POPULATION PRESSURE ACCELERATING NITROGEN LOADS IN BANGLADESH AGRICULTURE AND THE RESULTANT EFFECTS ON N_2O EMISSIONS

M.I. Khalil[1,3], M.H. Hossain[1], N.M. Talukder[2] and U. Schmidhalter[3]

[1]*Soil Science Division, Bangladesh Institute of Nuclear Agriculture, P.O. Box 4, Mymensingh 2200, Bangladesh*

[2]*Department of Agricultural Chemistry, Bangladesh Agricultural University, Mymensingh 2202, Bangladesh.*

[3]*Chair of Plant Nutrition, Department of Plant Sciences, Technical University Munich, 85350 Freising, Germany.*

Abstract: Asia seems to be a major contributor of reactive nitrogen (Nr) to the global atmosphere, likewise in Bangladesh. Consequences of them to global climate change will affect Bangladesh at the first place and appear to be devastating. N_2O is an important contributor to that effect and thus, an inventory of its emission from Bangladesh agriculture was made to generate baseline information. Information from 1961 to 2000 on relevant parameters was collected and N_2O emissions from different N sources were estimated using the revised version of Intergovernmental Panel on Climate Change (IPCC) methodology. Results indicated that the increasing population (~2.2 million per year) presumably led to occupying a large area for housing, extension of city areas as well as industrialization. This resulted in a decrease of arable land by 11% during the last decade. In 2000, N loads in Bangladesh agriculture and the subsequent increase in biomass N raised to 63 and 33%, respectively over 1990 level. Its load was enhanced by 14% from animal sources but seemed to be stable. Meanwhile, biologically fixed N was decreased by 24%, indicating high yielding cereals replaced the area under legumes. The ensuing release of N_2O followed similar trends with time. In 2000, its emission from animal production systems (N_2O-animal), other N loss processes from agricultural soil (N_2O-indirect) and directly from agricultural soil (N_2O-direct) was $48.2*10^6$, $32.8*10^6$ and $21.3*\ 10^6$ kg N yr^{-1}. In contrasting, the N_2O-direct was increased by 30%, which was higher than the other two sources (19-20%) in 2000 over 1990 level. Bangladesh added only 1.57%, probably an overestimation, of the total global emission estimated for 1996 ($6300*10^6$ kg N_2O-N yr^{-1}). Large seasonal variations and diversified cropping systems may cause broader uncertainty on its actual emission. Use of synthetic N fertilizers to Bangladesh agriculture is imperative to sustain the increased crop production based on population demand. It is suggested to introduce improved management options in order to reduce N loads from synthetic fertilizers and N_2O emissions.

Key words: Population, Bangladesh, N loads, N_2O emissions, IPCC

Introduction

As an essential element, nitrogen (N) plays a dynamic role in the soil-plant-atmosphere continuum. It is estimated that 70% of the plant nutrients will have to come from fertilizers by the year 2020 at a global level, with a view to feeding the projected future population of the world (Ayoub, 1999). The annual global use of fertilizers will need to be doubled by the year 2030 from about 130 million tonnes in the 1990s (Brown et al., 1997) to maintain the current per capita cereal production. In addition, anthropogenic N inputs into agricultural systems like N from animal excreta, wastes, increased biological N fixation, cultivation of mineral and organic soils and application of crop residues to the field are also a growing concern. During the last few decades, use of inorganic nitrogenous fertilizers has been increasing in the tropics to enhance crop production. Indiscriminate use of both inorganic and organic N fertilizers may bring significantly higher gaseous N losses, particularly

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nitrous oxide (N_2O). N_2O formation is mostly biogenic and occurs during both nitrification and denitrification processes. The main sources of N_2O are cultivated soils, biomass burning, fossil fuels and nitric and adipic acid production. It causes global warming and ozone layer depletion (Bouwman, 1990; Cicerone, 1987). The yearly increasing concentration of N_2O (0.25%) in the global atmosphere seems to create a genuine catastrophe on the global climate along with other greenhouse gases. Its consequences will affect Bangladesh at the first place and appears to be devastating.

Human activities have greatly increased the creation rate of reactive nitrogen (Nr) and consequently the global N cycle strongly depends upon the rates at which fixed N is denitrified to N_2 in land and aquatic systems (Galloway and Cowling, 2002). Uncertainty prevails on the Nr creation, particularly in Asia where the projected future changes in the human population, industrialization, nitrogen use, etc. will occur. Application of chemical N fertilizers and organic residue/amendment, preferably N-rich residue, to agricultural fields occupies the major share of atmospheric N_2O emissions. It is estimated that more than 75% of the added N fertilizer is lost from the residue-soil system on a year-to-year basis if the soil N content remains unchanged (Beauchamp, 1997). In general, N_2O emissions from agricultural land vary from 0.03 to 2.7% of the applied total N fertilizers (Eichner, 1990). Soil management and cropping systems, and variable rainfall have greater impacts on N_2O emissions than the type of fertilizers (Mosier, 1998). The redistribution of other N losses such as N runoff, leached NO_3^-, NOx emissions and volatilized NH_3 into formerly pristine areas changes the N biogeochemistry of the systems, which may result in indirect N_2O emissions (Smith et al., 1998; Mosier et al., 1998).

