CHEMICAL ENGINEERING TRANSACTIONS
VOL. 107, 2023

A publication of AIDIC
The Italian Association of Chemical Engineering
Online at www.cetjournal.it

Guest Editors: Petar S. Varbanov, Bohong Wang, Petro Kapustenko

ISBN 979-12-81206-07-6; **ISSN** 2283-9216

DOI: 10.3303/CET23107120

Greenhouse Gas Profiling to Increase Agricultural Mitigation Program Effectiveness in Indonesia

Daniel S. I. Sondakh*, Franky R. Tulungen, Jon K. Kampilong, Fadly S. J. Rumondor, Yolla S. Kawuwung

Universitas Kristen Indonesia Tomohon, Indonesia
dsisondakh@gmail.com

This study aims to provide an inventory of greenhouse gas emissions in the agricultural sector, map the distribution of greenhouse gas emissions, and formulate effective mitigation strategies in Minahasa District. Primary data on rice field types, land processing systems, and fertilizer doses were obtained from the respondents. The method is the interview, and the instrument is the questionnaire. Secondary data is in the form of planting area and emission factor data. Data processing uses the Tier-1 method to obtain the amount of CO_2, CH_4, and N_2O emissions. Spatial mapping of greenhouse gas emissions is done with the help of ArcMap. After that, the greenhouse gas mitigation strategy was formulated. Total agricultural greenhouse gas emissions: 3,578,093.27 t CO_2-eq/y, consists of emissions CH_4: 71,711.87 t CO_2-eq/y; CO_2 Fertilizer: 1,828,235.40 t/y; N20 Land Managed: 1,665,299.66 t CO_2-eq/y; and emission N_2O Indirect: 12,846.33 t CO_2-eq/y. The largest gas emissions are CO_2 (51.10 %) and N_2O Land Managed (46.54 %). The largest GHG-contributing is West Langowan District (285,165.25 t CO_2-eq/y). Various adaptation efforts are to adjust planting time and patterns and reduce the use of inorganic fertilizers. In contrast, mitigation efforts are implementing organic farming, regulating intermittent irrigation systems (dry and wet), using low-emission rice varieties, and utilizing soil improvement materials such as *biochar*.

1. Introduction

Greenhouse gas is a term used to describe the Earth's condition with a greenhouse effect. Global warming is a form of ecosystem imbalance on Earth due to the process of increasing the average temperature of the atmosphere, sea, and land on Earth so that there is a phenomenon of global average temperature on the surface of the Earth which has soared 0.74 ± 0.18 °C (1.33 ± 0.32 °F) in the last hundred years (Abbass et al., 2022). Today, climate change is one of humanity's most serious global problems. Climate change occurs due to human activities constantly affecting atmospheric composition and land use. The use of fossil fuels (Lee et al., 2021), deforestation (Erb et al., 2018), decay by microbes, waste, burning of plant litter, soil organic matter, and uncontrolled land conversion (Akram & Ali, 2021), Decomposition of organic matter that occurs in rice cultivation systems in wet (flooded) rice fields also contributes to the increase in CH_4 and N_2O production (da Cruz Corrêa et al., 2021), and natural factors such as volcanic eruptions and variations in solar radiation (Li et al., 2020). Although CH_4 and N_2O are emitted in smaller amounts than CO_2, they can potentially result in 21 and 310 times greater global warming, respectively (Paul et al., 2022). GHG production from the agricultural sector is less than from the energy sector. Still, the GHGs it releases have tremendous potential, so they need to be managed and even reduced. Minahasa Regency, North Sulawesi Province, Indonesia, is one of the largest suppliers of agricultural production. With a planting area of around 44.2 thousand hectares, it has supplied its superior products in the form of rice, corn, tomatoes, and cloves throughout North Sulawesi Province (BPS-Statistics of Minahasa Regency, 2023). It even became one of the suppliers of cloves for the national cigarette industry. Anthropogenic activities in the agricultural sector produce a large number of significant greenhouse gases (GHG), namely carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O), which are gases whose concentrations are increasing globally (Charkovska, 2019). This sector accounts for almost 14 % of global anthropogenic GHG emissions (Balafoutis et al., 2017;). Although many GHG emission studies have been

