Chapter

Mitigation of Climate Change by Nitrogen Managements in Agriculture

Kazuyuki Inubushi and Miwa Yashima

Abstract

Soil is one of the important sources of nitrous oxide (N_2O), which is generally producing through soil microbial processes, such as nitrification and denitrification. Agricultural soils receive chemical and organic fertilizers to maintain or increase crop yield and soil fertility, but several factors are influencing N_2O emissions, such as types and conditions of soil and fertilizer, and rate, form, and timing of application. Mitigation of N_2O is a challenging topic for future earth by using inhibitors, controlled-release fertilizers, and other amendments, but the cost and side effects should be considered for feasibility.

Keywords: N_2O, nitrification, denitrification, mitigation, soil type

1. Introduction

Global warming is significant and the impact of human activities is no doubt, such as mining of fossil fuels and deforestation, over-grazing, and constant increase of nitrogen fertilizer, resulting in atmospheric concentrations of CO_2, methane (CH_4) and nitrous oxide (N_2O) keep increasing, respectively, as indicated by Intergovernmental Panel on Climate Change (**IPCC**), under the United National Framework Convention on Climate Change (**UNFCCC**) (**Figure 1**, [1]). CH_4 and N_2O are the main Short-Lived Climate Forcers (**SLCPs**) because these participate in air pollution chemistry (ozone production, the oxidizing capacity of the atmosphere) and have very high Global Warming Potential (**GWP**) to compare with CO_2 = 1 as CH_4 GWP = ~28; N_2O GWP = ~298 (100 yr integration on per mole basis).

The Japanese government declared in 2020 that the year 2050 is the target of "Carbon Neutral Society", like other OECD countries. To achieve this target, we should reduce greenhouse gas emissions, not only CO_2 but also CH_4 and N_2O, both strongly related to food production and agriculture sectors.

Soil is one of the important sources of N_2O, which is generally producing through soil microbial processes, such as nitrification and denitrification. Agricultural soils receive chemical and organic fertilizers to maintain or increase crop yield and soil fertility. However, excess amount of chemical N fertilizer application may cause eutrophication and ground water pollution in the hydrosphere. Moreover, many factors are also influencing N_2O emission in the atmosphere, such as types and conditions of soil and fertilizer, and rate, form, and timing of application. Mitigation of N_2O emission to the atmosphere is a challenging topic in

