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# Indirect Estimation of Agricultural Nitrous Oxide Emission in Malaysia

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## ABSTRACT

Agricultural activities cause high nitrous oxide ($N_2O$) emissions through nitrification and denitrification processes. Nitrous oxide has a global warming potential of approximately 298 times higher than carbon dioxide on a 100-year time scale. The excess of $N_2O$ gas causes ozone layer depletion, leading to increased UV radiation of the earth's surface. The estimation of $N_2O$ can provide a basis for developing potential mitigation strategies as it is the most significant contributor to greenhouse gas emissions. This research aimed to estimate $N_2O$ emission from the agricultural sector caused by anthropogenic activities in Malaysia from 1994 to 2014. The inventory was prepared and calculated using the IPCC Tier 1 methodology. Input data were collected from national data inventories, literature research, surveys, and expert judgement reports. An increasing trend of $N_2O$ emissions, ranging from 4.9 to 12 kt, was observed due to agricultural activities. The increment was mainly associated with synthetic fertiliser use due to the expansion in oil palm cultivation acreage. Synthetic fertiliser consumption contributed to 78% of these emissions, followed by crop residue application to the soil (13%) and organic amendments (9%). The increased trend in emission and contribution from fertiliser input indicate that appropriate mitigation strategies are needed since it is the largest anthropogenic activity contributor to $N_2O$ emissions.

**Keyword:** **greenhouse gases, nitrous oxide, fertilisers, crop residue.**

## INTRODUCTION

Nitrous oxide ($N_2O$) is one of the main contributors to greenhouse gas emissions from agricultural sectors, which in turn contribute to global warming and various environmental issues. Nitrogen dioxide is produced when nitrogen (N) input is added to soils (Stehfest and Bouwman 2006). The nitrogen undergoes nitrification and denitrification processes with the latter releasing $N_2O$ gas to the atmosphere. Nitrous oxide emissions produced from these activities could either be direct or indirect. Direct $N_2O$ emission occurs due to N input to the soil. In contrast,

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indirect $N_2O$ emission occurs when the N molecules move from the area where they are deposited to other locations by volatilisation and leaching/run-off (IPCC Guidelines for National Greenhouse Gas Inventories 2006).

Agricultural activities inevitably result in $N_2O$ production mainly due to the application of synthetic fertilisers, crop residue and organic N to the soil and N sources from animal waste. The use of fertilisers, especially chemical fertilisers, is crucial for the production and maintenance of better-quality industrial crops (such as oil palm and paddy) and to improve crop yields in the agricultural sector (Lai *et al*. 2019). In 2014, oil palm cultivation covered 5,000,000 hectares (ha) while paddy cultivation was estimated at 300,000 ha (MESTECC 2018). To sustain the growth of these industrial and food crops, a large amount of fertilisers is applied.

The oil palm plantation industry and paddy cultivation generate an abundant amount of biomass residue. Palm oil biomass includes empty fruit bunches (EFB), mesocarp fibres (MF), palm shells (PS), oil palm fronds (OPF), and oil palm trunks (OPT). Meanwhile, paddy plantation generates paddy straw, rice husk and rice bran as biomass. The N available from paddy and oil palm biomass that is returned to the soil was also considered for N2O emissions estimation in our study (IPCC Guidelines for National Greenhouse Gas Inventories 2006).

Other sources of $N_2O$ production from agricultural soils are N from organic inputs applied as fertiliser and N in urine and manure deposited by grazing animals on pasture. Projection by the Food and Agriculture Organization Corporate Statistical Database (FAOSTAT) suggests that the national cattle (dairy and non-dairy) and poultry population will increase by 15% and 5%, respectively in 2030 and 19% and 15%, respectively by 2050 (FAO 2007). The growing population will contribute to the increment of the production of $N_2O$ since N sources from animal manure will be incorporated into the soils as organic N.

As a signatory of UNFCCC, Malaysia is obligated to account for anthropogenic emissions and removals corresponding to its nationally determined contributions under the Paris Agreement. The agricultural sector contributes significant amounts of carbon dioxide ($CO_2$), methane (CH4), and nitrous oxide ($N_2O$) to the atmosphere (Smith *et al*. 2007). According to the Third National Communication ($NC_3$) and Second Biennial Update Report (BUR2) of Malaysia to the UNFCCC in 2018, direct $N_2O$ emission from the soil is the critical category and one of the main GHG contributors in the agricultural sector.

The objective of this study was to estimate $N_2O$ emissions from Malaysian agriculture soils. Activity data were collected to observe $N_2O$ emissions from 1995 to 2014 on a yearly basis. Malaysia's greenhouse gas emission from 1995 to 2014 (19 years) were estimated to determine the contribution of $N_2O$ emissions from agricultural practices and the trend in these two decades. This emissions inventory can be used to assess the impact of specific human activities and the primary sources responsible for such emissions besides developing and evaluating the results of particular mitigation strategies (Winiwarter *et al*. 2009). The calculation and analysis of the data presented in this study constitute primary data collected for Malaysia under the Biennial Update Report for the UNFCCC.

## METHODOLOGY

Malaysia's $N_2O$ emissions from agricultural practices were estimated based on the methodology of IPCC. Tier 1 method was used since country-specific emissions factor (EF) was not available. Two types of EF values accounted for these activities: $EF_1$ and $EF_3$ (Table 1).

EF1 is EF values used to estimate $N_2O$ emissions from various sources, which in this study includes synthetic fertiliser application, organic N application to soils, and crop residue, depending on the type of soils (managed or flooded rice soils, Table 1). $EF_3$ is EF values used to estimate $N_2O$ emissions from urine and dung N deposited by grazing animals on pastures, ranges, and paddocks, depending on the type of animals (Table 1, IPCC Guidelines for National Greenhouse Gas Inventories 2006).