Paper Received: 25 August 2023; Revised: 07 October 2023; Accepted: 05 December 2023
Please cite this article as: Sondakh D.S.I., Tulungen F.R., Kampilong J.K., Rumondor F.S.J., Kawuwung Y.S., 2023, Greenhouse Gas Profiling to Increase Agricultural Mitigation Program Effectiveness in Indonesia, Chemical Engineering Transactions, 107, 715-720 DOI:10.3303/CET23107120

conducted in various places, there is still a gap in the availability of comprehensive academic information on agricultural GHG emissions in Minahasa District, where this study is ongoing. Based on literature searches, only two studies were found on this, and they were limited to CH_4 gas from rice plants. Those are conducted by (Mambu, 2012) and (Langi, 2007). This gap has implications for the difficulty of academic information for policymaking related to GHG mitigation efforts. Determining agricultural GHG mitigation requires spatial analysis in mapping the distribution of CH_4, CO_2, and N_2O by region to determine the type and origin of emission sources. Therefore, this research must be carried out to bridge or fill the existing gaps. This study aims to estimate GHG emissions in the Agricultural sector, map the distribution of GHG emissions, and formulate practical mitigation efforts to reduce emissions in Minahasa District, Indonesia.

2. Method and Material

2.1 Research Design

This study uses a mixed research method, combining quantitative and qualitative methods in analytical descriptive studies. It then continues spatial analysis based on GIS (*Geographic Information System*) to map the distribution of GHG emissions in all districts in Minahasa Regency. The respondents were farmers and agricultural extension workers spread across 25 districts in Minahasa Regency. Primary data acquisition uses interview and questionnaire methods as instruments. The criteria for respondents are those who manage the largest land area (the five largest). The data collected is in the form of data on the type of paddy field, water regime, type and dose of fertilizer, planting frequency, and harvest frequency. Secondary data in the form of agricultural activities are land area data and Emission Factor data. Data processing uses the *Tier method (from IPCC 2006 and 2019* Refinement to *2006) to obtain GHG emissions (*IPCC, 2006)(IPCC, 2006). After that, they mapped the distribution of GHG emissions using ArcMap, a GIS-based application, to determine how big the distribution of greenhouse gas emissions was in each sub-district in Minahasa Regency. Furthermore, GHG inventory and GHG mitigation formulation involved respondents through FGD methods and interviews.

2.2 GHG Emission Calculation

The GHG calculation method is based on IPCC guidelines, namely the Tier-1 method, based on *global* or regional emissions/removals factor defaults. The equation is:

1. CH_4 emissions of paddy fields: calculated using the equation (1).

   $$\text{Emission of } CH4_{Rice} = \sum Ef.T.A.10^{-6} \tag{1}$$

   Where: Emission of CH_{4Rice} = CH_4 emissions manage rice fields (Gg CH_4/y); *Ef* = CH_4 emission factor of paddy fields = 1.61 kg CH_4/ha/d (MEFRI = Ministry of Environment and Forestry Republic of Indonesia, 2019); *A* = Area of rice fields (Ha); *T* = Rice planting period.
2. CO_2 Emissions from Fertilizer Use: is calculated using the equation (2).

   $$\text{Emission of } CO2_{\text{Rice}} = M_{Fertilizer}.EF_{Fertilizer} \tag{2}$$

   Where: Emission CO_2 = C emissions fertilizer use (t CO_2/y); $EF_{fertilizer}$ = Fertilizer emission factor. EF value of urea fertilizer = 0.20 t C/y (IPCC, 2006); $M_{fertilizer}$ = The amount of fertilizer used (t/y). This value is obtained from the planting area multiplied by the recommended dose.
3. Direct N2O emissions: calculated using the equation (3).

   $$\text{Emission of } N2O_{\text{Direct}}\text{-N} = \left[\left(F_{SN} + F_{on}\right).Ef_1\right] + \left[\left(F_{SN} + F_{on}\right).Ef_{1FR}\right] \tag{3}$$

   Where: Emission of N_2O_{Direct} = N_2O directly land management (kg N_2O-N/y); F_{SN} = Sum of synthetic N fertilizer applied (kg N/y). The N in Urea/ZA/NPK is 46 %, 21 %, and 15 % (MEFRI, 2019); F_{on} = Sum of compost, manure, and other organic N is applied (kg N/y). The N in manure, compost, and crop residue is each 16 %, 0.5 %, and 0.5 % (MEFRI, 2019); Ef_1 = N_2O emission factor of N inputs for dryland (kg N_2O-N (kg N input) is default 0.010 (MEFRI, 2019); Ef_{1FR} = Emission factors N_2O dari N input on irrigated rice fields (kg N2O-N (kg N input) is default 0.003 (MEFRI, 2019).
4. Indirect N_2O emissions**:** calculated using the equation (4).

