow dung, and field application. Fig. 3 illustrates the contribution of each component to the total characterized values given in Table 5.

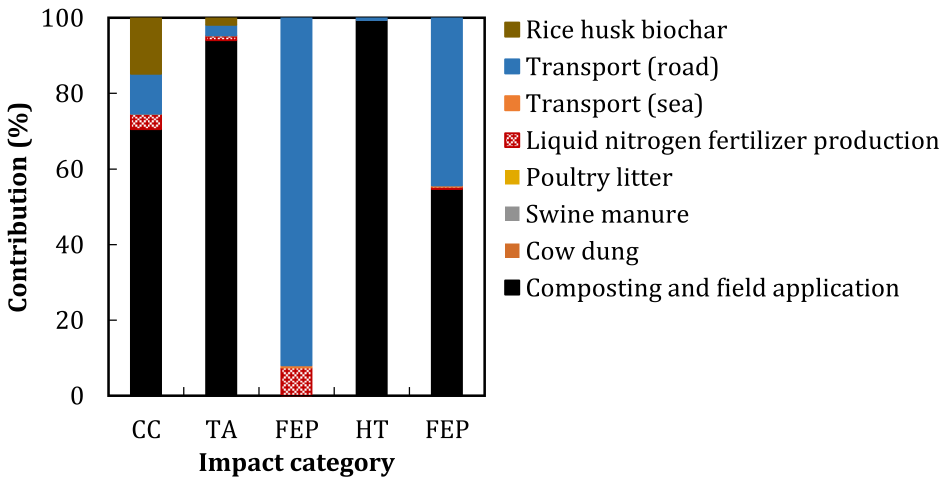

Fig. 3: Contribution of components for each impact category in organic fertilizer application (OFA)

The composting and field application process contributed significantly to climate change, terrestrial acidification, human toxicity, and freshwater ecotoxicity at 70.1%, 94.0%, 99.4%, and 54.8%, respectively. Road transportation also had high process contribution values at 91.9% in freshwater eutrophication and 44.3% in freshwater ecotoxicity. Rice husk biochar production showed a notable contribution to the climate change impact category at 14.8%, and liquid nitrogen fertilizer production contributed 7.3% to freshwater eutrophication. The other processes, including transport by sea, poultry litter composting, swine manure composting, and cow dung composting, did not have a significant impact in any of the evaluated impact categories according to the results of this study. Even though, the human toxicity index of OFA is very less compared to the CFA, more than 99% contribution has come from the composting and field application process as toxic emissions from other processes are negligible.

Contribution of unit processes to the characterized values in COA1

This study considers two different combinations of chemical and organic fertilizers, as a complete transition from chemical to organic is not yet practical in Sri Lanka. Fig. 4 shows the impact of each component in the combination of 70% chemical fertilizer and 30% organic fertilizer (COA1).

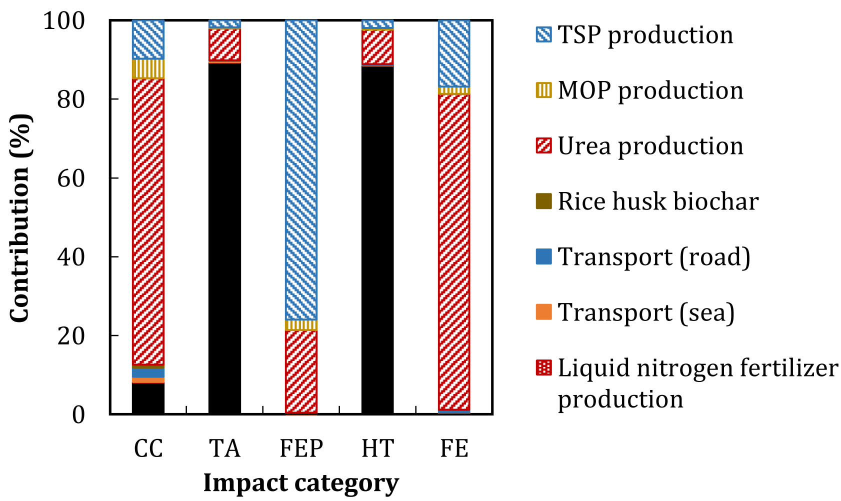

Fig. 4: Contribution of components for each impact category in 70% chemical fertilizer + 30% organic fertilizer application (COA1)

Urea production was found to have the largest contribution to freshwater ecotoxicity (80.1%), climate change (72.6%), freshwater eutrophication (20.9%), terrestrial acidification (8.0%), and human toxicity (8.7%). Composting and field application contributed significantly to terrestrial acidification (89.1%), human toxicity (88.1%), and climate change (8.8%). TSP production also played a considerable role in freshwater eutrophication (75.9%), freshwater ecotoxicity (16.8%), and climate change (9.7%). Other processes, such as MOP production, rice husk biochar production, transport (road/sea), liquid nitrogen fertilizer production, poultry litter composting, swine manure composting, and cow dung composting, made minimal contributions (less than 5%) to the relevant impact categories.