TABLE 1
Calculation of emissions factor values by activity for estimation of $N_2O$ emissions

| **Type of emission factor used in calculating direct nitrous oxide emissions** | **Emission factor value used** | **Uncertainty range** | **Reference** |
|---|---|---|---|
| $EF_1$ for N additions from mineral fertilisers, organic amendments, and crop residue | 0.01 | 0.003 - 0.03 | Stehfest and Bouwman (2006) |
| $EF_1$ for flooded rice fields (FR) | 0.003 | 0.000 - 0.006 | Akiyama *et al*. (2005) |
| $EF_3$ for cattle, swine, and chicken | 0.02 | 0.007 - 0.06 | de Klein (2004) |
| $EF_3$ for sheep and goat | 0.01 | 0.003 - 0.03 | |

The $N_2O$ emissions were assumed to occur in the year N was added to the soil. All input data for the estimation of $N_2O$ emissions were collected from data reported in surveys, expert judgement reports, national depository, and technical articles following the good practice guidance of the GHG inventory. Details on the data sources are presented in each section of soil emissions. Figure 1 illustrates the data source of direct $N_2O$ from soil. Default EF values from IPCC Emission Factor Database (EFDB) or 2006 IPCC Guidelines were used for all activity data collection. However, country-specific EFs were also adopted for some manure management systems based on animal types linked to the emissions from the organic amendment.

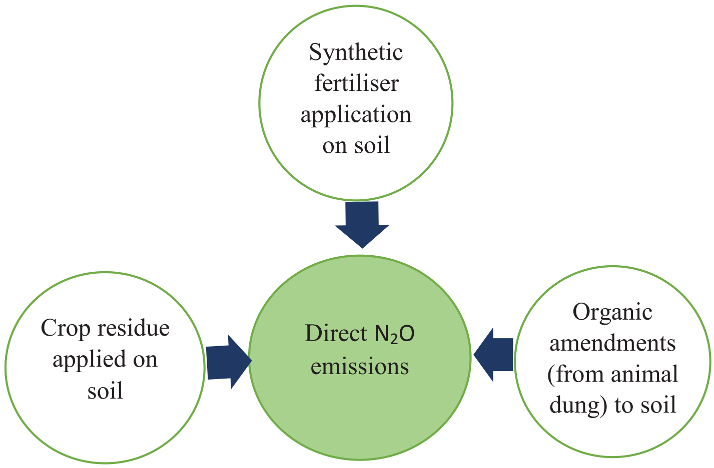


*Figure 1. Activity data source for estimation of direct $N_2O$ emissions*

*Parameters Used to Estimate Nitrous Oxide ($N_2O$) Emissions*
*Emissions from synthetic fertilisers*

Fertilisers are the major input applied to soil. Fertilisers are categorised into two clusters - synthetic and organic. To estimate the emissions, only synthetic fertilisers were considered due to its massive usage in agriculture compared to organic fertilisers. Synthetic N fertilisers applied to soil were calculated using the total amount of synthetic fertilisers utilised annually. The calculation was based on the equation below:

$$\text{Consumption} = \text{Production} + \text{Import} - \text{Export of Total N}$$

Fertiliser data were collected from the official country statistics, recorded as domestic, import, and export synthetic fertilisers. Urea is the only fertiliser produced in Malaysia, and data were obtained from the Food and Agriculture Organisation of the United Nations (FAO 2007). Import and export data on fertilisers under harmonised systems code were categorised into different groups (Table 2). The balance of the production, import and export data was summed up as fertiliser consumptions (not shown).

The conversion factor used to calculate N2O emissions is shown in Table 2 which represents N content availability (FAO 2007). The $N_2O$ emissions were expressed as the nitrogen content percentages from each fertiliser multiplied by fertiliser application to soil. Table 3 gives an example of a data worksheet to calculate N fertiliser consumption in 2014.

A separate calculation was done for fertiliser applied in paddy fields due to the differences in EF values which was 0.3% default value for flooded rice fields. In contrast, a value of 1% was used for managed soils. In this calculation, managed soils were accounted for by oil palm and other areas under agriculture.

TABLE 2
Types of synthetic fertiliser and N conversion factors

| Type of synthetic fertiliser | Conversion factor |
|---|---|
| Ammonium nitrate | 33% N |
| Ammonium sulphate | 21% N |
| Calcium ammonium nitrate | 21% N |
| Urea | 46% N |
| Urea and ammonium nitrate solutions | 32% N |
| Diammonium phosphate (DAP) | 18% N |
| Monoammonium phosphate (MAP) | 11% N |
| Other NP compounds | 20% N |
| NPK complex | 15% N |
| NPK blends | 15% N |
| Potassium nitrate | 13% N |

*Source:* FAO (2007)

The annual amount of animal manure was determined by adjusting the amount of manure N available ($N_{MMSAvb}$) with the fraction of animal manure used for feed ($Frac_{FEED}$). Only the data mentioned above were used for the calculation of $F_{AM}$ and was summarised as follows:

$$F_{AM} = N_{MMSAvb} \times 0.4$$

The calculation for $N_{MMSAvb}$ falls under livestock sector emissions. This information is available in Chapter 10 on emission from livestock and manure management of the IPCC Guidelines for National Greenhouse Gas Inventories (2006). Animal population numbers are needed to calculate $N_{MMSAvb}$ (Table 4). Animal population data were verified by the Department of Veterinary Services, Malaysia.

TABLE 3
A sample data worksheet to calculate N fertiliser consumption in 2014

| Types of fertiliser | A: Consumption | B: N % | kg N (AxB) | Item codes* |
|---|---|---|---|---|
| Ammonium nitrate | 39,033,621.60 | 0.33 | 12,881,095.13 | 2814 |
| Ammonium sulphate | 792,224,772.86 | 0.21 | 166,367,202.30 | 310230 |
| Calcium ammonium nitrate | 7,287,426.00 | 0.21 | 1,530,359.46 | 310221 |
| Diammonium phosphate (DAP) | 79,768,765.12 | 0.18 | 14,358,377.72 | 310240 |
| Monoammonium phosphate (MAP) | 49,854,413.66 | 0.11 | 5,483,985.50 | 310530 |
| NPK complex | | 0.15 | - | 310540 |
| NPK complex <=10kg | 12,949,120.99 | 0.15 | 1,942,368.15 | 310610 |
| NPK complex >10kg | 109,393,895.01 | 0.15 | 16,409,084.25 | 310510 |
| Other N and phosphate compounds | 7,600,800.00 | 0.2 | 1,520,160.00 | 310520 |
| Other N and phosphorus compounds | 154,598,564.74 | 0.2 | 30,919,712.95 | 310551 |
| Urea | 784,445,695.89 | 0.46 | 360,845,020.11 | 310210 |
| Urea and ammonium nitrate solutions | 26529.8 | 0.32 | 8,489.54 | 310280 |
| Total | | | 612,265,855.11 | |

*Note:* Data on N from fertiliser application will be used to estimate the $N_2O$ released.