   $$\text{Emission of } N2O\text{-} = \left[\left(F_{SN} + Frac_{Gasf}\right) + \left(\left(F_{ON}Indirect + F_{PRP}\right) \times Frac_{Gasm}\right)\right] \times EF_4 \tag{4}$$

   Where: Emission of N_2O- = Indirect N_2O land management (kg N_2O-N/y); F_{SN} =Sum of synthetic fertilizer N applied (kg N/y). The N content in Urea/ZA/NPK is 46 %, 21 %, and 15 % (MEFRI, 2019); F_{ON} =Sum of compost, livestock excretions, and other organic N is applied (kg N/y). The N content in manure, compost, and crop residue is respectively 16 %, 0.5 %, and 0.5 % (MEFRI, 2019); F_{PRP} = Sum of urine and feces N (kg N/y); $Frac_{Gasf}$ = synthetic N fertilizer fractions that volatilize as NH_3 and NO_X is default 0,011 (MEFRI, 2019); $Frac_{Gasm}$ = organic fertilizer fraction N (F_{ON}) and livestock manure deposited by livestock (F_{PRP}) which is volatilized as NH_3 and NO_X (kg N volatilized per kg N given or deposited), is default 0.021 (MEFRI, 2019); EF_4 = N2O emission factor from N deposits on the water surface and soil [kg N–N_2O per (kg NH_3–N + NO_X–N *volatilized*)], is default 0.01 (MEFRI, 2019).

An emission unit is a unit of gas type (t CH_4, N_2O, CO_2/y) converted into CO_2-equivalent using global warming potential (GWP) values.

3. Results and Discussion

3.1 Research Location

This research is conducted in Minahasa Regency, North Sulawesi Province, Indonesia (See Figure1), with an area of 121,043.31 ha and 25 districts. The population of Minahasa Regency is 350,317 people, consisting of 178,730 men and 171,587 women. The population growth rate in 2011-2022 was 0.47%. The rice harvest area in 2021 reached around 44.18 thousand ha, a decrease compared to 2020, which was 61.83 thousand ha. Horticultural crops and tomato plants are the flagship of Minahasa Regency. As for plantation crops in 2022, they are cloves. The planting area of clove plants is 17,044.63 ha (Central Bureau of Statistics Minahasa Regency, 2023).

3.2 Emission Calculation Results of CH4, CO2 and N2O

GHG emissions in the agricultural sector come from emissions: (1) methane (CH_4) rice cultivation, (2) carbon dioxide (CO_2) urea fertilizer use, (3) soil nitrous oxide (N_2O), including indirect N_2O emissions from adding N to the soil due to evaporation/precipitation and leaching. Calculating the emission burden of the agricultural sector requires secondary data on the area harvested per type of land and the type of fertilizer in rice cultivation, as described in Table 1.

Table 1: Data on Agricultural Land Area and Fertilizer application in Minahasa Regency