Contribution of unit processes to the characterized values in COA2

According to the characterized results in Table 5, COA2 (50% chemical fertilizer and 50% organic fertilizer) gives lower impacts compared to COA1. Fig. 5 demonstrates how individual components contribute to the total impacts of each category.

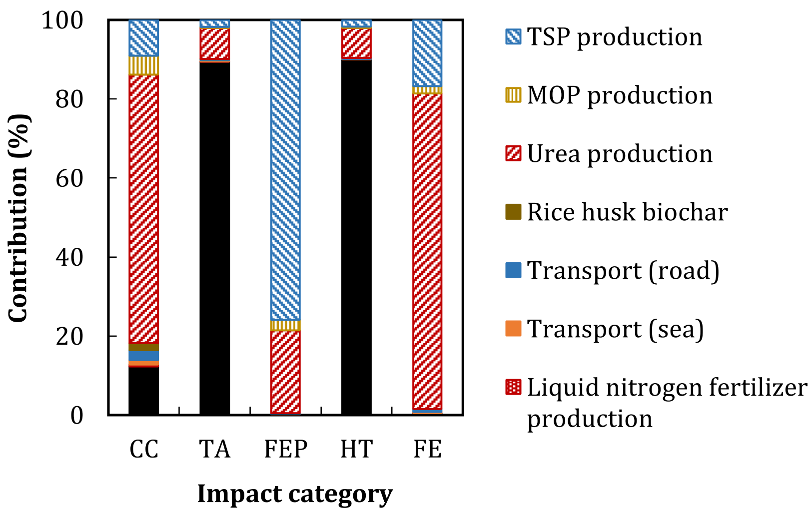

Fig. 5: Contribution of components for each impact category in 50% chemical fertilizer + 50% organic fertilizer application (COA2)

Even though the total impacts of categories are lower compared to COA1, a similar contribution pattern of components can be observed in COA2.

Specifically, the process of urea production showed a decrease in freshwater ecotoxicity, climate change, freshwater eutrophication, terrestrial acidification, and human toxicity. The contributions from composting and field application and TSP production were similar in both COA1 and COA2. Other processes such as MOP production, rice husk biochar production, transport (road and sea), liquid nitrogen fertilizer production, poultry litter composting, swine manure composting, and cow dung composting had low contributions, similar to COA1.

Comparison of the fertilizer application systems with normalized results

Normalized results are important to compare all the impact categories with the same units to obtain an idea about the magnitude of the impact of each category. Fig. 6 illustrates the normalized results of fertilizer application systems.