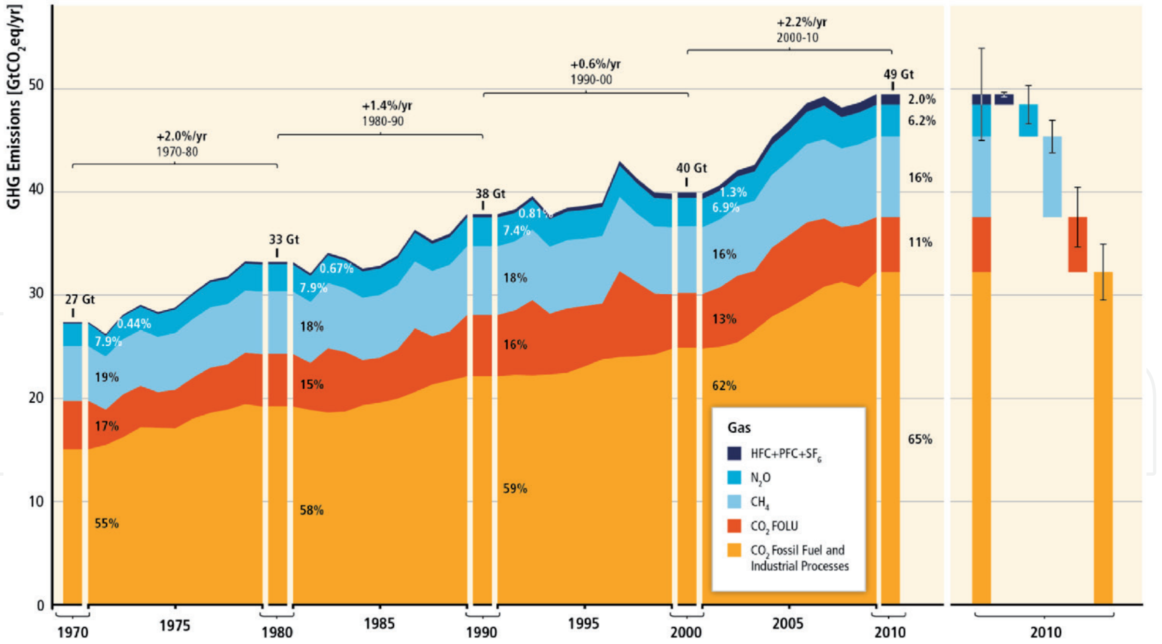

Figure 1.
Total annual anthropogenic GHG emissions by gases 1970–2010 (source: [1]).

sustainable agriculture, such as by using inhibitors, controlled-release fertilizers and other amendments, though the cost and side effects should be considered for feasibility. In this review, processes and influencing factors of N_2O production in the soil is reviewing and some trials for mitigation are introduced.

2. Global N_2O budget and production in soil

Global Carbon Project (GCP) published a comprehensive quantification of global nitrous oxide sources and sinks [2]. This reports details of the global N_2O budget in 21 natural and human sectors between 1980 and 2016 (**Figure 2**), indicating that

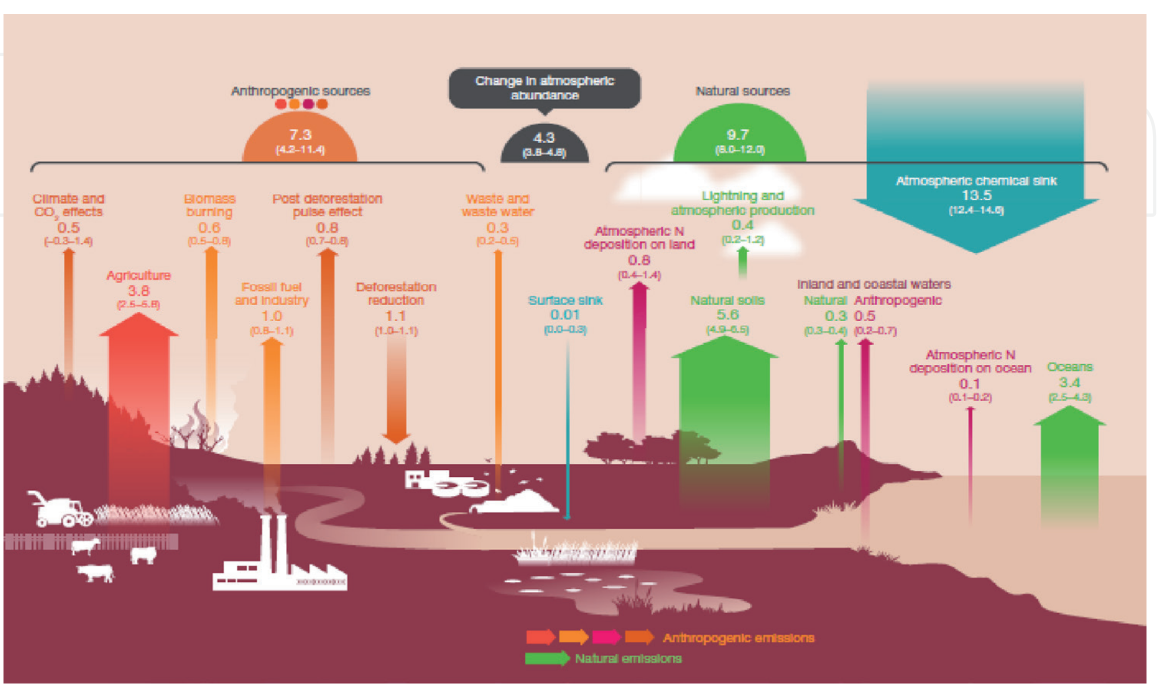

Figure 2.
Global N_2O budget [2].