Based on the United Nations Framework Convention on Climate Change (UNFCCC, 1997) or Kyoto Protocol, national inventories of anthropogenic sources and sinks of all greenhouse gases and their reduction are imperative for the sake of the living bodies and nature. Recently, comparable methodologies for greenhouse gas inventories were published in the "Revised 1996 Intergovernmental Panel on Climate Change (IPCC) guidelines for national greenhouse gas inventories" (Houghton et al., 1997). As such, attempts were made to generate baseline information on N_2O emissions from Bangladesh agriculture using the well-recognized IPCC methodology. It was to provide a direction of future research activities with a view to finding mitigation options.

Materials and Methods

Climate

Bangladesh enjoys a sub-tropical climate. The tropic of cancer (23°5′) passes through the middle of the country, dividing Bangladesh almost into two equal halves. High temperatures, excessive humidity and heavy rainfall characterize the climate. A fairly marked seasonal variation occurs throughout the year. The country is within the domain of a very active monsoon and experiences a reversal seasonal wind. It is well guarded by the Himalayas on the north. It has been well known as the "land of six seasons" with regard to cropping seasons, cultural festivities and weather conditions. Based mainly on the cropping systems, it can be divided into three main periods, namely the summer (March- May), the monsoon (June-October), and the winter (November-February).

Data collection and analysis

Required data on Agriculture and population were downloaded from the Food and Agriculture Organization database (FAO, 2002), Statistical Yearbooks of Bangladesh (BBS, 2000) and Krishi (Agriculture) dairy. Data on primary consumption of fossil energy (petroleum, dry natural gas and coal) were taken from the database of Energy Information Administration, USA (EIA, 2001). The FAO database provided records on harvest areas, the production of crops and animal populations as well as information on total land area, synthetic nitrogenous fertilizer consumption, and rural and total population numbers from 1961 to 2000. Data on human-driven flow rates of N-cycling among the sectors of crop production, animal production, fossil-energy consumption, atmosphere and aquatic systems at the national levels were collected. The Intergovernmental Panel on Climate Change (IPCC) method, designed on the basis of the whole N cycle to estimate national inventories of N_2O emissions for the agricultural sector, was used. Whenever possible, specific parameter values for Asia were applied and when those values were unavailable, the IPCC defaults were directly used.

Based on the IPCC methodology three sources were taken into account to make an inventory: (i) direct emissions from agricultural soil (N_2O-direct),

(ii) direct emissions due to animal production (N_2O-animals) and (iii) indirect N_2O emissions as a result of N losses from agricultural soils (N_2O-indirect). The N_2O emission is calculated by multiplying the levels of the different emission sources by their respective emission factors (EF). Mosier et al. (1998) and Houghton et al. (1997) have provided a detailed description on this method.

N_2O-direct

The anthropogenic N sources in agricultural systems mainly include synthetic fertilizers, animal manure, N-derived from enhanced biological N_2 fixation, crop residues returned to the field after harvest and to some extent human sewage sludge application. N_2O emitted directly from agricultural soils (N_2O-direct) in kg N yr^{-1} using the IPCC methodology was calculated, as follows:

N_2O-direct = [(FSN + FAW + FBN + FCR) * EF1] + FOS * EF2

Where, FSN (synthetic fertilizer N applied in a country, kg N yr^{-1}) = NFERT * (1 - FRACGASF); NFERT = effective synthetic N fertilizers used in a country (kg N yr^{-1}); FRACGASF = fraction of synthetic fertilizer N applied lost as ammonia (NH_3) and nitrogen oxides (NO_x) (0.1 kg N kg^{-1} input). FAW (animal waste N used as fertilizer in a country, kg N yr^{-1}) = [NEX * (1 – (FRACFUEL + FRACGRAZ + FRACGASM)]; NEX = amount of N excreted by livestock within a country (cattle 50, poultry 0.6, sheep 12, swine 16 & others 40; kg N yr^{-1}); FRACFUEL = fraction of livestock N excretion burned for fuel (0.25 kg N kg^{-1} N excreted); FRACGRAZ = ratio of livestock N excretion deposited during grazing (NEX grazing) and the total NEX produced by livestock in a country (0.34 kg N kg^{-1} N excreted); FRACGASM = fraction of livestock N excretion lost as NH_3 and NO_x (0.2 kg N kg^{-1} N excreted). FCR = N in crop residues returned to soil in a country (kg N yr^{-1}). FBN (N-fixed by N_2-fixing crops in a country, kg N yr^{-1}) = 2 * CROPBF * FRACNRBF; CROPBF = seed yield of pulses and soybeans in a country (kg dry biomass yr^{-1}); FRACNRBF = fraction of N in N_2 fixing crops (0.03 kg dry biomass yr^{-1}). FCR = 2 * (CROPO * FRACNCRO + CROPBF * FRACNCRBF) * (1 – FRACR) * (1 – FRACBURN); CROPO = production of all other crops in a country (kg dry biomass yr^{-1}); FRACNCRO = fraction of N in non N_2-fixing crops (0.015 kg N kg^{-1} dry biomass); FRACR = fraction of crop residue that is removed from the field as crop (0.45 kg N kg^{-1} crop N); FRACBURN = fraction of crop residue that is burned rather than left on field (0.25 kg N kg^{-1} crop N); FOS = area of cultivated organic soils within a country (ha of Histosols). EF1 = emission factor for direct N_2O emissions from the soil (0.0125 kg N_2O-N kg^{-1} N input); EF2 = emission factor for organic soil mineralization due to cultivation (10 kg N_2O-N ha^{-1} yr^{-1}).