*Harmonised systems code for each type of fertiliser

*Emissions from organic amendments*

Emissions from organic amendments were estimated based on three sources: the N percentage of the total amount of animal manure applied to the soil, N percentage from total sewage applied to the soil, and the N percentage from compost applied to the soil. However, since the total sewage and compost applied to soil were insignificant, only animal manure was taken as an organic amendment for calculation purposes. EF of 1% N in the form of $N_2O$ emissions from the organic amendment was used. The equation for N from animal manure applied to soil was as follows:

$$F_{AM} = N_{MMSAvb} \times [1 - (Frac_{FEED} + Frac_{FUEL} + Frac_{CNST})]$$

where

$F_{AM}$ = annual amount of animal manure N applied to soils

$NM_{MSAvb}$ = amount of managed manure N available for soil application, feed, fuel, or construction

$Frac_{FEED}$ = fraction of managed manure used for feed

$Frac_{FUEL}$ = fraction of managed manure used for fuel

$Frac_{CNST}$ = fraction of managed manure used for construction

TABLE 4
Total population of livestock

| Year | Chicken | Swine | Dairy cattle | Beef cattle | Sheep | Goats |
|---|---|---|---|---|---|---|
| 1995 | 83,196,223 | 3,110,440 | 35,626 | 676,898 | 219,337 | 280,398 |
| 1996 | 105,981,241 | 3,089,820 | 34,993 | 664,865 | 192,136 | 259,321 |
| 1997 | 117,537,784 | 2,983,735 | 34,977 | 664,567 | 173,531 | 244,034 |
| 1998 | 123,521,566 | 2,600,326 | 35,333 | 671,336 | 161,606 | 238,397 |
| 1999 | 119,285,674 | 2,184,893 | 36,052 | 684,996 | 154,221 | 237,014 |
| 2000 | 123,596,784 | 1,894,438 | 44,339 | 689,553 | 145,257 | 237,113 |
| 2001 | 148,990,824 | 1,972,532 | 34,666 | 707,505 | 129,108 | 247,338 |
| 2002 | 170,395,132 | 2,047,176 | 34,805 | 679,349 | 125,836 | 233,017 |
| 2003 | 183,345,888 | 2,070,686 | 34,734 | 717,766 | 115,131 | 246,977 |
| 2004 | 191,655,949 | 2,110,847 | 35,517 | 751,867 | 115,498 | 264,394 |
| 2005 | 174,694,165 | 2,035,647 | 34,592 | 755,473 | 115,922 | 287,670 |
| 2006 | 179,226,276 | 2,029,119 | 38,675 | 747,526 | 116,387 | 349,427 |
| 2007 | 188,383,841 | 2,020,117 | 38,813 | 803,373 | 125,988 | 428,263 |
| 2008 | 198,924,820 | 1,988,889 | 36,950 | 814,277 | 131,278 | 477,480 |
| 2009 | 201,967,963 | 1,831,308 | 41,368 | 819,123 | 136,285 | 514,223 |
| 2010 | 217,227,467 | 1,931,207 | 43,821 | 793,038 | 123,475 | 498,385 |
| 2011 | 229,142,007 | 1,816,557 | 44,330 | 724,380 | 126,412 | 479,444 |
| 2012 | 251,157,340 | 1,851,842 | 42,870 | 701,507 | 131,923 | 462,510 |
| 2013 | 272,451,321 | 1,842,953 | 42,976 | 708,521 | 141,918 | 434,202 |
| 2014 | 288,304,256 | 1,844,103 | 44,567 | 702,216 | 142,435 | 429,398 |

*Source*: Livestock Statistics (for various years) (Department of Veterinary Services, Malaysia)

*Emissions from crop residue*

Nitrogen added to the soil from crop residue was estimated using a combination of data from IPCC defaults and country-specific data. The procedure for estimation followed the equation provided in the Tier 1 method of the IPCC Guidelines for National Greenhouse Gas Inventories (2006). As both oil palm and paddy cultivation occupy large areas in the country, only the residues of these crops in soil were calculated. Calculation of paddy residue was as follows:

The annual amount of N in crop residues (FCR) =

$$\sum\{ Crop_{(T)} \times Frac_{Renew(T)} \times [(Area_{(T)} - Area\ burnt_{(T)} \times C_f) \times R_{AG(T)} \times N_{AG(T)} \times (1-FRAC_{Remove(T)}) + Area_{(T)} \times R_{BG(T)} \times N_{BG(T)}]\}$$

where

$Crop_{(T)}$ = harvested annual dry matter yield for paddy, kilogram dry matter/hectare

$Area_{(T)}$ = total annual area harvested of paddy, hectare/year

$Area\ burnt_{(T)}$ = annual area of paddy burnt, hectare/year

$C_f$ = combustion factor

$Frac_{Renew(T)}$ = fraction of total area under paddy that is renewed annually

$R_{AG(T)}$ = ratio of above-ground residue dry matter (AGDM(T) to harvested yield for paddy kilogram dry matter/hectare

$N_{AG(T)}$ = N content of above-ground residue dry matter for paddy, kilogram N

$FRAC_{Remove(T)}$ = fraction of above-ground residue of paddy crop removed annually for purposes such as feed, bedding, and construction, kilogram N

$R_{BG(T)}$ = ratio of below-ground residue to harvested yield for paddy, kilogram dry matter

$N_{BG(T)}$ = N content of below-ground residue for paddy, kilogram N

The estimation of N added to the soil from rice straw was based on the default factors from Table 11.2, Chapter 11 in the IPCC Guidelines for National Greenhouse Gas Inventories (2006). The percentage of dry matter yield for paddy was 89% (Table 11.2, IPCC 2006). The assumption for area burnt was 10% and the combustion was assumed to be wholly burnt during the land management period. The overall paddy area was renewed annually. Rice straw incorporated in soil was calculated based on N on the above and below-ground residue. N content for the above and below ground residue ratio was 0.4% and 0.7%, respectively (Azza Ebid *et al*. 2007). Although some of the above-ground paddy residue was removed from the field after harvesting, the amount was insignificant. Therefore, it was not included in the calculation.

Oil palm cultivation produces a huge amount of biomass residue. However, N added to the soil was only calculated from EFB, OPT and OPF dry weight as these parts are left on the ground and applied to the soil. The total area under oil palm cultivation is significant in the calculation of emissions from oil palm residue. OPT and OPF dry weight availability in Malaysia from 1995 to 2014 was based on Ng *et al.* (2011).