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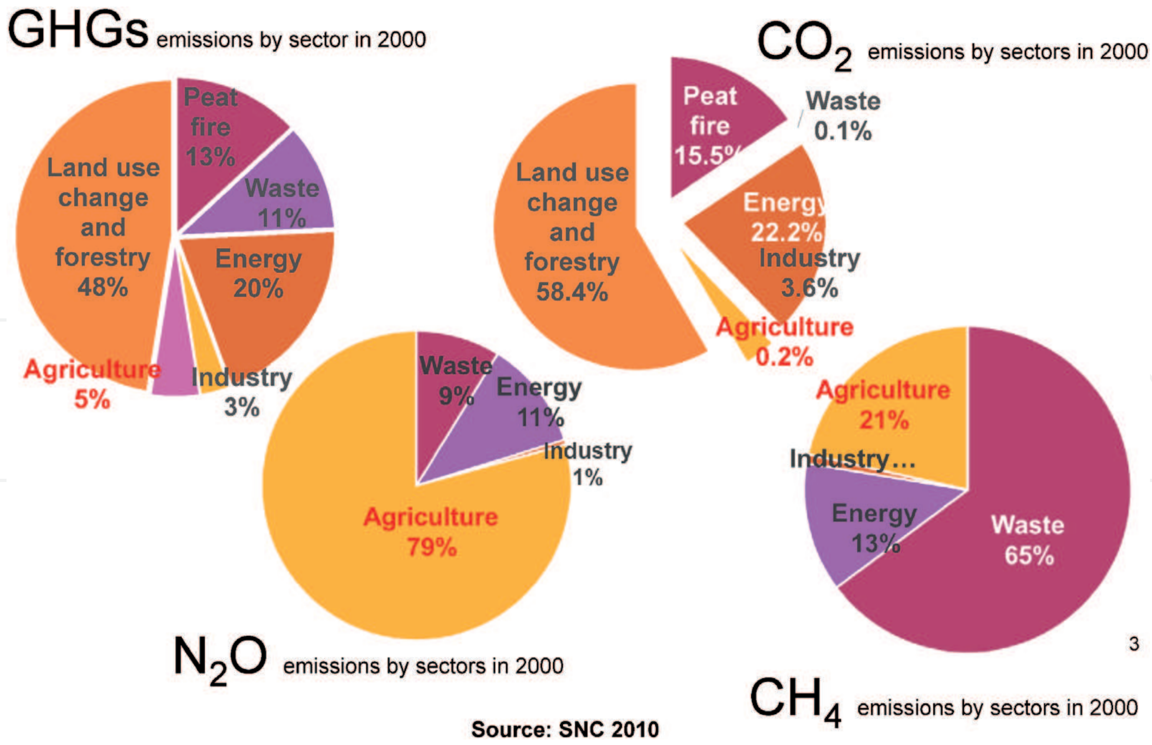

Figure 3.
National contribution of greenhouse gas emission by sector Indonesia source, [3].

natural and anthropogenic sources of N_2O were 57% and 43%, or 9.3 and 7.3 TgN yr^{-1} (1 Tg = 10^{12} g or 1 million ton), respectively and total as 17.0 (minimum 12.2 to maximum 23.5 Tg), while 13.5 Tg sink by atmospheric chemical reactions, resulting 3.5 Tg increase annually. By continental or regional estimates, Africa releases most (3 Tg yr^{-1}) due to large areas with tropical forests where high temperature and soil moisture, followed by Latin America and East Asia, where the agricultural contribution is largest. The annual increase of N_2O emission is more than 1%, and the agricultural sector is largest, especially in Asia, followed by Latin America, Africa, and particularly in East Asia, the input of chemical fertilizer and manure plus direct emission is increasing as more than double in past three decades. National inventory of greenhouse gas emission in developing countries such as Indonesia (**Figure 3**) [3] contributions of agricultural sectors in N_2O and CH_4 are bigger than other sectors.