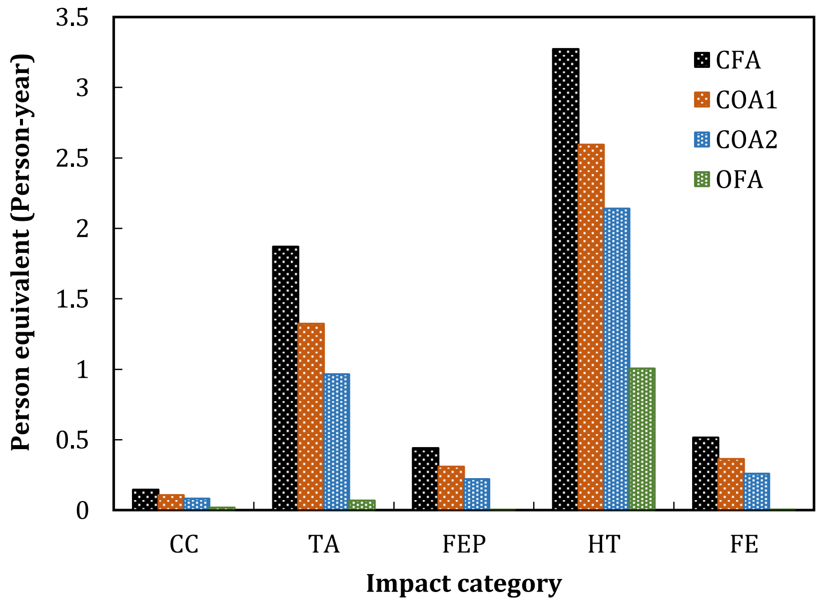

Fig. 6: Normalized impacts of CFA, OFA, COA1, and COA2

The overall impact of the CFA on the environment is 5.68, 1.33, and 1.70 times greater than that of the OFA, COA1, and COA2, respectively, as per the sum of all normalized results. This indicates that switching to organic fertilizer could reduce 82.4% of the current environmental impact. The greatest impact on the environment is attributed to human toxicity, accounting for 52.4%, 91.47%, 55.2%, and 58.3% of the normalized impacts of the CFA, OFA, COA1, and COA2, respectively. Climate change had the least impact on the CFA, COA1, and COA2, while the OFA had the least effect on freshwater ecotoxicity, as demonstrated by Fig. 6.

Conclusions

In conclusion, the study shows that the use of chemical fertilizer application (CFA) has significantly higher impact on the environment compared to organic fertilizer application (OFA). The reduction of chemical fertilizer in integrated application with organic fertilizer reduces environmental impacts. The production process of urea is identified as the most significant contributor to environmental impacts, particularly climate change. Composting and field application contribute significantly to several environmental impacts in the OFA and integrated systems. The study suggests that switching to organic fertilizers could reduce the environmental impact of paddy cultivation by 82.4%.

Integrating organic fertilizer and gradually reducing the use of chemical fertilizers can provide a practical solution to overcome various barriers in fully transitioning to organic farming in Sri Lanka. This approach offers significant environmental benefits and is likely to be more widely accepted.

Declaration of conflict of interest

Authors have no conflict of interest to declare.

References,

Agegnehu, G., Bass, A. M., Nelson, P. N., and Bird, M. I. (2016). Benefits of biochar, compost and biochar–compost for soil quality, maize yield and greenhouse gas emissions in a tropical agricultural soil. *Science of the Total Environment*, *543*, 295-306.

Agyarko-Mintah, E., Cowie, A., Singh, B. P., Joseph, S., Van Zwieten, L., Cowie, A., and Smillie, R. (2017). Biochar increases nitrogen retention and lowers greenhouse gas emissions when added to composting poultry litter. *Waste Management*, *61*, 138-149.

Ali, M. M., Ndongo, M., Bilal, B., Yetilmezsoy, K., Youm, I., and Bahramian, M. (2020). Mapping of biogas production potential from livestock manures and slaughterhouse waste: A case study for African countries. *Journal of Cleaner Production*, *256*, 120499.

Basnayake, S.K.., Hamangoda, I., Pushpakumari, G.G., 2020. Agricultural Statistics. Peradeniya.

Bouwman, A. F., and Van Der Hoek, K. W. (1997). Scenarios of animal waste production and fertilizer use and associated ammonia emission for the developing countries. *Atmospheric Environment*, *31*(24), 4095-4102.

Cecile De Klein, Novoa, R.S.A., Ogle, S., Smith, K.A., Philippe Rochette (Canada), and T.C.W. (USA), G., M.B., Mosier, A., Rypdal, K., 2006. Chapter 11: N_2O emissions from managed soils, and CO_2 emissions from lime and urea application, IPCC.

Chastain, J. P., Camberato, J. J., Albrecht, J. E., and Adams, J. (1999). Swine manure production and nutrient content. *South Carolina confined animal manure managers certification program*, *3*, 1-17.

Dandeniya, W. S., and Caucci, S. (2020). Composting in Sri Lanka: policies, practices, challenges, and emerging concerns. *Organic Waste Composting through Nexus Thinking: Practices, Policies, and Trends*, 61-89.

DAPH, 2020. Livestock statistical bulletin 2020. Department of Animal Production and Health, Peradeniya.

Davis, J. (1999*). Life cycle inventory (LCI) of fertiliser production: fertiliser products used in Sweden and Western Europe*. SIK Institutet för livsmedel och bioteknik, Göteborg, Sverige.

Department of Census and Statistics, 2020. Paddy statistics 2019/2020 Maha Season, Department of Census and Statistics Sri Lanka.

DOA, 2022. Rice in Sri Lanka - New Fwrtilizer Reccomendation [www. Document]. Dep. Agric.

