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Greenhouse Gas Emissions from Agro-Ecosystems and Their Contribution to Environmental Change in the Indus Basin of Pakistan

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ABSTRACT

There is growing concern that increasing concentrations of greenhouse gases in the atmosphere have been responsible for global warming through their effect on radiation balance and temperature. The magnitude of emissions and the relative importance of different sources vary widely, regionally and locally. The Indus Basin of Pakistan is the food basket of the country and agricultural activities are vulnerable to the effects of global warming due to accelerated emissions of GHGs. Many developments have taken place in the agricultural sector of Pakistan in recent decades in the background of the changing role of the government and the encouragement of the private sector for investment in new ventures. These interventions have considerable GHG emission potential. Unfortunately, no published information is currently available on GHG concentrations in the Indus Basin to assess their magnitude and emission trends. The present study is an attempt to estimate GHG (CO_2, CH_4 and N_2O) emissions arising from different agro-ecosystems of Indus Basin. The GHGs were estimated mostly using the IPCC Guidelines and data from the published literature. The results showed that CH_4 emissions were the highest (4.126 Tg yr^{-1}) followed by N_2O (0.265 Tg yr^{-1}) and CO_2 (52.6 Tg yr^{-1}). The sources of CH_4 are enteric fermentation, rice cultivation and cultivation of other crops. N_2O is formed by microbial denitrification of NO_3 produced from applied fertilizer-N on cropped soils or by mineralization of native organic matter on fallow soils. CO_2 is formed by the burning of plant residue and by soil respiration due to the decomposition of soil organic matter.

Key words: greenhouse gases, agriculture, Indus Basin, Pakistan

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1. Introduction

Global environmental change (GEC) is happening. It is altering the physical and socio-economic conditions that underpin various processes and productive systems. GEC encompasses changes in the physical, chemical and biophysical processes that shape the earth's environment. These changes can be brought about by natural events and forces, as well as by human influences. Human activities, particularly those since the Industrial Revolution in 1750, are considered largely responsible for accelerated global climate changes and giving rise to other globally and locally important environmental changes, such as greenhouse gas concentrations, alterations in land use cover and soils, atmospheric composition, water availability and quality, nitrogen availability and cycling, biodiversity, sea currents, salinity and sea level (GECAFS, 2002). The need for research for some of theses issues is enshrined in MAIRS (Monsoon Asia Integrated Regional Study Initial Science Plan) in Fu et al. (2006). The increase in the concentration of greenhouse gases is believed to alter the redistribution of energy in the atmosphere and consequently, affect climate by altering the weather patterns and hydrological cycle, among others.

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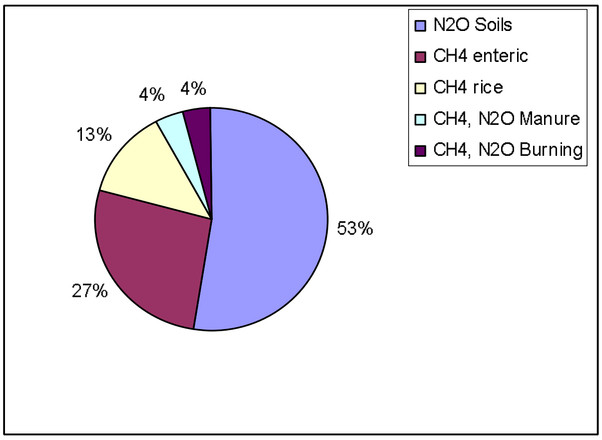

Fig. 1. GHG (O_2, CH_4, and N_2O) emissions, expressed in CO_2-equivalents, by the main sources in the agricultural sector from the countries of South Asia.

The last two centuries have witnessed the development of a greenhouse gas problem which threatens to change the climate and environment in an unprecedented manner. Though present in very small concentrations in the atmosphere, GHGs are very effective in causing warming of the atmosphere by insulating the earth from heat loss like a blanket on a bed. The greenhouse gases include Carbon dioxide (CO_2), Methane (CH_4) and Nitrous oxide (N_2O), hydro fluorocarbons, per-fluorocarbons, and sulphur hexafluoride; only the first three of these are important in agriculture sector. The global concentrations of these gases have increased significantly since 1750, due to increasing demand for energy caused by industrialization and rising population, and due to changing land use, human life style and human settlement patterns (IPCC, 2007). Agricultural activities release significant amounts of CO_2, CH_4 or N_2O into the atmosphere (Cole et al., 1997; Paustian et al., 2004). The fluxes are, however, complex and heterogeneous. On the global scale, agriculture accounts for about 14% of anthropogenic non-CO_2 emissions, comprising 84% of N_2O (2825 Mt CO_2-eq in 2000, Bouwman, 2001) and 47% of CH_4 (2778 Mt CO_2-eq in 2000, US-EPA, 2006). CO_2-eq is a measure for describing how much global warming a given type and amount of greenhouse gas (N_2O in this case) may cause using the functionally equivalent amount or concentration of CO_2 as the reference. The magnitude of emissions and the relative importance of different sources vary widely, regionally and locally. The emissions from developing countries of South Asia are given in Fig. 1 (US-EPA, 2006).

The Indus Basin covers 66% (529000 km^2) of the total area of Pakistan and spans over the provinces of Punjab, Sindh, North West Frontier Province and 23% of Baluchistan province (Fig. 2). It comprises the main Indus river, feeding rivers of Swat, Chenab and Jhelum, and many tributaries. Almost 97% of population of Pakistan is settled within the basin. The Indus Basin is the food basket for the country and agricultural activities directly or indirectly provide sustenance and livelihood to millions of people. Being open to the vagaries of nature, in particular to the variable monsoon, the agriculture in the Indus Basin is highly prone to the effects of global warming including accelerated GHG emissions. Unfortunately, no published information is available, save some isolated studies, on greenhouse gas emissions in the Indus Basin to assess their magnitude and historical trends.