Districts	Agriland Area (Ha)						Fertilizer	
	Paddy	Dry land	Corn	Horti culture	Plntation	Land area	UREA (kg)	NPK (kg)
Eris	97.4	100	1,000	744	1,795.0	1,196	197,299	306,465
Kakas	397.9	1,000	1,500	737	1,980.0	2,599	590,400	327,810
West Kakas	1,200.7	600	2,500	635	1,446.0	1,015	209,399	310,759
Kawangkoan	360.6	100	1,000	410	398.6	1,287	319,548	339,532
West Kawangkoan	112.7	100	900	64	766.0	1,857	455,750	478,250
North Kawangkoan	43.1	100	800	80	517.5	573	164,200	191,978
Kombi	0.0	3,600	1,100	182	7,257.3	2,341	587,250	567,045
West Langowan	357.5	50	1,550	81	63.8	5,124	736,070	1,166,025
South Langowan	141.6	100	650	30	1,676.0	1,321	237,740	170,567
East Langowan	646.8	50	110	165	97.5	1,993	526,702	390,772
North Langowan	206.2	50	100	795	10.8	3,619	560,667	794,462
East Lembean	0.0	2,500	1,500	650	5,515.5	680	170,048	174,662
Mandolang	37.5	100	500	281	2,239.0	365	91,419	96,856
Pineleng	3.6	100	500	619	2,872.0	68	17,024	19,238
Remboken	694.9	100	900	211	143.8	1,877	435,169	621,079
Sonder	205.2	300	1,250	209	2,847.0	2,416	597,400	630,235
East Tombariri	29.4	2,000	2,000	487	3,052.0	1,259	306,750	269,474
Tombulu	19.0	1,000	1,750	470	4,335.3	473	118,375	142,050
Tompaso	749.1	50	750	605	127.8	3,001	442,165	659,457
West Tompaso	134.8	50	750	750	46.8	3,970	703,950	785,568
Tombariri	23.0	2,000	2,000	451	3,347.5	782	193,750	186,506
West Tondano	456.3	100	850	58	128.4	564	138,710	113,858
South Tondano	420.2	100	1,000	193	436.3	2,209	536,226	469,006
East Tondano	686.1	50	750	795	784.5	3,202	724,600	760,452
North Tondano	149.3	270	1,200	300	245.0	339	80,566	97,498
TOTAL	7,172.6	14,570	26,910	10,002	42,129	44,138	9,141,177	10,069,604

These GHG emissions are then calculated in each district based on the type of emissions and using data in (Table 1) and each emissions factor, and integrate into the equations (1) to (4), will result in the total emissions of the agricultural and plantation sector amounting to: 3,578,093.27 t CO_2-eq/y. CH4 emissions contribute this amount: 2.00 %, CO2: 51.10 %, and N2O: 46.54 % of total emissions. Based on result mapping (Figure2) dark green color showed that the highest GHG emissions were in the West Langowan District (285,165.25 t CO_2-eq/y), followed by the East Tondano District (282,633.12 t CO_2-eq/y), West Tompaso District (269,322.73 t CO_2-eq/y) and Sonder District (230,396.37 t CO_2-eq/y). The primary source of emissions is agricultural activities because these districts are rice granaries or rice production centers in North Sulawesi. In addition, the region is the largest producer of horticultural crops in the form of tomatoes, onions, and chilies. This high emission is caused by increased fertilizer use, not under the recommended dose. Total fertilizer use (see Table. 1) on all land types reached 736,070 kg/y (Urea), 1,166,025 kg/y (Phonska/NPK), and organic fertilizers 5,255,550 kg/y so that the highest emission contribution is generated from CO_2 emissions (147,214.00 t/y) and emissions N_2O (134,377.24 t CO_2-eq/y). The high application of this fertilizer causes CO_2 to be in excessive condition, which increases the greenhouse effect. Various factors have caused CO_2 emissions to be high. Fertilization and water availability have a positive and significant relationship with CO_2 emissions.

Nitrogen fertilizers can lead to increased CO_2 emissions from the soil because nitrogen fertilizers can stimulate microbial activity in the soil, increasing the Decomposition of organic matter and releasing CO_2 (Kong et al., 2020). The interviews with farmers show that the time of application and fertilizer dose did not follow the recommended doses. Excessive application of fertilizers can cause nutrient imbalances in the soil, negatively impacting soil health and increasing CO_2 emissions. In addition, most plants meet nitrogen requirements as inorganic nitrates from soil solutions. From the results of the calculation of N_2O emissions, Land Managed produces 1,678,145.33 t CO_2-eq/y or contributes 46.54 % to total agricultural emissions. Those are also due to the high and frequent application of urea fertilizer. Nitrogen fertilizer applications can undergo nitrification and denitrification processes to release N_2O into the atmosphere. When large amounts of organic fertilizers with available nitrogen (N) and degradable carbon infiltrate the soil or settle on the surface, it will increase N_2O (Hansen *et al.*, 2019).