3. N_2O production and its affecting factors

N_2O is generally producing in the soil through microbial processes, mainly via nitrification and denitrification (**Figure 4**). Nitrification is carried out under aerobic conditions by two groups of autotrophic nitrifiers, namely ammonium oxidizers and nitrite oxidizers, both do not require organic matters, not only in bacteria group but also archaea group. Autotrophic nitrification is the dominant process in aerobic soil (less than 60% water-holding capacity), while heterotrophic nitrification is negligible [4]. N_2O is producing as a byproduct during nitrite oxidation during nitrification. On the other hand, denitrification is carried out under wet and anaerobic conditions, such as in paddy soil and wetland soil, by heterotrophic denitrifiers, not only the bacteria but also fungi, both requires not only nitrate but also N-rich organic matter. N_2O is producing as an intermediate product during denitrification between nitrite and N_2. However, N_2O emission from flooded paddy soil is generally low, probably due to the high solubility of N_2O and complete denitrification to N_2. Chemical denitrification was also negligible [4]. Microbial

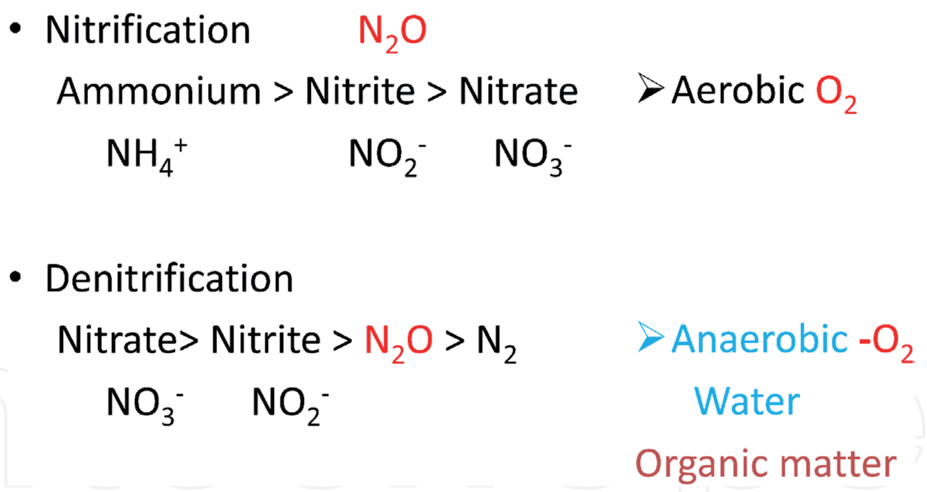

Figure 4.
Main processes of N_2O production in soil.

community structure was investigated also in tropical acid tea soil [5] and peat soil [6, 7]. Anaerobic ammonium oxidation (ANAMMOX) and dissimilatory nitrate reduction to ammonium (DNRA) are also focusing recently to see the possibility to relate N_2O production and contribution in soil N dynamics [8, 9].

Based on above knowledges about N_2O production processes, several mitigation technologies are proposed. To apply such mitigation technologies, it is important to understand factors affecting N_2O production, which are (1) Soil type and amendments such as manure, compost, and biochar, (2) Soil management and mitigation technologies such as controlled-release chemical fertilizers and nitrification inhibitors, and (3) Trade-off effects with other greenhouse gas mitigation such as water management in paddy field to reduce CH_4.

4. Effect of soil types and amendment on N_2O production and plant growth

Generally, soil with a large amount of soil organic matter (SOM) tended to produce more N_2O. However, in a case study using various soils in Japan and Hungary [10], Andosol, typical upland soil in Japan with higher SOM contents, produced less N_2O than Chernozem with lower SOM contents, typical upland soil in Europe, under the same incubation conditions, especially amended with chemical N fertilizer and biochar (**Figure 5**). However sandy soils with fewer SOM contents, N_2O production was small. Biochar is focused on soil C sequestration to build up C stock in soil, but also in Andosol, N_2O tended not to be increased with biochar and N fertilizer. Leafy vegetable (Komatsuna; *Brassica rapa*) growth and yield were also enhanced by amendments of chemical N fertilizer and biochar.

