Research article

Environmental Impact Assessment of Air Emission from Fertilizer Utilization and Rice Straw Burning from Rice Production in Cambodia

LEAKHENA HANG*
Faculty of Hydrology and Water Resources Engineering, Institute of Technology of Cambodia, Phnom Penh, Cambodia
Email: leakhena.hang@itc.edu.kh

SREYNEANG THEY
Faculty of Chemical and Food Engineering, Institute of Technology of Cambodia, Phnom Penh, Cambodia

SELA KONG
Faculty of Chemical and Food Engineering, Institute of Technology of Cambodia, Phnom Penh, Cambodia

CHENDA LAI
Faculty of Hydrology and Water Resources Engineering, Institute of Technology of Cambodia, Phnom Penh, Cambodia

DALIN UM
Research and Innovation Center, Institute of Technology of Cambodia, Phnom Penh, Cambodia

RAKSMEY YIM
Department of Air Quality, Noise, and Vibration Management, Ministry of Environment, Phnom Penh, Cambodia

Received 1 August 2023 Accepted 10 November 2023 (*Corresponding Author)

Abstract Rice is the most important staple food for feeding nearly half of the world's population, and almost the entirety of the population of Asia. An increase in food demand leads to an increase in agricultural residues, resulting in impacts on human health and environmental consequences. The current study aimed to estimate the emission of primary and secondary fine particulate matter attributable to fertilizer from the open burning or rice straw in Cambodia in terms of country-specific characterization factors (CFs), and to estimate the human health and ecosystem impact of particulate matter formation and terrestrial acidification. Additionally, the study aimed to propose an alternative scenario to reduce the negative impact on human health and the ecosystem. Three scenarios were set to conduct the study's assessment, including a baseline scenario representing current farmer practices, including typical fertilizer application rates and open burning of rice straw after harvest (S0); a scenario reducing fertilizer use to 60% while still allowing open rice straw burning (S1); and a scenario with no open rice straw burning and a 60% reduction in fertilizer use (S2). Human health damage was calculated in units of Disability Adjusted Life Year (DALY), and ecosystem impact was expressed in the units of Potentially Disappeared Fraction of species (PDF/m^2/yr) presented under the scenarios. The total human health impact of S0 was 5.35E+01 DALY, S1 was 5.27E+01 DALY, and S2 was 3.75E-01 DALY, while the total ecosystem impact of S0 was 4.38E-02 (PDF/m^2/yr), S1 was 3.60E-02 (PDF/m^2/yr), and S2 was 4.85E-03 (PDF/m^2/yr). The results of this study indicated that minimizing the use of chemical fertilizer and zero open burning of agricultural waste can reduce the number of pollutants that affects human health and ecosystem soil acidification. It showed that reducing burning straw waste can reduce the toxins that affect human health by 99% and reduce the increase of soil acidity by 94%.

Keywords air pollution, DALY, LCA, particulate matter ($PM_{2.5}$), rice production