Hasler, K., Bröring, S., Omta, S. W. F., and Olfs, H. W. (2015). Life cycle assessment (LCA) of different fertilizer product types. *European Journal of Agronomy*, *69*, 41-51.

Hokazono, S., and Hayashi, K. (2012). Variability in environmental impacts during conversion from conventional to organic farming: a comparison among three rice production systems in Japan. *Journal of cleaner production*, *28*, 101-112.

Kahandage, P. D., Piyathissa, S. D. S., Ariesca, R., Namgay, Ishizaki, R., Kosgollegedara, E. J., and Noguchi, R. (2023). Comparative Analysis of Paddy Harvesting Systems Toward Low-carbon Mechanization in the Future: A Case Study in Sri Lanka. *Processes*, *11*(6), 1851.

Lanka, S. (1986). Department of Census and Statistics. *Statistical abstract of the Democratic Socialist Republic of Sri Lanka*, 213-65.

Li, H., Qian, Y., 2012. Human Toxicity Potential - an overview | ScienceDirect Topics [www Document].

Manogaran, M. D., Shamsuddin, R., Yusoff, M. H. M., Lay, M., and Siyal, A. A. (2022). A review on treatment processes of chicken manure. *Cleaner and Circular Bioeconomy*, *2*, 100013.

Menegat, S., Ledo, A., and Tirado, R. (2022). Greenhouse gas emissions from global production and use of nitrogen synthetic fertilisers in agriculture. *Scientific Reports*, *12*(1), 14490.

MOA, 2022a. Ministry of Agriculture - Sri Lanka - Promotion of Production And Use Of Organic Fertilizer [www Document].

MOA, 2022b. Several Institutions are contributing to meet the Maha season organic fertilizer requirements [www Document]. Minist. Agric.

Mohammadi, A., Cowie, A. L., Mai, T. L. A., Brandao, M., de la Rosa, R. A., Kristiansen, P., and Joseph, S. (2017). Climate-change and health effects of using rice husk for biochar-compost: Comparing three pyrolysis systems. *Journal of Cleaner Production*, *162*, 260-272.

Mortvedt, J. J. (1995). Heavy metal contaminants in inorganic and organic fertilizers. *Fertilizer research*, *43*, 55-61.

Mulbry, W., and Ahn, H. (2014). Greenhouse gas emissions during composting of dairy manure: Influence of the timing of pile mixing on total emissions. *Biosystems Engineering*, *126*, 117-122.

Saja, A. M. A., Zimar, A. M. Z., and Junaideen, S. M. (2021). Municipal solid waste management practices and challenges in the southeastern coastal cities of Sri Lanka. *Sustainability*, *13*(8), 4556.

SimaPro, 2022. Article: Perspectives and weighing approach in ReCiPe method [www Document]. SimaPro Help Cent.

Karlsdottir, M. R., Heinonen, J., Palsson, H., and Palsson, O. P. (2020). Life cycle assessment of a geothermal combined heat and power plant based on high temperature utilization. *Geothermics*, *84*, 101727.

SLSI, 2019. Specification for Compost Made From Raw Materials of Agricultural Origin. Sri Lanka Standards Institution, Colombo 8.

Sonoki, T., Furukawa, T., Jindo, K., Suto, K., Aoyama, M., and Sánchez-Monedero, M. Á. (2013). Influence of biochar addition on methane metabolism during thermophilic phase of composting. *Journal of Basic Microbiology*, *53*(7), 617-621.

Sparrevik, M., Adam, C., Martinsen, V., and Cornelissen, G. (2015). Emissions of gases and particles from charcoal/biochar production in rural areas using medium-sized traditional and improved "retort" kilns. *Biomass and Bioenergy*, *72*, 65-73.

United Nations, 2014. Environmental and Health Impacts of Pesticides and Fertilizers and Ways of Minimizing Them.

Walling, E., and Vaneeckhaute, C. (2020). Greenhouse gas emissions from inorganic and organic fertilizer production and use: A review of emission factors and their variability. *Journal of Environmental Management*, *276*, 111211.

Zhong, J., Wei, Y., Wan, H., Wu, Y., Zheng, J., Han, S., and Zheng, B. (2013). Greenhouse gas emission from the total process of swine manure composting and land application of compost. *Atmospheric Environment*, *81*, 348-355.

Zhu-Barker, X., Bailey, S. K., Burger, M., and Horwath, W. R. (2017). Greenhouse gas emissions from green waste composting windrow. *Waste management*, *59*, 70-79.