N_2O-animals

N_2O emissions from three potential sources in animal production systems are: the animals themselves, wastes from confined animals, and dung and urine deposited on the soil during grazing (Mosier et al., 1998). Its emission (kg N yr^{-1}) from the systems was calculated, as follows:

$$N_2O\text{-animals} = \sum_{i=1}^{n}\sum_{j=1}^{m} N(T)i \times NEX(T)i \times AWMSj \times EF3j$$

Where, N(T)i = amount of animals per type; NEX(T)i = fraction of NEX, which is treated or stocked per animal waste management system (AWMS) per type of animal; EF3j = N_2O emission factor for an AWMS, g N_2O-N kg^{-1} N excreted (anaerobic lagoons and liquid systems = 1, Solid storage & drylot and pasture range and paddock, grazing = 20, used as fuel = 25, and other systems = 5). For N_2O-animals liquid systems, solid storage and drylot, and other systems were considered per type of animals. These data are default values for Asia and Far East (Mosier et al., 1998). Per animal type, N_2O-animals were calculated as the sum of the AWMS fractions per animal type multiplied by its total yearly N excretion and the respective EF for N_2O. N_2O-grazing was calculated from the amount of manure N produced in the AWMS "pasture range and paddock", using a default emission factor of 0.02 kg N_2O-N kg^{-1} manure N, which was considered as the N_2O-direct.

N_2O-indirect

To estimate indirect N_2O emissions, five processes were considered: emission and subsequent deposition of NH_3 and NO_x, N leaching and runoff, human consumption of crops followed by municipal sewage treatment, formation of N_2O in the atmosphere from NH_3 and food processing. The latter two were not included in the inventory because of the high uncertainty (Mosier et al., 1998). Based on the above, N_2O-indirect (kg N yr^{-1}) was calculated, as follows:

N_2O-indirect = $N_2O(G) + N_2O(L) + N_2O(S)$

Where, $N_2O(G)$ = N_2O produced from atmospheric deposition of NO_x and NH_3 (kg N yr^{-1}) = (NFERT* FRACGASF + NEX * FRACGASM) * EF4; FRACGASF = fraction of synthetic fertilizer N applied to soils that volatilizes as NH_3 and NO_x (0.1 kg NH_3-N and NO_x-N kg^{-1} N input), FRACGASM = fraction of livestock N excretion that volatilizes as NH_3 and NO_x (0.2 kg NH_3-N and NO_x-N kg^{-1} N excreted) and EF4 = emission factor for atmospheric deposition (0.01 kg N_2O-N kg^{-1} NH_3-N and NO_x-N emitted). $N_2O(L)$ = N_2O produced from N leaching and runoff (kg N yr^{-1}) = NLEACH * EF5; NLEACH = N leaching in country (kg N yr^{-1}) i.e. (NFERT + NEX * 0.8) * FRACLEACH; FRACLEACH = fraction of N input to soils that is lost through leaching and runoff (0.3 kg N kg^{-1} N applied) and EF5 = emission factor for leaching/runoff (0.025 kg N_2O-N kg^{-1} N leaching/runoff). $N_2O(S)$ = N_2O produced from human sewage (kg N yr^{-1}) i.e. = NSEWAGE * EF6; NSEWAGE = PROTEIN * NRPEOPLE * FRACNPR; FRACNPR = fraction of N in protein (0.16 kg N kg^{-1} protein), NRPEOPLE = number of people in country (FAO data), PROTEIN = annual per capita protein consumption in country (15.0-17.1 kg^{-1} protein $person^{-1}$ yr^{-1}) and EF6 = emission factor for sewage treatment (0.01 kg N_2O-N kg^{-1} sewage-N produced).

Results and Discussion

Population growth and arable lands

Bangladesh, having a total area of 144,000 square kilometers, is a densely populated country and the total population rose to around 137 million by 2000. Since 1961, a dramatic increase of population (~2.2 million per year) can be observed (Fig. 1). By 2000, the population was increased by 160% over 1961 and by 25% over 1990. The annual growth rate of the population has come down to 1.75% (estimated in 2002) with the acceptance of family planning practices. However, the trend of increase in population is dramatic and unmanaged. Human beings are not only contributing directly to liberate CO_2, the most important greenhouse gas (GHG), but also directly or indirectly responsible for releasing a large amount of N_2O to the atmosphere. Consumption of foodstuffs by humans results in the production of sewage. Sewage is disposed of either directly on land (night-soil or spray irrigation) or discharged into a water source (e.g. rivers and estuaries). Thus, a separate parameterization, unlike developed countries, may be needed to estimate N_2O emission from this system. Under Bangladesh conditions, improper managements of sewage seem to be potential sources of gaseous compounds and become hazardous for human health as well. As such, attention is needed to take septic measures and to introduce wastewater treatment facilities to keep the environment safer for all living beings.