INTRODUCTION

Rice has now become a foreign exchange earner for several countries and plays an important role in their economies (Kumar et al., 2017). In the case of Cambodia, rice production has increased significantly in the last decades, particularly since the major economic reforms in 1989. The planted areas of rice increased from 1.9 million hectares (ha) in 1990–1991 to about 2.6 million hectares in 2009–2010 (ASEAN Development Bank, 2012). Favorable weather conditions, an increase in the availability of rural credit and private investment, technology improvement, new high-yield rice varieties, application of chemical fertilizer and other inputs are the factors of the increasing rice yield (The World Bank, 2015). Excessive fertilization and mindless use, obviously caused soil salinity, heavy metal accumulation, water eutrophication, and accumulation of nitrate, considered in terms of air pollution in the air of gases containing nitrogen and sulfur, which can lead to problems such as the greenhouse effect (Savci, 2012; Chandini et al., 2019). In the United States, uncontrolled agricultural emissions will influence states' ability to satisfy global environmental impacts. Despite recent progress to reduce sulfur oxide (SO_x) and nitrogen oxide (NO_x) emissions, NH_3 plays a substantial role in $PM_{2.5}$ formation, and increasing ammonia may increase $PM_{2.5}$ (aerosols with aerodynamic diameters less than or equal to 2.5 µm) concentrations (Clappier et al., 2021). The compound of these pollutants such as criteria pollutants of known tropospheric O_3, SO_2, and $PM_{2.5}$ affects human health and the environment. Animal production, chemical fertilizer application, land use land changes, biomass burning, and other agricultural practice is a primary producer of increased gases and particulate matter (Clappier et al., 2021). Particulate Matter of air pollution is an air-suspended mixture of solid and liquid particles that vary in number, size, shape, surface area, chemical composition, solubility, and origin. The size distribution of total suspended particles (TSPs) in the ambient air is tri-modal, including coarse particles, fine particles, and ultrafine particles (Chow, 1995). Agricultural residue open burning in Southeast Asia accounts is up to 43% of the total open biomass burning (BB) which contributes significantly to air pollution. BB is a source of global air pollution that typically contains $PM_{2.5}$ sulfur dioxide (SO_2), nitrogen oxides (NOx), carbon monoxide (CO), carbon dioxide (CO_2), ammonia (NH_3), methane (CH_4), and other air pollutants (Le et al., 2020). It is estimated that in developing countries approximately 300,000 to 700,000 people can be saved from premature death if aerosol levels are reduced to a safe level (an Air Quality Index (AQI) under 100 signifies good or acceptable air quality) (Seinfeld and Pandis, 2016). Thus, this study aims to investigate the impact assessment of air pollutants emitted from chemical fertilizer and rice straw open burning from rice production in Cambodia and to analyze human health impact assessment and ecosystem impact terrestrial acidification using an analytical tool called Life Cycle Assessment (LCA). Also, to provide a recommendation on negative impact reduction under three scenarios are set to conduct the study's assessment.

METHODOLOGY

Data Collection

The chemical fertilizer application data was collected from the survey questionnaires of three provinces known as Prey Veng, Svay Reing, and Kampong Thom province. The practical application of chemical fertilizer (Urea; DPA; KCl) from the farmers is 27 kg/1ton of rice production; it was considered as scenario S0 and from a lab-scale experiment at Cambodia Agriculture Research Development Institute (CARDI) which was carried out by the plantation in the column-based experiment of a known diameter by Lai et al. (2022) based on the soil type used in the experiment with the application of 11kg chemical fertilizer/1ton of rice production (Chemical fertilizer application was recommended by CARDI); represent the scenario S1, and the scenario S2 is the condition of combination chemical fertilizer application recommendation by CARDI with Zero burning after harvesting.

Emission Inventory Assessment

Emission of NH_3 and NO_x from chemical fertilizer and $PM_{2.5}$, NO_X, NH_3, and SO_2 from rice straw open burning were estimated according to the methodology of the EMEP guidelines 2016 (EEA (European Environment Agency) 2016) and Tier1 of the EMEP/EEA guidebook 2019, respectively.

Emission from fertilizer:

$$NH_3 = 17/14 \sum_{m-1}^{M} (\mathrm{EF}a_m \times P + EFb_m \times (1 - P)) N_{min,m} \quad (1)$$

where NH_3 is ammonia emission after mineral fertilizer application [kg NH_3]; m is fertilizer type; *M* is the number of fertilizer types; $\mathrm{EF}a_m$ is the emission factor on soil with pH ≤ 7 [kg NH_3-N/kg N]; $\mathrm{EF}b_m$ is the emission factor on soils with pH > 7 [kg NH_3-N/kg N]; *P* is the fraction of soils with pH ≤ 7 [%/100]; N_{min} is mineral fertilizer application [kg N]; 17/14 is the conversion factor from N to NH_3 (NH_3 = 17 g/mol and N = 14 g/mol).

Emission from rice straw open burning:

$$E = Activity\ data \times Emission\ factor\ (EF) \quad (2)$$

where *E* is the emission of the pollutant; *EF* is the emission factor obtained from EMEP/EEA tier 1 The *EF* of $PM_{2.5}$ 140 g/GJ, NOx 91 kg/GJ, SO2 11 g/GJ table 3.5 page 17 in 1.A.2 EMEP/EEA 2019; Activity data is the amount of burnt source categories.