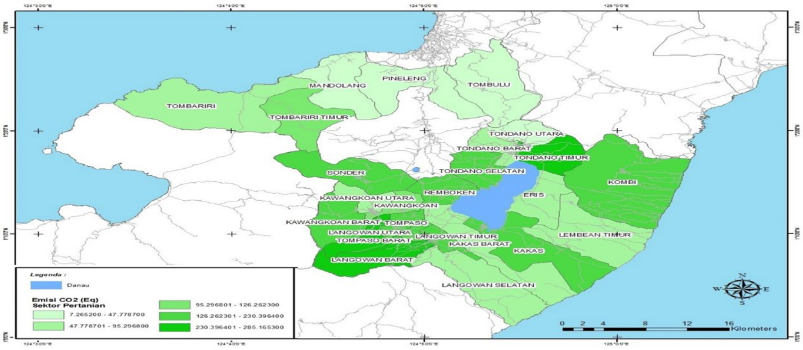
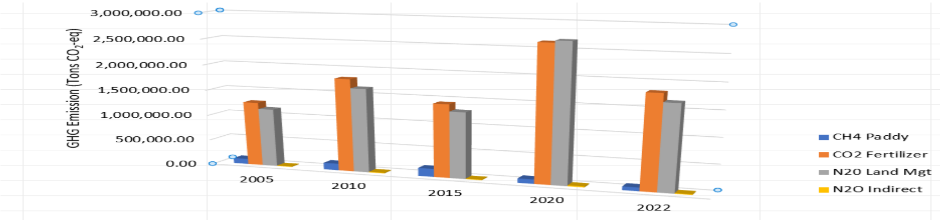


Figure 2. GHG Emission Distribution Map in Minahasa Regency.

3.3 Agriculture GHG Emissions Profile

The GHG inventory of Minahasa Regency (period 2005-2022) shows that the level of GHG emissions in 2022 is 3,578,093.27 t CO_2-eq/y or an increase of 1,056,184.66 t CO_2-eq/y compared to the level of emissions in 2005. Figure 3 shows fluctuating variations in agricultural GHG emissions over the five years from 2005 to 2022. For the first five years (2005-2010), there was an increase in GHG emissions of 39.03 %; period 2 (2010-2015) decreased by -17.39 %. A sharp rise occurred in 2015-2020, amounting to 83.88 %. Finally, in 2020-2022, there was another decrease in GHG emissions by -32.82 %. The variation in GHG emission figures is due to the influence of various factors such as the type of crops grown, the types of animals raised, waste management systems, land use, and many other factors. Changes in land use in Minahasa Regency, such as deforestation and conversion of natural ecosystems to agricultural land, can release excessive carbon dioxide (CO2), contributing to global warming. Soil moisture content plays an essential role in N_2O and CH_4 emissions. Excessive soil moisture can create anaerobic conditions, promote denitrification, and increase N_2O emissions (Bianchi, 2021). Conversely, dry soil conditions can limit denitrification and reduce N_2O emissions. In addition, soil type, soil conditions, temperature, rainfall, plant types, plant residues, sludge waste, N mineralization in soil organic matter through soil drainage/management, and land use changes in mineral soils also affect the rate of N_2O emissions (Xu et al., 2020). At the same time, CH_4 emissions are 71,711.87 t CO_2-eq/y, relatively low or contribute 2.00 % of total Agricultural emissions. As a notice to the 2020-2022 period, CH_4 emissions tend to decrease. As a notice to the 2020-2022 period, CH_4 emissions tend to fall; on the other hand, CO_2 and N_2O emissions continue to rise. This phenomenon indicates that excessive use of urea fertilizer is occurring in agriculture in Minahasa district. Meanwhile, rainfed rice cultivation, which experiences periods of drought during the growing season, can withstand the rate of CH_4 emissions.



	2005	2010	2015	2020	2022
CH4 Paddy	103,180.39	131,744.96	159,039.78	86,525.66	71,711.87
CO2 Fertilizer	1,265,200.00	1,818,520.00	1,431,880.00	2,640,691.20	1,828,235.40
N2O Land Mgt	1,144,703.62	1,645,325.97	1,295,509.18	2,679,670.51	1,665,299.66
N2O Indirect	8,824.61	12,683.94	9,987.18	19,115.96	12,846.33

YEAR

Figure3. Agriculture GHG Emissions Profile (2005-2022)

3.4 Adaptation and Mitigation Efforts in Minahasa Regency

Mitigation efforts in the agricultural sector are to implement organic farming, namely limiting the application of synthetic fertilizers, herbicides, pesticides, and fungicides contained therein, potentially reducing GHG emissions and the flow of nitrates and toxic chemicals. In addition, using cover crops, crop rotation, and compost in organic farming can play an essential role in maintaining optimal soil health, increasing carbon sequestration, and reducing GHG emissions. The rice varieties selection that produces lower emissions or varieties with good root oxidizing capacity can potentially mitigate CH_4 emissions and utilize soil improvement materials such as biochar. Another mitigation effort is the management of rice field irrigation systems with semi-irrigation/intermittent irrigation inundation. In flooded conditions, CH_4 gas is higher than in dry conditions. Intermittent irrigation is the most efficient irrigation system in reducing CH_4 emissions and can reduce emissions by 41 % to 45 %, compared to continuous irrigation. This research still needs to be continued in future studies, especially to calculate the potential reduction in greenhouse gas emissions from several mitigation options based on proposals from all stakeholders.