Arable land comprised of 67% of the total area, as estimated in 2002. A decreasing trend was observed over time and population pressure is largely responsible for the consequences. This results in overexploitation of them through intensive cultivation with a view to growing more foods. In 1961, the total arable land was 8,605 thousand ha and an increasing trend was observed till 1989 (Fig. 1). During the period, it was increased probably by including the followings under cultivation: (i) marshy land, haor (confined water body) etc., (ii) hill area. (iii) waste and fallow land, (iv) forest area and (v) some time raised land on the river bed. A sharp decrease (15%) of arable land can be observed from 1990 to 1994 and afterwards increased to a small extent and it may be underestimated. This change might be associated with (i) increasing population, (ii) industrialization, (iii) the land damaged into the river bank, (iv) building houses, roads, school, college, market etc. The decreased arable land could with increasing population have been considerable factors to increase N_2O in particular, which are discussed below.

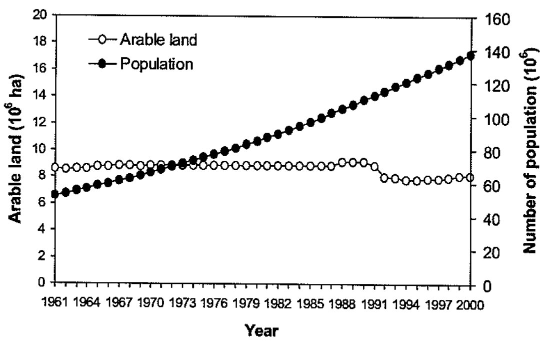

Fig. 1. Changes in the area of arable land and population of Bangladesh over time.

Nitrogen loads

The contribution of N to food and fodder production is greatly emphasized with a view to feeding the ever-increasing population of the globe. However, the consequences of the increased use of N fertilizers are also large with respect to polluting the soil-atmosphere continuum through creation of Nr.

There are many sources of N viz. synthetic N-fertilizer (NFERT), animal manure (NEX), N-fixing crops (CROBF), N-non-fixing crops (CROPO), crop residue, animal grazing, human sewage, etc. In 1961, the estimated amount of N from CROBF, CROPO, NFERT and NEX was $10.39*10^6$, $597.94*10^6$, $8.3*10^6$ and $272.57*10^6$ kg, respectively (Fig. 2a). A several-fold increase of those amounts was observed in 1990 and 2000 except the N derived from CROBF. The corresponding increase of N loads in 1990 was 111, 76, 2938 and 113%, and it was 60, 133, 4858 and 143% in 2000 over 1961.

The N loads from NEX were estimated to be higher than derived due to the use of NFERT. However, a remarkable increase of N loads from NFERT was depicted. The N load from CROBF during the last decade was decreased to a large extent (24%). The decreased area under CROBF like pulses, oil seeds etc. was presumably replaced by the cereals particularly due to extension of irrigation facilities, as the latter technology became agroeconomically sound for the farmers. However, the fate of overexploitation of groundwater to environment and human health was not considered. It is observed that the estimated amount of N loads has been increased in Bangladesh agriculture through anthropogenic activities and it was profound at the late 70's onwards. It may be attributed to the increased cropping intensity with the introduction of high yielding crop varieties and irrigation facilities. The ever-increasing population resulted in a growing demand for food production, leading to increased application of N (Fig. 2b) into the limited arable lands, and becoming an important contributing factor to atmospheric build-up of N_2O emissions.

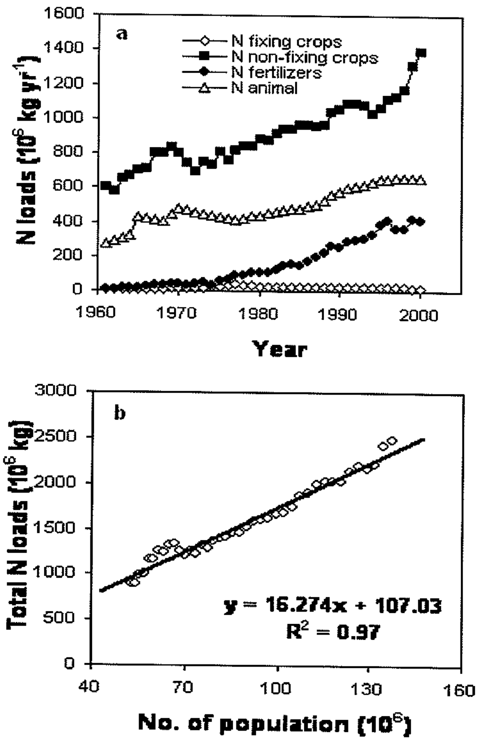

Fig. 2. Estimated nitrogen loads in Bangladesh agriculture from different sources (a) and relations between population and total N loads (b) over time.

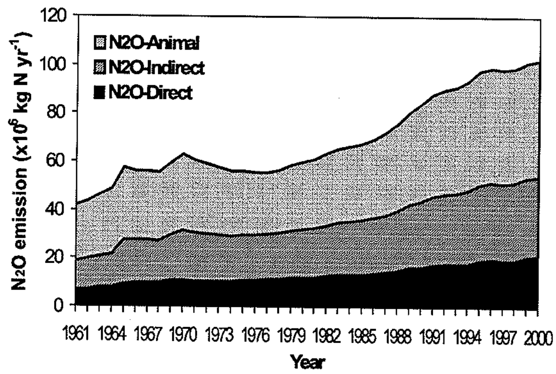

Fig. 3. N_2O emissions from Bangaldesh agrculture as estimated from three source categories over time.