Where the total amount of rice straw from rice production was calculated following the formula developed by (Shrestha et al., 2013).

Life Cycle Impact Assessment

The human health impact assessment was estimated from particulate matter formation ($PM_{2.5}$, NOx, NH_3, and SO_2), while the Ecosystem impact assessment was estimated from the terrestrial acidification (NH_3, SO_2, and NOx).

Human Health Impact Assessment

The human health impact is expressed as DALYs (disability-adjusted life years), the years of life lost due to death + years of lived with disability, was calculated by applying the ReCiPe 2016 v1.1 (A harmonized life cycle impact assessment method at midpoint and endpoint level by (Huijbregts et al., 2017).

$$HI = E \times CFs \quad (3)$$

where *HI* is human health impact expressed in DALYs; E is the emission of pollutants; *CFs* is endpoint characterization factors of human health (yr. $kton^{-1}$) level in Cambodia.

Ecosystem Impact Assessment (Terrestrial Acidification)

$$Ecosystem\ impact = E \times CF \quad (4)$$

where *E* is the emission of the pollutant; Ecosystem impact is the potentially disappeared fraction of species ($PDF/m^2/yr$); *CF* is the endpoint characterization factors of an ecosystem (species/kg) level in Cambodia.

To propose a scenario to reduce air pollution that affects human health and ecosystem impact, the estimation was carried out under three scenarios. First scenario S0; the baseline is the condition of using chemical fertilizer (Urea, DAP, KCl) and rice straw open burning by farmers practiced from the survey. The second scenario (S1), is the application of chemical fertilizer (Urea, DAP, KCl) recommended by CARDI with the practice of rice straw open burning by column based-experimental (Lai et al., 2022). The third scenario (S2); the optimization is the application of chemical fertilizer NPK recommendation by CARDI with zero burning of rice straw.

RESULTS AND DISCUSSION

Emission Inventory

The estimation of air pollutants NH_3, NOx, $PM_{2.5}$, NO_x, and SO_2 from chemical fertilizer and rice straw open burning is expressed as kg/1ton of rice production. Figure 1 reveals the concentration of emissions released from chemical fertilizer and rice straw open burning under the three studied scenarios. It is noticed that the pollutants released from the application of fertilizer by farmers practiced (S0) are higher than the pollutants emitted from the reducing fertilizer application recommended (S1) by 76%. In addition, the result showed that rice straw open burning is the majority of source of $PM_{2.5}$ and SO_2 (Fig. 1) of scenario S2. The study by (Lorn et al., 2022) investigating $PM_{2.5}$ from fertilizer usage, fuel combustion, and straw residue burning revealed that 51.56% of the total emission in the study is generated by rice straw open burning and 24.10% generated from fertilizer.

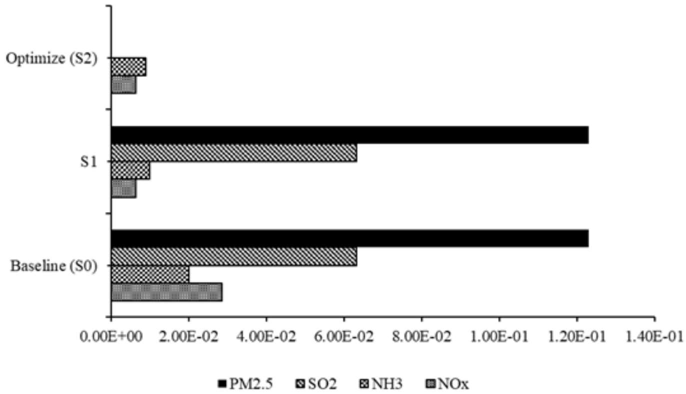

Fig. 1 Emission of pollutants of the studied scenarios from 1 ton of rice production

Life Cycle Impact Assessment

Life cycle impact assessment from two endpoint categories, human health impact (the particulate matter formation) and ecosystem impact (terrestrial acidification) are estimated from the emission of chemical fertilizer and rice straw open burning, is represented as kg/ton of rice production, are expressed as DALYs and PDF/m^2/yr, respectively. The human health impact estimation revealed the highest value in scenario S0 (5.35E+01 DALYs) if compared to scenario S1 (5.27E+01DALYs) and S2 (3.75E-01DALYs).