Effects of amendments on N_2O production were studied by many researchers, showing compost and N fertilizer generally increase N_2O production [11–16]. Under field conditions, N_2O emission to the atmosphere was much diversified in space and also soil depth [16, 17], and land-use [18]. Further study is needed for feasible soil and fertilizer management to meet sustainable developments.

5. Soil and fertilizer managements and mitigation technologies

To reduce N_2O emission, controlled-release chemical fertilizers and nitrification inhibitors have been examined [19, 20], and meta-analysis of 113 field experiment

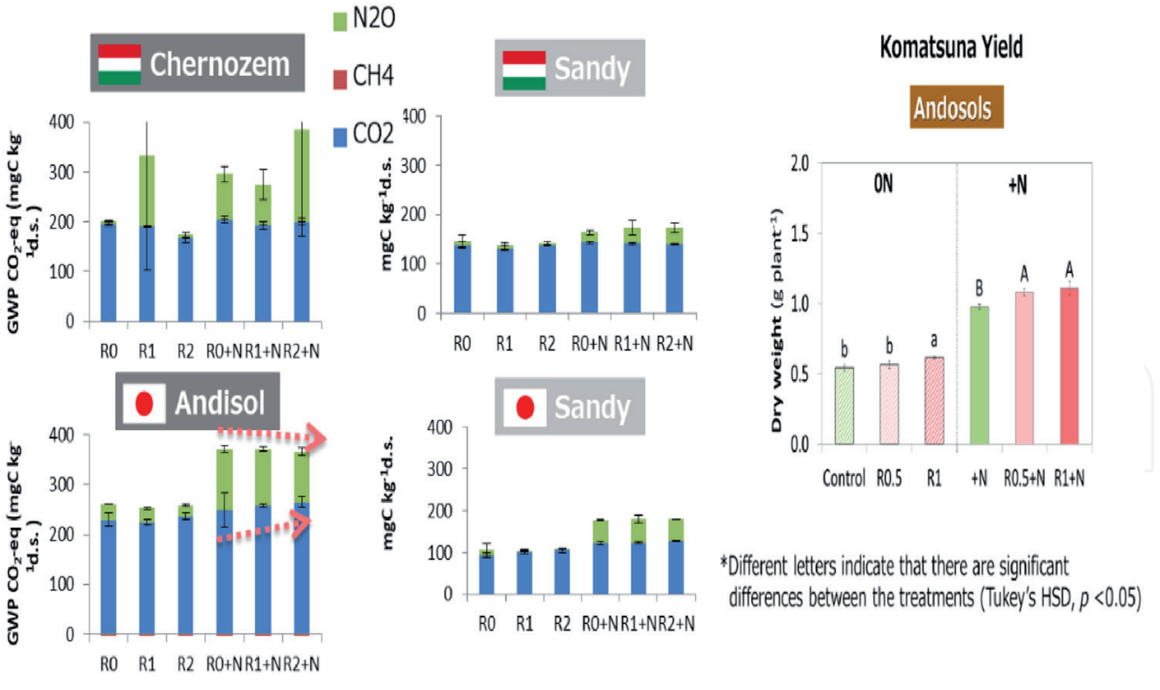

Figure 5.
Effect of soil types and amendment on N_2O production and plant growth (R: Rice husk biochar, 0, 1, 2: Application rate as 0, 1, 2%w/w, respectively, N: Urea).

datasets showed that polymer-coated fertilizers significantly reduced N_2O emissions (mean: −35%, 95% confidential interval: −58% to −14%) and nitrification inhibitors (−38%, −44% to −31%), respectively, depending on soil type and regions [21].