N_2O emissions from agriculture

As of N loads, N_2O emissions generally depended on the amount of N derived form different N sources and increased with time. A detailed inventory of N_2O emissions from agricultural systems of Bangladesh starting from 1961 to 2000 is presented in Fig. 3. Total contribution of N_2O from different sources to the atmosphere was distinguished into N_2O-direct, N_2O-indirect and N_2O-animals, as well as the effect of the various N inputs to N_2O-direct. Share of the different source categories to N_2O emissions are also discussed by giving emphasis to 1990 and 2000.

N_2O-direct

A historical estimation, starting from 1961 to 2000, of the N_2O emissions directly from agricultural systems (N_2O-direct) was made and it was increased at a rate of $0.3321*10^6$ kg N_2O-N yr^{-1} (Fig. 3). Mainly four out of the six N sources influenced the N_2O-direct, which are: NFERT, NEX, CROBF, and CROPO. Similar to the N loads, results indicate a notable increase of N_2O emissions in 1990 and 2000 over 1961 from different source categories, except the N derived from CFOBF (Fig. 4). In 1961, CROBF, CROPO, NFERT and NEX emitted $0.13*10^6$, $7.47*10^6$, $0.10*10^6$ and $3.41*10^6$ kg N_2O-N, respectively. In 1990, the corresponding amount was $0.27*10^6$, $13.16*10^6$, $3.15*10^6$, and $7.26*10^6$ kg N_2O-N. In 1990, 54.89% was released directly from CROP0, while the share of NEX and NFERT was 30.28 and 13.15%, respectively (Fig. 4). The contribution of CROBF and Histosol was low and responsible for only 1.14 and 0.54% of the N_2O-direct, respectively. In 2000, its share for CROP0, NEX, NFERT, CROBF and Histosol was 55.86, 26.57, 16.48, 0.67 and 0.42%, respectively (Fig. 4). Its emissions from CROPO followed by NEX were estimated to be higher than from NFERT. The increased N loads from NFERT could have been dominating N_2O emissions, as this is

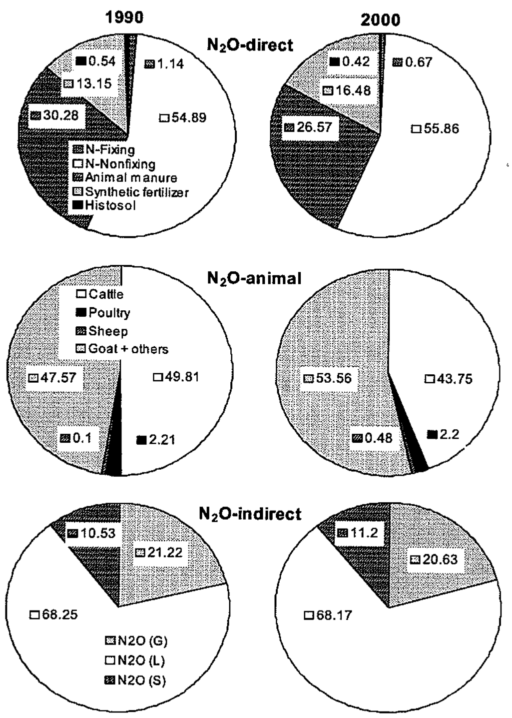

Fig. 4. Share of different source categories of N_2O-direct, -animal and -indirect to N_2O emissions for 1990 and 2000. [N_2O(G)= N_2O from atmospheric deposition of NO_x and NH_3; N_2O (L) = N_2O from N leaching and runoff and N_2O(S) = N_2O from human sewage].

very much linked to the production of crop biomass. The N_2O emissions reduced with the decrease in N loads from CROBF, which was probably related to lessen the area under legumes cultivation over time. Findings indicate the importance of increased use of NFERT for crop production over time towards the enhancement of N_2O-direct. This also resulted in an increased contribution of CROPO to the N_2O-direct with time. Indeed, farmers of Bangladesh are used to apply more synthetic N fertilizers to maximize crop yields without considering the soil health and environmental consequences.

In 1990, the N_2O-direct was $16.36*10^6$ kg N_2O-N and it was $21.26*10^6$ kg N_2O-N in 2000. The estimated direct N_2O emission from Belgium was $4.07*10^6$ kg in 1996 (Van Moortel et al., 2000), which is 5 times lower than in Bangladesh ($19.61*10^6$ kg N_2O-N). However, N released from the systems under subtropical climate is largely variable in comparison to Belgium conditions. The default IPCC values could lead to an overestimation of the N_2O emissions from Bangladesh agriculture due to lack of accurate data on NEX and crop dry matter contents. This overestimation could also have been due to the emission factors considered. Lack of specific data for Bangladesh, and their effect on the final estimate could not be judged properly. It is suggested that process-oriented models should be developed to improve the emission factors used in the inventory methodology for N_2O (Webb et al., 1999; Mosier et al., 1999). The calculation of N_2O-direct could be improved by considering soil and climatic variables and by differentiating between N_2O emissions from arable land and fertilizer N sources applied.