OPT and OPF biomass from replanting was also included for the calculation of N from oil palm residue. N percentages for OPF and OPT was 0.38% (Rahman *et al.* 2014) and 0.169% (Loh 2016), respectively. It is estimated that around 50% of oil palm waste is left for direct decaying on the site (Loh 2016) and was considered for calculating the emission. In contrast, the remaining 50% removed from the fields was not considered in the calculation. The value of 0.249% N for dry weight of the EFB was calculated from the amount of per tonne EFB received by mills (Loh 2016). Data on EFB were obtained from the Malaysian Palm Oil Board (2015). The input of the overall residue from EFB, OPT, and OPF in kilogram N was used to estimate $N_2O$ emissions from managed soils.

## RESULTS AND DISCUSSION

*Total Nitrous Oxide ($N_2O$) Emissions from the Agricultural Sector*

Antropogenic activities from agriculture contribute to changes in atmospheric $N_2O$ level. $N_2O$ emission levels from these activities are estimated in the study. Figure 2 shows the percentage of $N_2O$ emissions from agricultural land. The highest $N_2O$ emissions were produced from the application of synthetic fertilisers at 78%, followed by crop residue at 13%, and organic amendments at 9%. Approximately more than 6 million hectares of land area in the country are classified as agricultural land, including industrial and food cropland (Olaniyi *et al.* 2013). N fertiliser is an essential input for plant growth and development (Liu *et al.* 2014). The application of synthetic N fertiliser is crucial for maintaining yields in the agricultural sector. However, applying excessive amounts of N fertilisers causes severe environmental problems such as air and water pollution and climate change issues. Excess N will be lost to the atmosphere in the form of gas through leaching, volatilisation and denitrification process (Tamme *et al*. 2009). Further details on $N_2O$ emissions are discussed in the next sections.

Figure 3 shows the production of $N_2O$ emissions from 1995 to 2014. The lowest and highest $N_2O$ emissions from anthropogenic activities were recorded in 1996 (4.9 kt) and 2008 (12.0 kt), respectively. Overall, the emissions show an increasing trend over the years. From 1955, as Malaysia began moving towards industrialisation, land use for cultivation of food crops decreased to 16.3% of the total land in Malaysia by the year 2005 (Olaniyi *et al*. 2013). Nevertheless, the demand for palm oil as a major vegetable oil has continued to grow over the years. Between 2007 to 2010, the high demand for palm oil led to the expansion of areas of oil palm plantations, with Sarawak and Riau having a quarter of the

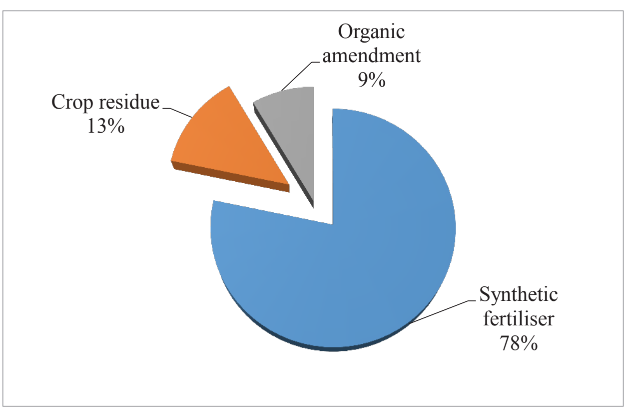


*Figure 2. Distribution of $N_2O$ emission from agricultural land practices*

2.1 Mha at a rate of 190,000 ha/year (Miettinen *et al*. 2012). Fertiliser application increased as the plantation areas increased to supply nutrients for plant growth and maximise crop yield and productivity. This has resulted in an increasing trend in anthropogenic emissions over the recent decades (Figure 3).

*Greenhouse gas emissions from synthetic fertilisers*

Synthetic fertilisers are commonly used in agriculture. The main synthetic fertilisers used for crops are urea, ammonium sulphate, calcium ammonium nitrate, nitrogen-phosphorus-potassium fertilisers (NPK), and compound fertilisers. In order to calculate $N_2O$ emissions, the estimation of synthetic fertilisers used in flooded rice fields was done separately from managed soils as management practices are different. Thus, their EFs values are different. A total of 8,916 tonnes of $N_2O$ per year was produced from the use of synthetic fertilisers in 2014 (Figure 4). This is in line with studies of other countries which also reported high $N_2O$ emissions due

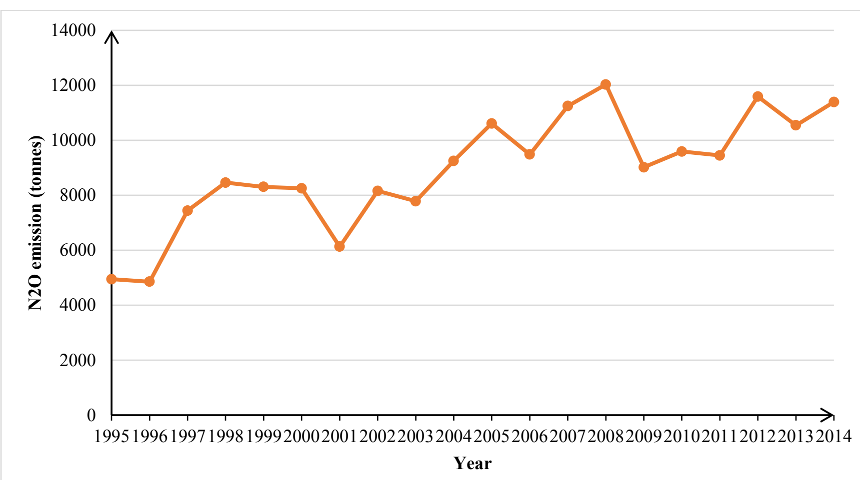


*Figure 3. Increasing trend of nitrous oxide emission from agricultural activities in Malaysia*

to synthetic fertiliser application. For example, China reported a rapid increase in fertiliser application over time with the emission being at 73.7% (Xing and Yan 1999). A study by Ambarita *et al.* (2018) in Sumatera Utara Province reported that 3.47% of emissions from the agricultural sector is contributed by the oil palm industry, fertiliser, and livestock sectors.