Figure 2 showed that the human health impact is contributed majority from $PM_{2.5}$ and SO_2 which contributed from rice straw open burning, following by NO_x, and NH_3. It is also noticed that the highest value of ecosystem impact estimation is found in scenario S0 (4.38E-02 PDF/m^2/yr), while S1 and S2 are 3.60E-02 PDF/m^2/yr and 4.85E-03 PDF/m^2/yr, respectively (Fig. 3). Based on the finding result, SO_2 is the most contributor to ecosystem impact following by NH_3, and NO_x, respectively. As can be seen in the result, a great negative impact on both human health impact and the ecosystem impact happened under scenario S0. The particulate matter formation from both primary and secondary sources of rice straw open burning practiced and excessive application of chemical fertilizer are seriously affecting both human health and the ecosystem. In the case of eastern and north-central China, regions with large population densities and high levels of $PM_{2.5}$, approximately 4% of all-cause mortality in the country can be avoided (95% confidence interval: 1-7%) by reducing emissions of primary particulate matter and gaseous particulate matter precursors, and thus lower ambient concentrations of $PM_{2.5}$ (Zhao et al., 2011). Mahmood and Gheewala, (2020) stated that rice straw open burning which emitted the majority of $PM_{2.5}$, exhibited significant impacts on the environment, terrestrial acidification, freshwater eutrophication, and human damage to ozone formation. To reduce the amount of particulate matter formation and terrestrial acidification emitted to the environment which affects greatly human health and the ecosystem, it is suggested to stop the activity of open burning and excessive use of chemical fertilizer so it can prevent damage to human health by 99% and to the ecosystem by 94%.

In Asia, managing rice straw remains a challenging matter. The available information and knowledge are scattered and either cannot reach the target practiced (farmers, and rural people) (Van Hung et al., 2020). The common management practice of rice straw is to leave straw to integrate into the soil known as rice straw incorporation. The incorporation practice can improve soil fertility yet adequate time must be allowed to ensure the effectiveness of the decomposition, thus it may not be considered by a short cycle of crop growing practice (Zhang et al., 2021). Cattle feed and mushroom cultivating are other alternatives to rice straw management (Gummert et al., 2020), and recommended rice straw used in biochar studies is suggested (Ly et al., 2015; Chandra and Bhattacharya, 2019). However, positive and effective results can be obtained unless all parties must involve (farmers and government) and recognize the serious effect of the uncertain method of managing rice straw.