N_2O-animals

A sharp increase of N_2O emissions from animal systems was observed from late 70's and the rate of increase over time was almost two-fold higher ($0.6079 *10^6$ kg N_2O-N yr^{-1}) than the N_2O-direct (Fig. 3). Its emission from animal systems was $23.04*10^6$ kg N_2O-N in 1961, which was lower than that released in 2000 ($48.15*10^6$ kg N_2O-N). During 1961-1990, its release from the systems was increased by 1.75 times. The yearly increase of N_2O-animals was rapid and on average it was ~$0.76*10^6$ kg during 1990-2000. The animal systems of Bangladesh had contributed more N_2O than as estimated for Belgium, amounting to $0.93*10^6$ kg N_2O-N in 1996 (Van Moortel et al. 2000).

Different type and number of animals reflected the distribution of N_2O from animal systems (Fig. 4). In 1990, N_2O emissions from the cattle, goat + others, poultry and sheep were $20.12*10^6$, $19.22*10^6$, $0.89*10^6$ and $0.17*10^6$ kg N_2O-N, respectively. In 2000, the corresponding amount was $21.07*10^6$, $25.79*10^6$, $1.06*10^6$ and $0.23*10^6$ kg N_2O-N. It was found that the number of animals had increased over time except cattle. In 1990, the total number of livestock was 176,387 thousand and it was 210,030 thousand in 2000. However, the unexpected transboundary leakage of animals particularly cattle was not included in the calculation. Indeed, those are mostly used for meat purpose. Results show that cattle and goat + others were the major providers of N_2O emissions where the latter enhanced the release with time. The increasing number of poultry farms throughout the country was probably not accounted for. As such, contribution of poultry towards N_2O emissions differed slightly over time. Thus, the share of cattle to N_2O emissions decreased and it was reverse in case of goat + other animals. Under Bangladesh conditions, the animal systems are mostly unmanaged and major portions of animals are being reared at household levels. However, the animal sources could be highly potential in reducing N_2O emissions provided that they are managed properly particularly in confined areas and the wastes are recycled, as a supplement of agro-inputs like synthetic fertilizers.

N_2O-Indirect

Trend for N_2O emitted indirectly from agricultural systems (N_2O-indirect) was similar to the N_2O-animals, showing a lower annual rate (0.4939 $*10^6$ kg N_2O-N yr^{-1}) than the latter but higher than the N_2O-direct (Fig. 3). This indicates that the N_2O released indirectly from different sources collectively contributed more than the N_2O-direct and –animals with time and seemed to depend on N inputs. In comparison to the estimated value of N_2O-indirect (4.32$*10^6$ kg N_2O-N) for Belgium in 1996 (Van Moortel et al., 2000), Bangladesh had contributed several times higher (32.13$*10^6$ kg N). The population density could also be an important factor to that effect. Under the N_2O-indirect, three emission sources that are indirectly emitting a large amount of N_2O particularly through denitrification were taken into account. Concerning some specific years, the N_2O-indirect was 11.81$*10^6$ kg N_2O-N in 1961 and it was 27.40$*10^6$ and 32.83$*10^6$ kg N_2O-N in 1990 and 2000, respectively. In 1990, the percent share of N_2O(G), N_2O(L) and N_2O(S) for the N_2O-indirect was 21.22, 68.25 and 10.53, respectively (Fig. 4). An increase in the total amount of N_2O-indirect in 2000 over 1990 level was probably related to the increased population, as the share of N_2O(S) increased to some extent with time. However, the share of N_2O(L) had practically no change and of N_2O(G) decreased slightly in comparison to 1990 level. The increased number of inhabitants supports the above findings and was probably related to protein consumption that increased in 2000 as compared to 1990.

In the 1997 Guidelines (IPCC, 1997), N_2O emitting from sewage were reported as waste emissions rather than under agricultural sources. The N_2O associated with sewage treatment and land disposal was assumed to be negligible and it was considered that most of the N enters into rivers and/or estuaries. It should be mentioned that the N_2O-indirect could be an important factor for the calculation of its budget for Bangladesh agriculture. Under Bangladesh conditions, appropriate database and research work on the current environmental issues related to greenhouse gases are lacking. The IPCC leaching parameter (0.3 kg N kg^{-1} N applied) is probably underestimated, as the recovery of added N under both up- and wetland crops are generally with a maximum of 40%. The generalized parameters of Van Aardenne (1999) or default values of IPCC might not be effective to a great extent for different agricultural management systems of an individual country. The magnitude of N losses from soils depends on many environmental factors (crops, soil, fertilizers, etc.), its method of application and climate. As such, the above-mentioned factors have to be researched to fill in the inaccuracies of input variables for precise estimation of N_2O and other greenhouse gases for a specific country/region.