Total $N_2O$ emissions from synthetic fertiliser application demonstrated an increased pattern over the years due to the growth of cultivation area for oil palm and paddy (Figure 4). An expansion in area under cultivation inevitably leads to increased fertiliser use since fertilisers are needed to improve soil fertility and crop productivity (Rahman *et al.* 2014). As shown in Figure 4, the highest emission was recorded in 2008. The increasing trend from 2006 till 2008 might be due to the increase in urea production and a rise in fertiliser price. The cost of urea increased to USD 493 $t^{-1}$ in 2008 compared to USD 309 $t^{-1}$ in 2007 and USD 223 $t^{-1}$ in 2006 (Mohd Arif 2010). According to the Scottish Agricultural College (SAC 2008), the increase in biofuel demand boosted agricultural production and increased the need for chemical fertilisers from emerging economies.

In this study, it was assumed that emission values were from the application

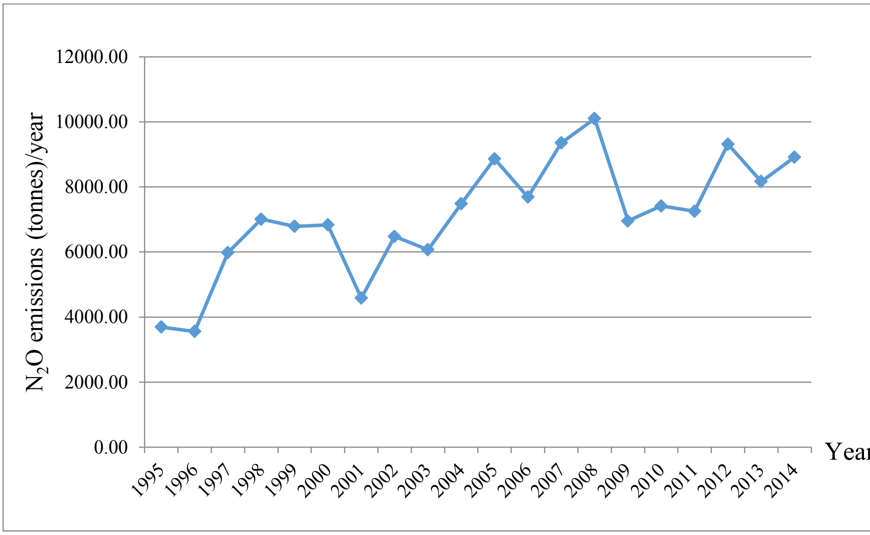


*Figure 4. Total $N_2O$ emissions from synthetic fertiliser application for years 1995 to 2014*

of fertilisers produced in Malaysia and used for agriculture. Hence, the calculation of $N_2O$ emissions was based on synthetic fertiliser application on two crops, oil palm and rice, which take up the major cultivation areas in Malaysia. Other cultivated crops were distributed along with oil palm plantations under managed soils. $N_2O$ production from managed soils where N was applied ranged between 4,300 and 9,800 tonnes per year (Figure 5).

In 2014, oil palm cultivation area accounted for total land use of 5,392,235 ha (MPOB 2015). Oil palm planting area expands every year to meet the increasing demand for palm oil. Fertiliser application is based on soil conditions, the environment, and the age of the plant. The use of N fertiliser in oil palm plantation is usually in the range of 108-134 kg N/ha, with a higher amount of fertiliser being applied for plants aged between 5-20 years than others (Faradiella *et al.* 2015). As the oil palm plantation area increases, the amount of N fertiliser required to maintain productivity increases significantly. A study by Fitri *et al.* (2015) in Indonesia found that the production of $N_2O$ emissions is significant based on fertiliser application rather than on land-use conversion. They also showed that the emissions rate from synthetic fertiliser application in oil palm plantations is high even after 44 days of fertiliser application.

Conventional rice cultivation in Malaysia relies heavily on synthetic fertilisers for crop productivity and yield. The area under paddy cultivation shows an increasing trend from 1994, with 679,239 ha in 2014 (DOA, 2015). Paddy cultivation in Malaysia requires 104 kg N/ha. Data on acreage of paddy cultivation was obtained to determine the use of synthetic fertiliser in paddy fields. The balance from the production, import and export of fertiliser was assumed to be N applied to managed soils. Fertilisation in paddy planting involves the application of urea, compound NPK (17.5N: 15.5P: 10K), and additional NPK (17.5N: 15.5P: 10K) in three phases: vegetative, reproductive, and ripening phase (Mohammad Hariz *et al*. 2019). In 2014, fertiliser application in paddy planting released approximately 301.8 tonnes $N_2O$ while the rest of agriculture

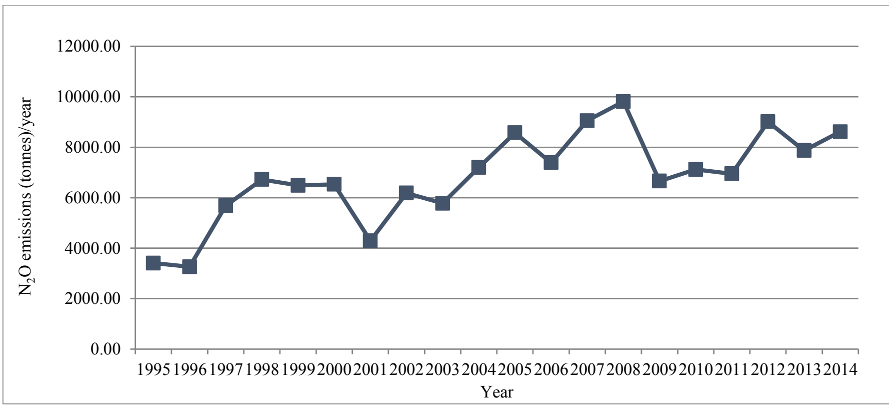


*Figure 5. Total $N_2O$ emissions from synthetic fertiliser application on managed soils*

under managed soils released 8615.1 tonnes $N_2O$. Figure 6 shows the effect of N fertiliser application in an irrigated paddy field based on paddy productivity (yield/ha). We observed an increasing trend in the yield of rice with the amount of fertiliser used. Over the years, improved technology and high yield varieties have been introduced (Adedoyin *et al*. 2016). Furthermore, through the Economic Transformation Programme, the Malaysian government has listed scaling up and strengthening paddy productivity to increase self-sufficiency and reduce dependency on fertiliser subsidies (Nordin *et al.* 2014).