Controlled-release coated urea (CRCU) is a type of polymer-coated fertilizer. CRCU was examined to compare with conventional chemical fertilizer in tropical oil palm plantations over 340–580 days, where vast areas have been converted from rainforest and other plantations. Sakata et al. [22] reported the effect of CRCU compare with conventional fertilizer on N_2O emission and yield (**Figures 6** and 7). In Tungal sandy loam soil, controlled-release nitrogen fertilizer (CRNF; M) showed lower N_2O emission than conventional fertilizer (C), while in Simunjan sandy soil, N_2O was low in both M and C. On the other hand in Tatau peat soil, both M and C emitted a similar amount of N_2O, and much larger than other sites, and even from control (B; without fertilizer) (**Figure** 7). No significant effect on oil palm yield

Figure 6.
Field experimental sites in Sumatra, Indonesia and Sarawak, Malaysia [22], ① Tunggal, ② Simunjan, ③ Tatau.

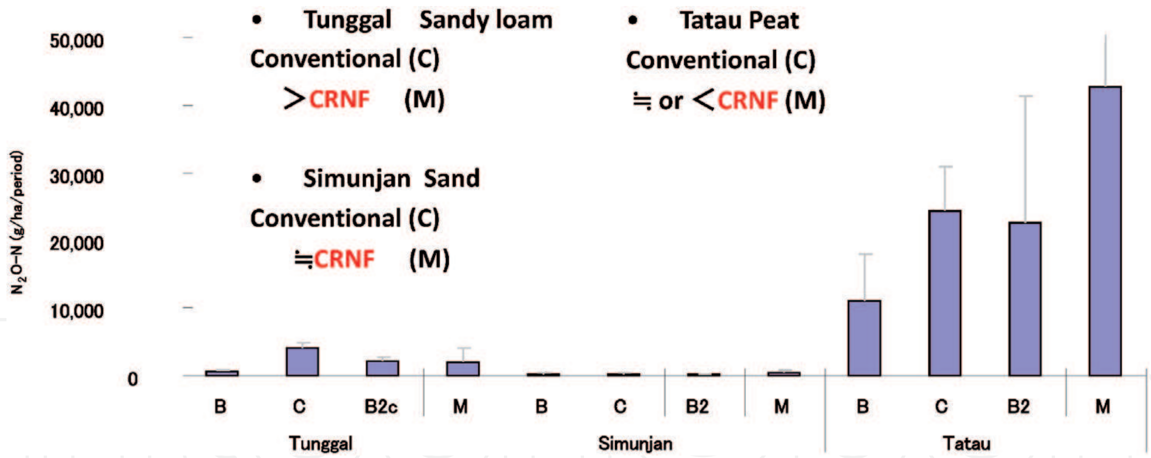

Figure 7.
N_2O emission from field experiments with different soil and fertilizer [22].

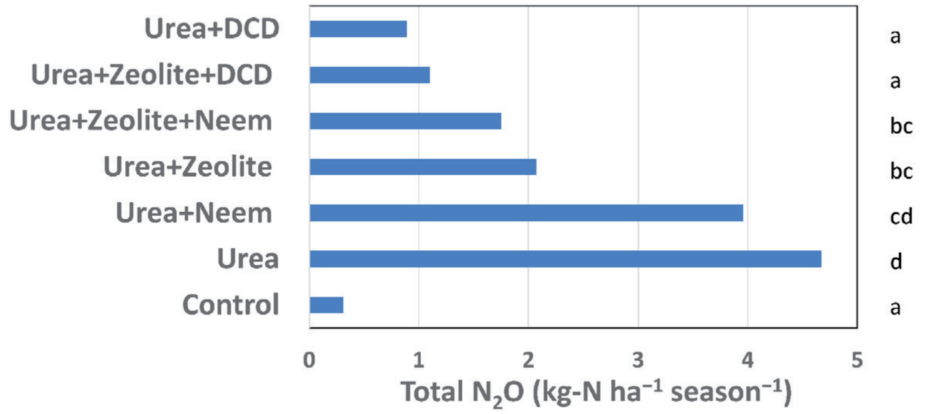

Figure 8.
Nitrification inhibitors on N_2O emission [29].