Total N_2O emissions

Total N_2O-emission was calculated from the three main source categories: (i) N_2O-direct (ii) N_2O-animal and (iii) N_2O-indirect (Fig. 5). In 1961, the total N_2O release was 41.76$\times10^6$ kg N_2O-N, where the corresponding share of them was 16.55, 28.28 and 55.17%, respectively. On the other hand, it was 84.16$*10^6$ in 1990 and 102.26$*10^6$ kg N_2O-N in 2000. The corresponding contribution was 19.44, 32.56 and 48.0% in 1990 and it was 20.79, 32.11 and 47.10% in 2000. This shows that the N_2O-animals followed by the N_2O-indirect played a more important role than the N_2O-direct (Fig. 3). This was contrasting to the % increase of N_2O emissions where the N_2O-direct added more than the others during the last decade (Fig. 5). The percent increase in N_2O emissions was 30, 20 and 19 for the N_2O-direct, N_2O-animal and N_2O-indirect, respectively in 2000 over 1990 level (Fig. 6). This increased amount to be reduced from the agricultural systems of Bangladesh as per Kyoto protocol and adoption of strategic managements in all categories may be important options to decrease the N_2O emissions.

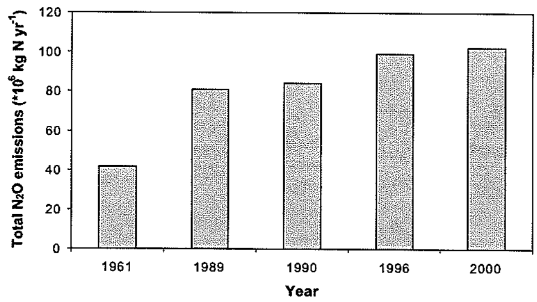

Fig. 5. Estimated total N_2O emissions from three main emission categories of Bangladesh agriculture in selected years.

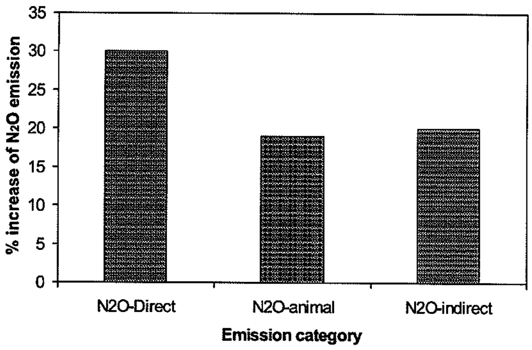

Fig. 6. Percent increase of N_2O emissions from Bangaldesh agrculture in 2000 over 1990 level from three main source categories.

The estimated agricultural-induced N_2O emissions were compared with the values obtained in some countries for 1996 (Van Moortel et al., 2000; Webb et al., 1999; Xing, 1998). The total agricultural land under Bangladesh was $13.69*10^6$ ha (BBS, 2000), which was 1.25 times lower than United Kingdom (UK) and 10.34 times higher than Belgium. The N_2O emission per unit of agricultural land from Bangladesh (7.23 kg N_2O-N ha^{-1}) was about 1.31 times lower than from Belgium (9.45 kg N_2O-N ha^{-1}) and 1.90 times higher than UK (3.80 kg N_2O-N ha^{-1}). It indicates that Belgium had been contributing more N_2O than the other countries, based on the per unit area of arable land. Under Bangladesh conditions, intensive agricultural systems appeared to result in a large N_2O emission. However, the diversified crops, irrigated /rainfed rice production systems and amount of N fertilizer, which are lower than in developed countries, applied to crop fields are to be considered. This seemed to cause lesser production of N_2O than as it was estimated using the IPCC method. Therefore, inventories showing the spatial distribution of N_2O emissions could be useful tools for the identification of regions, which contribute significant N_2O emissions from agriculture (Webb et al., 1999). However, fertilizer use policies for agricultural production can be more effective to reduce its emissions.

In 1996, the total global N_2O emission was estimated to be 6.3 Tg or 6300×10^6 kg N_2O (Mosier et al., 1998). As such, Bangladesh added 1.57% of the total global emissions estimated for 1996, which was higher than from Belgium (0.2%) and UK (1.05%). A substantial difference was observed when comparing the N_2O emissions from agriculture with the other countries and the IPCC default values. An overestimation of 45% was reported using the Belgian input data and thus, country-specific N-input data were more appropriate under Belgium situations. Similarly, Khalil et al. (2002) also reported an overestimation of N_2O emissions from an upland cropping system of humid tropics using the IPCC default values, ranging from 42-153%.

Conclusions

Global emissions of N_2O are directly related to land use and agricultural practices. Between one-half and two-thirds of all anthropogenic N_2O emissions are thought to derive from cultivated soils, with much of the remainder coming from tropical land conversion. Recent research has suggested that N_2O emissions from fertilized agricultural fields are the most significant anthropogenic sources. A large portion of N_2O emissions is emitting from animal sectors, as observed from the present estimation. Based on the diversified agricultural systems, it is revealed that the use of accurate country-specific data of the N budget could improve the estimates of N_2O emissions using the IPCC methodology. Bangladesh agriculture seems contributing a large amount of N_2O to the atmosphere. However, use of synthetic N fertilizers is importantly needed to grow more foods in order to feed the ever-increasing population. Formulation of research-based fertilizer use policies and its proper implementation in agricultural systems can be useful tools to reduce N_2O emissions. Management of animal farms and the subsequent use of organic residues/wastes for agricultural purpose by adopting integrated plant nutrient system could further improve the situation through replacing a part of synthetic N fertilizers. Therefore, agricultural research should be centered to boost agricultural production by taking into consideration the environmental consequences as well.