It is estimated that the $N_2O$ emissions from synthetic fertiliser applied to paddy are in the range of 280-300 tonnes $N_2O$/year (Figure 7). Direct $N_2O$ emissions from the paddy field are considered lower compared to methane ($CH_4$) emissions. Yodkhum *et al.* (2017) estimated total field emission of 1.34 kg $CO_{2eq}$/kg of paddy in northern Thailand. This amount is similar for Malaysian paddy field emission with a value of 1.39 kg $CO_{2eq}$/kg paddy rice (Mohammad Hariz *et al.* 2019). A lower emission of 0.48 kg $CO_{2eq}$/kg of paddy could be achieved by eliminating fertiliser application and adopting organic practices (Yodkhum *et al.* 2017).

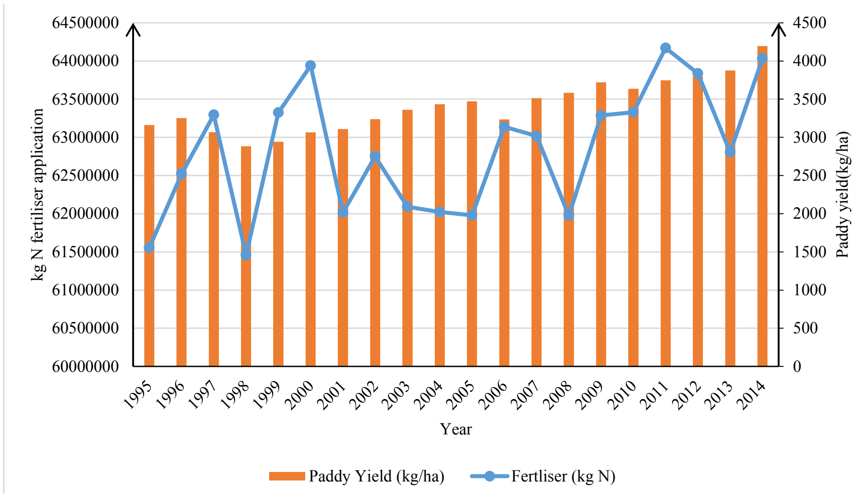


*Figure 6. Effect of synthetic fertiliser application (kg N) on paddy production (yield/ha)*

*Greenhouse gas emissions by organic amendment*

Emissions from organic amendments in Malaysia were calculated for the application of animal manure on soil under agriculture (excluding pasture range and paddock). Animal manure from swine, dairy cattle, cattle, sheep, chicken, and goat were summed up for the calculation.

An increasing trend of $N_2O$ emissions from organic amendments was observed from 1995 with the range being 480 to 970 tonnes $N_2O$ (Figure 8). This trend corresponds to the total chicken population which adopted the manure management system with or without litter.

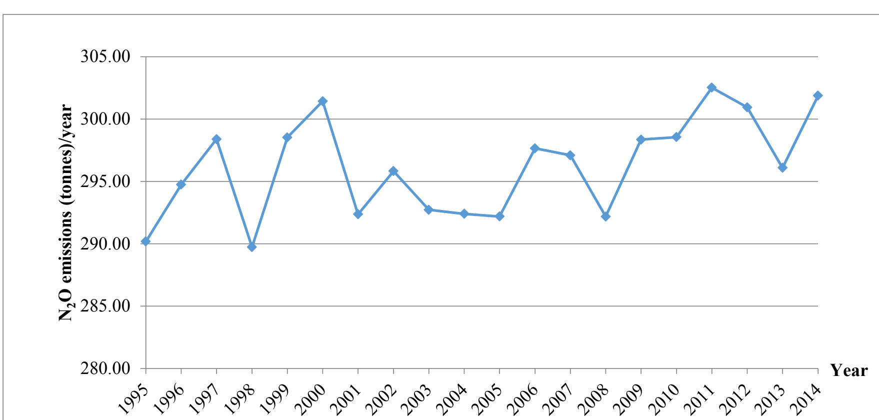


*Figure 7. Estimation of $N_2O$ emissions from synthetic fertiliser application on paddy fields*

The main source of $N_2O$ emissions from organic amendments is from the population of these animals (swine, dairy cattle, cattle, sheep, chicken and goat). The poultry industry in Malaysia accounts for more than 50% of the total livestock sector (Abdurofi *et al.* 2017). Poultry meat in Malaysia was 120% self-sufficient in 2007 to 2012 (DVS 2012). This in turn, has resulted in higher and abundant quantity of poultry litter available from this industry. Poultry litter and manure serve as organic fertilisers for crops as they contain 3-5% N, 1.5-3.5% phosphorus, and 1-3% potassium and micro-nutrients available for crop uptake (Amnullah *et al.* 2010). Dikinya and Mufwanzala (2010) also showed that chicken manure applied to soil acts as a potential source of plant nutrients that can

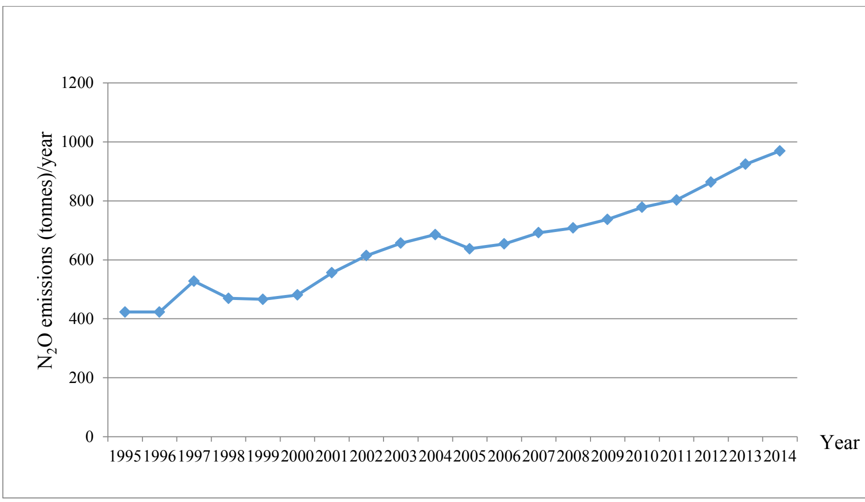


*Figure 8. $N_2O$ emissions from organic amendments*

improve soil fertility and increase plant yield. According to Truong *et al.* (2018), $N_2O$ emission from livestock farming in Vietnam is at 5.5 kt $CO_2$ eq/year and poultry husbandry is estimated to contribute approximately 27% of total GHG emissions in the country. However, of all livestock in Vietnam, pig farming is the most significant contributor to emissions (Truong *et a*l. 2018).