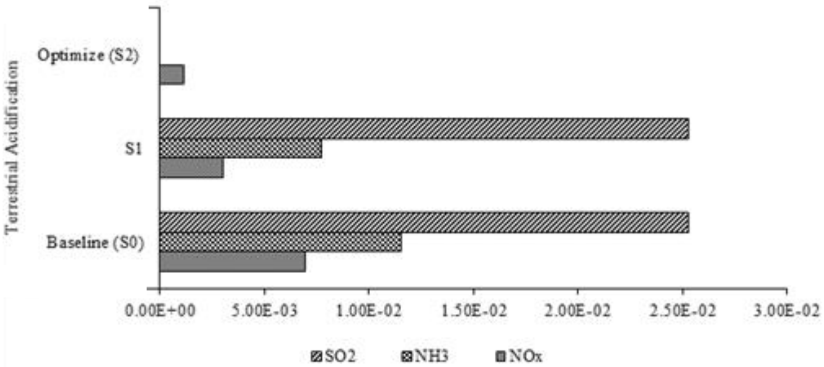

Fig. 2 Human health impact from particulate matter formation

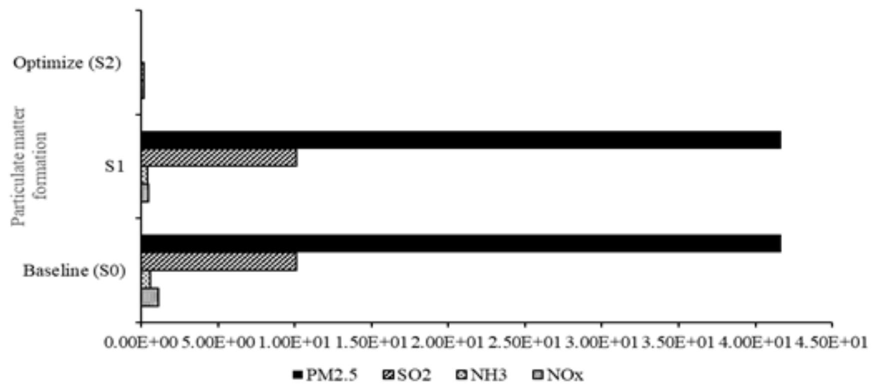

Fig. 3 Ecosystem impact from terrestrial acidification

CONCLUSION

Chemical fertilizer and rice straw open-burning activity emitted pollutants that are harmful to both human health and the ecosystem. Rice straw open burning released the majority of $PM_{2.5}$ and SO_2 while the most pollutant emitted from chemical fertilizer is NOx. Emissions released from rice straw open burning alone cause great effects on both human health and the ecosystem. It is suggested to stop the activity of open burning and the excessive practice of applying chemical fertilizer, therefore it can reduce 99% of human health impact and 94% of ecosystem impact.

To tackle this issue, educating people about the harmful effects of burning rice straw and other agricultural waste is crucial. Additionally, implementing improvements in straw utilization rates and minimizing open-field burning are vital steps towards establishing a circular bio-economy that utilizes agricultural straw as a valuable resource. Moreover, it is important to invest in improving technology for mushroom and ruminant farming. Lastly, promoting the elimination of agricultural waste and open burning is crucial for a sustainable future.

ACKNOWLEDGEMENTS

This paper was funded by Cambodia Higher Educational Improvement Project (credit No.6221-KH). The author would like to thank the Institute of Technology of Cambodia for all its facilities.

REFERENCES

Chandini, Kumar, R., Kumar, R. and Prakash, O. 2019. The impact of chemical fertilizers on our environment and ecosystem. In Research Trend in Environment Science, 2nd Edition, 71-86, Retrieved from URL https://www.researchgate.net/publication/331132826

Chandra, S. and Bhattacharya, J. 2019. Influence of temperature and duration of pyrolysis on the property heterogeneity of rice straw biochar and optimization of pyrolysis conditions for its application in soils. Journal of Cleaner Production, 215, 1123-1139, Retrieved from DOI https://doi.org/10.1016/j.jclepro.2019.01.079

Chow, J.C. 1995. Measurement methods to determine compliance with ambient air quality standards for suspended particles. Journal of the Air and Waste Management Association, 45 (5), 320-382, Retrieved from DOI https://doi.org/10.1080/10473289.1995.10467369

Clappier, A., Thunis, P., Beekmann, M., Putaud, J.P. and de Meij, A. 2021. Impact of SO_x, NO_x and NH_3 emission reductions on $PM_{2.5}$ concentrations across Europe, Hints for future measure development. Environment International, 156, 106699, Retrieved from DOI https://doi.org/10.1016/j.envint.2021.106699

Gummert, M., Hung, N.V., Chivenge, P. and Douthwaite, B. 2020. Sustainable rice straw management. Springer Nature, Retrieved from DOI https://doi.org/10.1007/978-3-030-32373-8

Huijbregts, M.A.J., Steinmann, Z.J.N., Elshout, P.M.F., Stam, G., Verones, F., Vieira, M., Zijp, M., Hollander, A. and van Zelm, R. 2017. ReCiPe2016, A harmonised life cycle impact assessment method at midpoint and endpoint level. The International Journal of Life Cycle Assessment, 22 (2), 138-147, Retrieved from DOI https://doi.org/10.1007/s11367-016-1246-y

Kean, S. 2012. The rice situation in Cambodia. Asian Development Bank, Retrieved from URL https://www.adb.org/projects/documents/rice-situation-cambodia-tacr

Kumar, V., Mahajan, G. and Chauhan, B. S. 2017. Rice weeds and their management. In B. S. Chauhan, B.S., Jabran, K. and Mahajan, G. (Eds.), Rice Production Worldwide, 361-392. Springer International Publishing, Retrieved from DOI https://doi.org/10.1007/978-3-319-47516-5_14