4. Conclusions

Total agricultural and plantation sector emissions are 3,578,093.27 t CO_2-eq/y, which is contributed by emissions per type of gas: Emission CH_4: 71,711.87 t CO_2-eq/y; CO_2 Fertilizer: 1,828,235.40 t/y; N_2O Land Managed: 1,665,299.66 t CO_2-eq/y; and N_2O Indirect: 12,846.33 t CO_2-eq/y. The most significant contributors in the agricultural sector are CO_2 emissions (51.10 %) and land-managed N_2O emissions (46.54 %) of total emissions. Adaptation and mitigation efforts that have been formulated need to be carried out simultaneously. This study still has the potential to be continued in future studies, explicitly calculating the potential reduction in greenhouse gas emissions from several mitigation options.

Acknowledgments

Thank you to the Minister of Education and Culture of the Republic of Indonesia, via the Director of Research, Technology, and Community Service, for funding this research through the PFR-Bima 2023.

References

Abbass, K. et al. (2022) ‘A review of the global climate change impacts, adaptation, and sustainable mitigation measures’, Environmental Science and Pollution Research, 29(28), pp. 42539–42559. doi:10.1007/s11356-022-19718-6.

Akram, V. and Ali, J. (2021) ‘Global disparities of greenhouse gas emissions in agriculture sector: panel club convergence analysis’, Environmental Science and Pollution Research [Preprint]. doi:10.1007/s11356-021-14786-6.

Arisandi, F.D. and Setyanto, P. (2019) ‘Rendah Emisi Gas Metana Heritability and Characteristics of Rice Plant’, Jurnal Produksi Tanaman, 6(6), pp. 1042–1047. Available at: http://protan.studentjournal.ub.ac.id/index.php/ protan/article/view/745.

Balafoutis, A. et al. (2017) ‘Precision agriculture technologies positively contributing to ghg emissions mitigation, farm productivity and economics’, Sustainability (Switzerland), 9(8), pp. 1–28. doi:10.3390/su9081339.

Bianchi, A. (2021) ‘Review of Greenhouse Gas Emissions from Rewetted Agricultural Soils’, Wetlands, 41(8). doi:10.1007/s13157-021-01507-5.

BPS-Statistics of Minahasa Regency (2023) Minahasa Regency in Figures, 2023, minahasakab.bps.go.id. Available at:https://minahasakab.bps.go.id/publication.html?Publikasi%5BtahunJudul%5D=2023&Publikasi%5BkataKunci%5D=Minahasa+dalam+angka&Publikasi%5BcekJudul%5D=0&yt0=Tampilkan.

Chai, R. et al. (2019) ‘Greenhouse gas emissions from synthetic nitrogen manufacture and fertilization for main upland crops in China’, Carbon Balance and Management, 14(1), p. 20. doi:10.1186/s13021-019-0133-9.

Charkovska, N. (2019) ‘High-resolution spatial distribution and associated uncertainties of greenhouse gas emissions from the agricultural sector’, Mitigation and Adaptation Strategies for Global Change, 24(6), pp. 881–905. doi:10.1007/s11027-017-9779-3.

da Cruz Corrêa, D.C. et al. (2021) ‘Are ch4, co2, and n2 o emissions from soil affected by the sources and doses of n in warm-season pasture?’, Atmosphere, 12(6). doi:10.3390/atmos12060697.

Erb, K.H. et al. (2018) ‘Unexpectedly large impact of forest management and grazing on global vegetation biomass’, Nature, 553(7686), pp. 73–76. doi:10.1038/nature25138.

Hansen, S. et al. (2019) ‘Reviews and syntheses: Review of causes and sources of N2O emissions and NO3 leaching from organic arable crop rotations’, Biogeosciences, 16(14), pp. 2795–2819. Available at: https://bg.copernicus.org/articles/16/2795/2019/.