was observed even N application rate of M was half of C. Tropical peat soil has been pointed out as a significant N_2O emission source, even without fertilizer, strongly influenced by groundwater level [6, 7, 23–27]. Therefore CRCU has a significant impact even under tropical conditions to reduce N_2O in certain mineral soils, but not in organic peat soil. Long-term evaluation and cost–benefit analysis are important with yield evaluation in various soil types under diverse climate conditions.

Another mitigation option, nitrification inhibitors to stop ammonium oxidation have been also examined, typically DCD (Dicyandiamide; [20]) which is biologically and temperature-dependently decomposed [28]. However, it caused contamination in exposed milk powder in New Zealand, so NZ banned DCD from 2013. Nitrapyrin and 3,4-dimethyl pyrazole phosphate (DMPP) are other chemicals of nitrification inhibitors, but less effective. Neem cake is derived from natural compounds, so less expensive, but also less effective to compare with chemical inhibitors [21]. Combined effects of a nitrification inhibitor, including DCD, neem, and clay mineral (zeolite) on N_2O fluxes and corn growth were examined ([29]; **Figure 8**). Another biological nitrification inhibitor is also examined [30].

6. Trade-off with other mitigation

Mitigation options of other greenhouse gases, such as water management in the paddy field to reduce CH_4, have been examined in Japan [31]. The controlling irrigation water level was also examined in Indonesia [32]. Groundwater level

Varietyc	Treatment	CH_4 (kg ha^{-1})	N_2O (kg ha^{-1})	GWP (kg CO_2-eq/ha)	Reduction %
ADT 43	SRI	59.97 a	1.94 a	2077.4	**28.8%**
	MSRI	45.11 a	2.69 a	1929.4	**33.9%**
	CT	99.44 b	1.45 a	2918.1	
CO 51	SRI	51.73 a	2.09 a	1916.1	**27.1%**
	MSRI	50.76 a	1.53 a	1724.9	**34.3%**
	CT	88.86 b	1.36 a	2626.8	

SRI as a type of AWD with reduce seedling numbers, and MSRI as modified SRI with seedling age to compare with control CT [38].

Table 1.
Effects of water management and crop establishments on N_2O emission in field experimental site conducted at Tamil Nadu Rice Research Institute

control by alternate wet and drying (AWD) have established by IRRI and examined in Indonesia, the Philippines, Thailand, Vietnam [33–37] and India [38]. AWD has merit for saving labor and water. However, it may have a trade-off effect to increase N_2O, because of the removal of flooded water to expose anaerobic soil directly to the atmosphere. To examine this trade-off, they measured not only CH_4 but also N_2O emissions in the same field experiments and found that N_2O emission was mostly negligible without losing rice yield although CH_4 was significantly reduced (**Table 1**). Such trade-off should be examined not only for water management but also other soil managements including biochar for soil C sequestration.

7. Conclusions

Nitrogen is one of the most critical elements for food production, local and global environments. Nitrous oxide (N_2O) is an important greenhouse gas emitted from the soil via biological processes in N cycling. N_2O emission keeps increasing to induce global warming, climate change, and stratospheric ozone layer depletion. N_2O production in the soil is related to soil and fertilizer management and is influenced by many factors, such as soil conditions, chemical fertilizer, and organic manures. Mitigation is possible by appropriate soil and fertilizer management (controlled-release fertilizer and nitrification inhibitors), but exceptional soil such as peat soil should be careful. Feasibility is important to harmonize with yield and other factors (cost and economic merits, side effect, etc.). Under the COVID-19 pandemic, the balance of food production, human health, and environmental management become more and more crucial issues. Sustainable development goals become more important view-points than before [39, 40].

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