Lai, C., Ly, N., Touch, V., Hin, S., Podwojewski, P., Ket, P., Jouquet, P., Degré, A. and Ann, V. 2022. Evaluating the effect of biochar on nutrient leaching and rice growth in disturbed and undisturbed soil-columns. Biology and Life Sciences Forum 2022, 16, 5, Retrieved from URL https://doi.org/10.3390/IECHo2022-12497

Le, H.A., Phuong, D.M. and Linh, L.T. 2020. Emission inventories of rice straw open burning in the Red River Delta of Vietnam, Evaluation of the potential of satellite data. Environmental Pollution, 260, 113972, Retrieved from DOI https://doi.org/10.1016/j.envpol.2020.113972

Lorn, S., Ket, P., Or, C., Kong, S., Um, D., Aun, S., Taing, C. and Hang, L. 2022. Health impact assessment from rice straw production in Cambodia. Applied Sciences, 12 (20), 10276, Retrieved from DOI https://doi.org/10.3390/app122010276

Ly, P., Duong Vu, Q., Jensen, L.S., Pandey, A. and de Neergaard, A. 2015. Effects of rice straw, biochar, and mineral fertiliser on methane (CH_4) and nitrous oxide (N_2O) emissions from rice (*Oryza sativa* L.) grown in a rain-fed lowland rice soil of Cambodia, A pot experiment. Paddy and Water Environment, 13 (4), 465-475, Retrieved from DOI https://doi.org/10.1007/s10333-014-0464-9

Mahmood, A. and Gheewala, S. 2020. A comparative assessment of rice straw management alternatives in Pakistan in a life cycle perspective. Journal of Sustainable Energy and Environment, 11, 21-29, Retrieved from URL https://jseejournal.com/media/216/attachment/A%20comparative%20assessment%20pp.%2021-29.pdf

Savci, S. 2012. Investigation of effect of chemical fertilizers on environment. APCBEE Procedia, 1, 287-292, Retrieved from DOI https://doi.org/10.1016/j.apcbee.2012.03.047

Seinfeld, J.H. and Pandis, S.N. 2016. Atmospheric chemistry and physics, From air pollution to climate change. In John Wiley and Sons, ISBN 978-1-118-94740-1, Retrieved from URL https://bcs.wiley.com/he-bcs/Books?action=index&itemId=1118947401&bcsId=10410

Shrestha, P.M., Rotaru, A.E., Aklujkar, M., Liu, F., Shrestha, M., Summers, Z.M., Malvankar, N., Flores, D. C. and Lovley, D.R. 2013. Syntrophic growth with direct interspecies electron transfer as the primary mechanism for energy exchange. Environmental Microbiology Reports, 5 (6), 904-910, Retrieved from DOI https://doi.org/10.1111/1758-2229.12093

The World Bank. 2015. Cambodian agriculture in transition, Opportunities and risks. World Bank, Retrieved from URL https://www.worldbank.org/en/country/cambodia/publication/cambodian-agriculture-in-transition-opportunities-and-risks

Van Hung, N., Maguyon-Detras, M.C., Migo, M.V., Quilloy, R., Balingbing, C., Chivenge, P. and Gummert, M. 2020. Rice straw overview, Availability, properties, and management practices. In Gummert, M., Hung, N.V., Chivenge, P. and Douthwaite, B. (Eds.), Sustainable Rice Straw Management, 1-13. Springer International Publishing, Retrieved from DOI https://doi.org/10.1007/978-3-030-32373-8_1

Zhang, J., Li, W., Zhou, Y., Ding, Y., Xu, L., Jiang, Y. and Li, G. 2021. Long-term straw incorporation increases rice yield stability under high fertilization level conditions in the rice–wheat system. The Crop Journal, 9 (5), 1191-1197, Retrieved from DOI https://doi.org/10.1016/j.cj.2020.11.007

Zhao, Y., McElroy, M.B., Xing, J., Duan, L., Nielsen, C.P., Lei, Y. and Hao, J. 2011. Multiple effects and uncertainties of emission control policies in China, Implications for public health, soil acidification, and global temperature. Science of The Total Environment, 409 (24), 5177-5187, Retrieved from DOI https://doi.org/10.1016/j.scitotenv.2011.08.026