References

Brown, L.R., Renner, M. and Flavin, C. 1997. The Environmental Trends that are Shaping our Future. Worldwatch Institute, Washington, DC, USA. pp. 85-97.

Ayoub, A.T. 1999. Fertilizers and the environment. Nutrient Cycling in Agroecosystems. 55: 17-121.

BBS (Bangladesh Bureau of Statistics). 2000. National Data Bank. Statistics Wing, Ministry of Planning, Govt. of Bangladesh (www.bbsgov.org).

Beauchamp, E.G. 1997. Nitrous oxide emission from agricultural soils. Canadian Journal of Soil Science. 77: 113-123.

Bouwman, A.F. 1990. Exchange of greenhouse gases between terrestrial ecosystems and the atmosphere. In Bouwman A.F. (ed.) Soils and the Greenhouse Effect. John Wiley and Sons, New York. pp. 61-127.

Cicerone, R.J. 1987. Changes in stratospheric ozone. Science. 237: 35-42.

EIA (Energy Information Administration, USA) 2001. World energy consumption statistics. (http://www. eia.dep.gov).

Eichner, M.J. 1990. Nitrous oxide emissions from fertilized soils: summary of available data. Journal of Environmental Quality. 19: 272-280.

FAO (Food and Agriculture Organizations of the United Nations). 2002. http:// faostat.fao.org/faostat /collections?subset=agriculture.

Galloway, J.N. and Cowling, E.B. 2002. Reactive nitrogen and the world: 200 years of change. Ambio. 31: 64-71.

Houghton, J.T., Meira Filho, L.G., Lim, B., Tréanton, K., Mamaty, I., Bonduki, Y., Griggs, D.J. and Callander, B.A. 1997. Greenhouse gas inventory: Revised 1996 IPCC guidelines for national greenhouse gas inventories. IPCC, Bracknell, UK. Reference Manual vol I-III.

IPCC (Intergovernmental Panel on Climate Change). 1996. Climate Change 1995: The Science of Climate Change--Contribution of Working Group I to the Second Assessment Report of the IPCC. Cambridge (UK): Cambridge University Press.

IPCC (Intergovernmental Panel on Climate Change). 1997. Guidelines for National Greenhouse Gas Inventories. OECD/OCDE, Paris.

Khalil, M.I., Rosenani, A.B., Van Cleemput, O., Fauziah, C.I. and Shamshuddin, J. 2002. Nitrous Oxide Emissions from an Ultisol of the Humid Tropics under Maize-Groundnut Rotation. Journal of Environmental Quality. 31: 1071-1078.

Mosier, A.R. 1998. Soil processes and global change. Biology and Fertility of Soils. 27: 221-229.

Mosier A.R., Kroeze, C., Nevison, C., Oenema, O., Seitzinger, S. and Van Cleemput, O. 1998. Closing the global N_2O budget: nitrous oxide emissions through the agricultural nitrogen cycle. Nutrient Cycling in Agroecosystems. 52: 225-248.

Mosier A.R., Kroeze, C., Nevison, C., Oenema, O., Seitzinger, S. and Van Cleemput, O. 1999. An overview of the revised 1996 IPCC guidelines for national greenhouse gas inventory methodology for nitrous oxide from agriculture. Environmental Science & Policy. 2:325-333.

Smith, K.A., McTaggart, I.P., Dobbie, K.E. and Conen, F. 1998. Emissions of N_2O from Scottish agricultural soils, as a function of fertilizer N. Nutrient Cycling in Agroecosystems. 52: 123-130.

UNFCCC (United Nations Framework Convention on Climate Change). 1997. Kyoto Protocol to the United Nations Framework Convention on Climate Change. Document FCCC/CP/1997/77/Add.1. http://www. unfccc.de/

Van Aardenne, J.A., Kroeze, C., Pulles, M.P.J. and Hordijk, L. 1999. Uncertainties in the calculation of agricultural N_2O emissions in the Netherlands using IPCC Guidelines. In van Ham, J., Baede, A.P.M., Meyer, L.A. and Ybema, R. (eds.) Non-CO_2 Greenhouse Gases: Scientific understanding, control and implementation. Summary Report of an International Symposium, Noordwijkerhout, the Netherlands, 8-10 September 1999. -Den Bosch, The Netherlands. Vereniging van milieukundigen.

Van Moortel, E., Boeckx, P. and Van Cleemput, O. 2000. Inventory of nitrous oxide emissions from agriculture in Belgium-calculations according to the revised 1996 Intergovernmental Panel on Climate Change guidelines. Biology and Fertility of Soils. 30: 500-509.

Webb, J., Cowell, D., Kroeze, C., Lekkerkerk, L.J.A., Sutton, M.A., Skiba, U., Pain, B. and Simpson, D. 1999. Incorporation of biogenic greenhouse gas emissions in overall modelling on the European scale. In Approach to Greenhouse Gas Inventories of Biogenic Sources in Agriculture. Proceedings of EU Concerted Action F AIR3-CT96-1877. 9-10 July 1998, Lokeberg, Sweden. pp 195-186.

Xing, G.X. 1998. N_2O emission from cropland in China. Nutrient Cycling in Agroecosystems. 52: 249-254.