*Greenhouse gas emissions by crop residues*

Crop residue is usually left to decay on agricultural land after the harvest. This process improves soil fertility and increases organic matter in the soil for plant uptake (Singh *et al*. 2008). However, the presence of the residue in soil initiates the denitrification process, thus releasing $N_2O$ (Henderson *et al.* 2010). We calculated $N_2O$ emissions from paddy and oil palm, the major crops cultivated in Malaysia, and by far the largest fertiliser-consuming crops in Malaysia due to extensive plantation areas.

Paddy planting in Malaysia is done two times a year: main-season and off-season. The main-season period occurs when paddy is grown without dependence on any irrigation system, usually between August and February of the following year (DOA 2004). Off-season known as dry season occurs between March and July of the same year where paddy planting usually depends on the irrigation system (DOA 2004). An abundance of rice straw is produced from the rice field after planting seasons. During the off-season, rice straw burning is commonly practised to manage paddy residue; however, the incorporation of rice straw usually occurs during the main season. $N_2O$ emission from the incorporation of rice straw into the fields was calculated as the nitrification and denitrification processes occur during this event.

Data on incorporation of rice straw to soil is presented as kilogram N per year (tonnes N/yr). $N_2O$ emission from paddy crop residue and the amount of rice straw (N) incorporated into the soil are shown for 1995 to 2014 (Figure 9).

In Malaysia, the ratio of grain harvested to rice straw was reported as 1:1 (Lembaga Kemajuan Pertanian Muda 2010). This indicates that the figures for rice yield and the amount of straw produced in the field are similar. Production of $N_2O$ emissions from rice straw ranges from 90 to 110 tonnes $N_2O$/year (Figure 9) depending on the amount of N from paddy residue incorporated into the soil. Insignificant amounts of N from paddy residue incorporated into the soil have been recorded each year, ranging between 20,000 and 24,000 tons per year. The amount presented was based on the assumption that all straw produced were incorporated back into the soil. This study could be improved by conducting a field survey to determine the amount of straw used for animal feed or other uses. A study by Feng *et al*. (2018) showed that crop residue removal could reduce $N_2O$ emissions by 10.9% in no-tillage paddy cultivation. However, they observed that the $N_2O$ emissions produced from no-tillage paddy and conventional tillage paddy

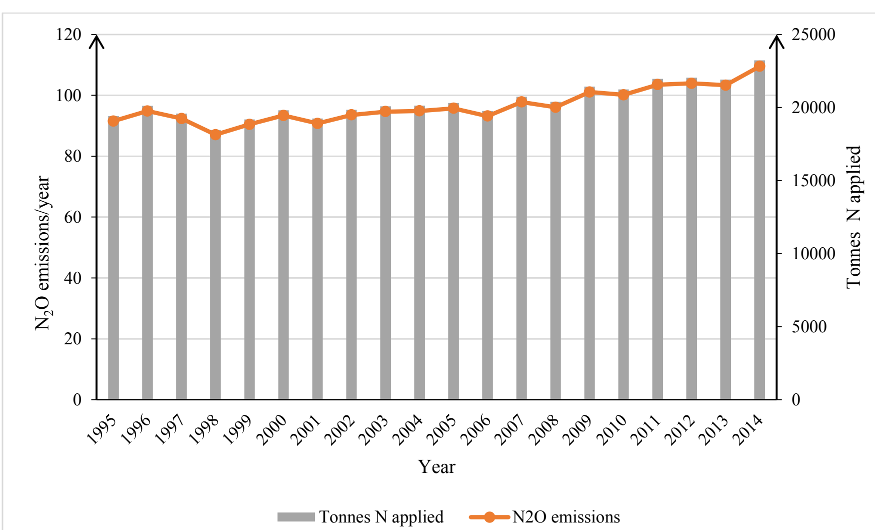


*Figure 9. Application of paddy straw residue (N) incorporated into soil on $N_2O$ emissions production*

are insignificantly different when paddy residue is not removed. In rice planting systems, $CH_4$ is the main gas produced due to crop residue incorporation as it acts as a substrate for the complex microbial community (Yavinder-singh *et al.* 2005). The presence of $N_2O$ in rice fields is due to the nitrification-denitrification process during periods of alternate wetting and drying (Yavinder-singh *et al*. 2005). Therefore, $N_2O$ emissions are usually low in an irrigated rice field. In comparison to palm oil, paddy produces quite a high level of $N_2O$ emission from adding residue to the soil.

Oil palm produces an abundance of biomass waste. For our calculation, three categories of residue from oil palm plantations incorporated into the soil are EFB, OPT, and OPF. The calculation of oil palm biomass produced was based on planted area and replanting area. According to Loh (2016), 50% of biomass from plantations will be retained in the fields as part of soil management. A factor considered necessary in estimating $N_2O$ from crop residue is the amount of N content of the residue from the different plant parts. The amount of N from each plant part is different. In this study, the amount of N was 0.38% for OPF (Rahman *et al.* 2014), 0.17% for OPT, and 0.25% for EFB (Loh 2016).

Table 5 shows the production of total tonnes in dry weight of OPT, EFB, and OPF used to estimate $N_2O$ emissions. OPF biomass is the main contributor to the production of $N_2O$ emissions (Figure 10). Emissions emitted from crop residue of managed soils ranged from 698 to 1400 tonnes $N_2O$. The emissions increased throughout the year due to expanding oil palm plantation acreage (MPOB 2018). In 2014, the main source of soil $N_2O$ emissions was from OPF (21,728,501.74 tonnes in dry weight) (Figure 10).

*Mitigation approach in agriculture*

Malaysia is committed to reducing greenhouse gas emission as it is a signatory to the Paris Agreement under the United Nations Framework Convention on Climate Change (UNFCCC). Strategies to decrease and/or optimise synthetic fertiliser rates have been developed to reduce emissions and shift towards a sustainable agricultural environment. One of the approaches is organic farming or the utilisation of organic fertilisers. Malaysia has acknowledged organic farming through Malaysia Organic Certification (SOM), which was launched in 2003 (Kala *et al.* 2011). The use of synthetic fertilisers has been banned in organic farming, therefore minimising the loss of N through leaching, volatilisation, and denitrification. Organic farming contributes to less emission than conventional farming, as reported by Skinner *et al.* (2019), who observed that $N_2O$ emissions are 40.2% lower in organic farming than in conventional farming.