IPCC (2006) ‘IPCC Guidelines for National Greenhouse Inventories’, Prepared by the National Greenhouse Gas Inventories Programme, p. 20. Available at: https://www.ipcc-nggip.iges.or.jp/support/Primer_2006GLs.pdf.

Jacinthe, P.A. and Dick, W.A. (1997) ‘Soil management and nitrous oxide emissions from cultivated fields in southern Ohio’, Soil and Tillage Research, 41(3–4), pp. 221–235. doi:10.1016/S0167-1987(96)01094-X.

Kong, D. et al. (2020) ‘Effect of nitrogen fertilizer on soil CO2 emission depends on crop rotation strategy’, Sustainability (Switzerland), 12(13). doi:10.3390/su12135271.

Langi, Y.A.R. (2007) ‘Model Penduga Biomassa dan Karbon Pada Tegakan Hutan Rakyat Cempaka (Elmerrillia ovalis) dan Wasian (Elmerrrillia celebica) Di Kabupaten Minahasa - Sulawesi Utara’, Sekolah Pascasarjana Institut Pertanian Bogor, p. 10593. Available at: http://repository.ipb.ac.id/handle/123456789/10593.

Lee, D.S. et al. (2021) ‘The contribution of global aviation to anthropogenic climate forcing for 2000 to 2018’, Atmospheric Environment, 244(July 2020). doi:10.1016/j.atmosenv.2020.117834.

Li, C. et al. (2020) ‘Impact of irrigation and fertilization regimes on greenhouse gas emissions from soil of mulching cultivated maize (Zea mays L.) field in the upper reaches of Yellow …’, Journal of Cleaner Production [Preprint]. Available at: https://www.sciencedirect.com/science/article/pii/S0959652620309203.

Licite, I. and Lupikis, A. (2020) ‘Impact of land use practices on greenhouse gas emissions from agriculture land on organic soils’, Engineering for Rural Development, 19, pp. 1823–1830. doi:10.22616/ERDev.2020.19.TF492.

Lister, B.C. and Garcia, A. (2018) ‘Climate-driven declines in arthropod abundance restructure a rainforest food web’, Proceedings of the National Academy of Sciences of the United States of America, 115(44), pp. E10397–E10406. doi:10.1073/pnas.1722477115.

MEFRI (Ministry of Environment & Forest of the Republic of Indonesia) (2019) Report of Indonesia GHG Inventory and Monitoring, Reporting, Verification (MRV) - 2019, Kementrian Lingkungan Hidup dan Kehutanan RI. Jakarta. Available at: https://www.menlhk.go.id/.

Paul, B.K. et al. (2022) ‘Crop-livestock integration provides opportunities to mitigate environmental trade-offs in transitioning smallholder agricultural systems of the Greater Mekong Subregion’, Agricultural Systems, 195, p. 103285. doi:10.1016/j.agsy.2021.103285.

Rehman, A., Ozturk, I. and Zhang, D. (2019) ‘The causal connection between CO2 emissions and agricultural productivity in Pakistan: Empirical evidence from an autoregressive distributed lag bounds testing approach’, Applied Sciences (Switzerland), 9(8). doi:10.3390/app9081692.

Styles, D. et al. (2018) ‘Climate mitigation by dairy intensification depends on intensive use of spared grassland’, Global change … [Preprint]. doi:10.1111/gcb.13868.

Tahat, M.M. et al. (2020) ‘Soil health and sustainable agriculture’, Sustainability (Switzerland), 12(12), pp. 1–26. doi:10.3390/SU12124859.

Xu, X. et al. (2020) ‘The role of soil N2O emissions in agricultural green total factor productivity: An empirical study from China around 2006 when agricultural tax was abolished’, Agriculture (Switzerland), 10(5). doi:10.3390/agriculture10050150.

Yahya, M.N. et al. (2021) ‘A study on the hydrolysis of urea contained in wastewater and continuous recovery of ammonia by an enzymatic membrane reactor’, Processes, 9(10). doi:10.3390/pr9101703.

Yan, Q. et al. (2017) ‘Energy-related GHG emission in agriculture of the European countries: An application of the Generalized Divisia Index’, Journal of Cleaner Production, 164, pp. 686–694. doi: 10.1016/j.jclepro.2017.07.010.