TABLE 5
Estimated total tonnes in dry weight of EFB, OPT and OPF. Crop residue from replanted areas has been included in this estimation

| Total dry weight (tonnes) | | | |
|---|---|---|---|
| **Year** | **EFB** | **OPF** | **OPT** |
| 1995 | 3,702,456.21 | 10,641,440.48 | 3,783,713.60 |
| 1996 | 3,928,449.12 | 11,279,062.97 | 4,010,429.23 |
| 1997 | 4,254,865.99 | 12,120,307.06 | 4,309,545.37 |
| 1998 | 3,787,498.61 | 12,895,459.17 | 4,585,161.59 |
| 1999 | 4,913,828.09 | 13,881,128.63 | 4,935,630.21 |
| 2000 | 4,765,857.34 | 13,459,185.45 | 1,493,696.40 |
| 2001 | 5,156,773.91 | 14,076,766.77 | 2,216,487.56 |
| 2002 | 5,078,478.54 | 14,899,700.54 | 3,014,987.64 |
| 2003 | 5,559,456.95 | 15,213,711.73 | 1,985,562.32 |
| 2004 | 5,550,243.33 | 15,513,357.12 | 2,056,727.96 |
| 2005 | 5,889,725.47 | 16,154,273.10 | 1,821,669.08 |
| 2006 | 6,286,142.48 | 16,642,625.25 | 2,050,062.00 |
| 2007 | 6,084,088.78 | 17,291,414.40 | 2,585,200.80 |
| 2008 | 6,817,116.08 | 17,887,333.80 | 1,978,077.08 |
| 2009 | 6,666,749.40 | 18,956,947.70 | 3,404,480.80 |
| 2010 | 6,461,695.47 | 19,775,024.80 | 4,351,121.60 |
| 2011 | 7,223,783.64 | 20,121,875.43 | 3,198,729.80 |
| 2012 | 7,181,412.24 | 20,443,149.49 | 3,310,300.84 |
| 2013 | 7,371,101.35 | 21,045,670.63 | 3,344,077.52 |
| 2014 | 7,397,140.52 | 21,728,501.74 | 3,596,788.16 |

The adoption of precision agriculture will allow for more precise amounts of fertiliser and manure application in farming. The new technologies and techniques adopted in precision farming could reduce the number of inputs for GHG contribution, thus minimising emissions from agriculture and increasing agricultural productivity (Balafoitus et al. 2017). Numerous studies in Malaysia have developed precision farming models for optimum use of inputs in agriculture (Chan *et al*. 2002; Aimrun *et al*. 2007; Razak *et al*. 2014). The implementation of precision farming in agriculture offers much potential to farmers for sustainable and optimum production of crops.

Another approach to reducing the production of $N_2O$ from crop residue is by optimising the use of crop biomass. The oil palm industry has been shifting towards green technology approaches such as composting, leading to zero

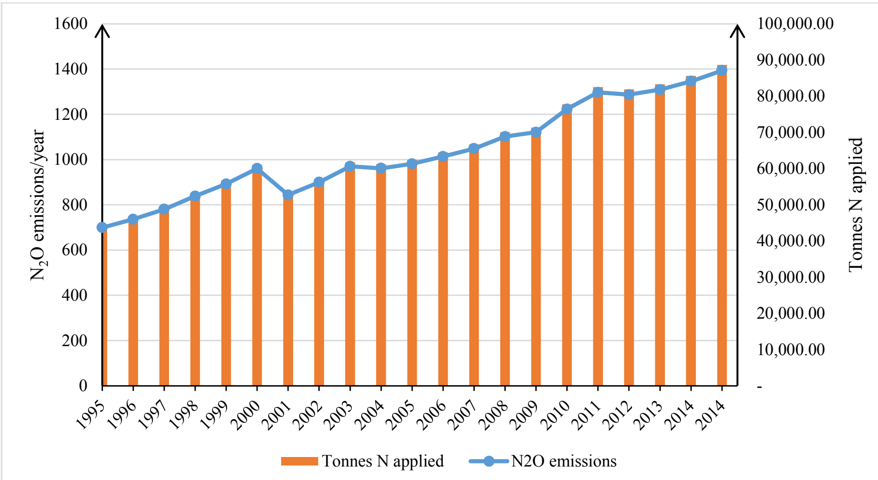


*Figure 10. Effect of incorporation of oil palm residue (N) into soil on $N_2O$ production in oil palm plantations*

discharge (Teo *et al.* 2010). Another approach to maximising oil palm biomass use is by its conversion to three subcategories: biofuel, bioproduct, and biopower (Tueku Muerah *et al.* 2019). Furthermore, exploring conversion of lignocellulosic biomass to a value-added product could resolve the disposing and management of biomass and reduce waste treatment costs (Goh *et al*. 2010).

Malaysia has developed the National Biomass Strategy 2020 as one of its efforts to utilise all crop residue as a renewable resource. With the new development in research and technologies, Malaysia is determined to create wealth and value-added products from biomass for the nation. One such value-added product from biomass is biofuel and towards this, National Biofuel Malaysia was established in 2006. Malaysia is also looking towards converting biomass into high-value products such as furniture (Lim *et al*. 2000) and biofertilisers (Abas *et al*. 2011), while research is also being carried out on the use of biomass for electricity generation (Shafie *et al*. 2014) and as feedstock (Mayulu 2014).

## CONCLUSION

Nitrous oxide is emitted mainly from soils applied with synthetic fertilisers. Increased use of synthetic fertilisers is a consequence of increasing plantation acreage and the need to maintain and improve crop production. Meanwhile, it is observed that the lowest contributor of $N_2O$ emissions is from organic amendments. Therefore, an approach to mitigating emissions from agricultural practices is by reducing the use of synthetic fertilisers. The plantations industry should be encouraged to work towards improving nutrient use efficiency of the synthetic fertilisers to reduce excessive application. Furthermore, utilisation of organic fertilisers and organic farming practices should also be encouraged to mitigate the production of $N_2O$ from agriculture.

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