Many developments have occurred in the agriculture sector in Pakistan during the past two decades. The government is assuming new roles in agriculture (Qureshi, 2007). Huge investments have been made in the ventures and enterprises utilizing agricultural raw materials and by-products in view of government incentives and support, and access to new technologies. These include an increased number of dairy farms, evolution of high yielding varieties of crops requiring higher inputs, enhanced use of agrochemicals, etc. (Qureshi, 2007). These interventions have considerable GHG emission potentials. In addition, the rice-wheat system in the Indo-Pak subcontinent experiences burning of wheat and rice straw/stubbles in areas by the farmers who use mechanized harvesters such as the Combine Harvester. Burning is done to ensure quick seedbed preparation and to avoid risk of losses in yield associated with immobilization of N during residue decomposition and infestation by insect pests (Singh et al., 2004). Cane sheath, bagasse of sugarcane, and cobs and dry stalks of maize are burnt as

Fig. 2. Indus Basin of Pakistan.

fuel in the field. The major gases released during burning are CO_2, CO, CH_4, NO_x and SO_2. The use of fertilizers in Pakistan has increased which has the potential to generate, under suitable conditions, gaseous nitrogen losses, chiefly N_2O, through the process of denitrification. These emissions not only cause environmental degradation but leave harmful effects on human health.

The purpose of the present study was to estimate the GHG emissions (CO_2, CH_4 and N_2O) arising from different agro-ecosystems in the Indus Basin of Pakistan and to assess their magnitude, sources and past trends, in order to see how these are contributing to environmental and climate change. The information will help devise strategies to mitigate the potential emissions from the agriculture sector.

2. Methodology

For the estimation of GHGs from agricultural ecosystems, possible sources of the gases must be known. The estimation of emissions from all sources was based on methodology provided by IPCC guidelines for National greenhouse gas inventories (2006).

2.1 *Methane*

Methane is produced by fermentative digestion of feed and fodder in the stomach of ruminants, and by rice grown under flooded conditions and when organic materials decompose in oxygen-depleted conditions (Mosier et al., 1998). To estimate CH_4 emissions from livestock, the enteric fermentation factors for different livestock species (in kg CH_4 per head per year) were adopted from IPCC (2006) with respect to the developing countries for the Tier 1 method. The number of various livestock species was obtained from the Agricultural Statistics of Pakistan 2005–06 (Government of Pakistan, 2006). The total emissions from a livestock species were determined by multiplying the selected emission factor with the associated animal population by the equation:

$$\text{Emission} = \text{EF}_{(\text{T})} \cdot [\text{N}_{(\text{T})}/10^6] ,$$

Where: Emissions= methane emission from Enteric Fermentation, Gg CH_4 yr^{-1}; $EF_{(T)}$=the emission factor of livestock species/category T in the country; $N_{(T)}$=the number of head of livestock species/category T in the country; T=species/category of livestock.

Total emissions from livestock enteric fermentation were calculated by summing up the emissions from all the livestock categories and subcategories. To estimate CH_4 emissions from flooded rice fields, the CH_4 emission factor (kg CH_4 ha^{-1} d^{-1}) was adopted from IPCC (2006), without organic matter. The factor was multiplied by the length of the rice growing (123 days) and the rice acreage to get total emissions in Tg yr^{-1}. To estimate CH_4 emissions from residue burning, the ratios of economic yield to residue yields of wheat, sugarcane and maize were multiplied with dry matter fractions of the residues and with the proportion of residues burnt (Table 1), and then with the emission factor for each residue adapted from IPCC (2006). Multiplying this figure with total acreage of the respective crops will give total CH_4 emissions from residue burning.

Methane emissions from manure management were estimated by adopting the emission factors for manure from different livestock from IPCC (2006) and multiplying it with respective livestock populations.

For both dairy cows and buffalo, the value of 5 kg CH_4 $head^{-1}$ yr^{-1} was adopted for the Indian subcontinent at an average annual temperature of 16°C (IPCC Table 10.14). For other animals, the values for temperate (15°C–25°C) areas of developing countries were used as given in IPCC Table 10.15. The total emissions were obtained by summing up the emissions from different livestock species.

2.2 *Nitrous oxide*

Nitrous oxide is generated by the microbial transformation of nitrogen in soils and manures, especially under wet conditions (Oenema et al., 2005; Smith and Conen, 2004). The Nitrous oxide emissions from lowland rice fields were calculated by adapting an emission factor as reported by Aggarwal et al. (2006) from India. As the agroclimatic conditions for growing rice in India are similar to those prevailing in Pakistan, the emission factor is largely valid. The figure of emission per acre was then multiplied by the land acreage under lowland rice; these data were obtained from Agricultural Statistics of Pakistan (2006).

The estimates of Nitrous oxide emissions from other arable crops in Pakistan, such as wheat, maize and cotton were obtained from the published literature. The studies referred to were basically designed to estimate denitrification losses (wherein Nitrous oxide is a major product) from applied fertilizer to soil under irrigated conditions. Denitrification is considered as a major source of N_2O in wet soils where the supply of oxygen is limited (Smith, 1990). The proportion of N_2O in the gaseous N products of denitrification increases with NO_3 concentration or with transition from anaerobic to microaerophilic conditions (Knowles, 1982). Soil structure, moisture content (Smith, 1990; Iqbal, 1992) and water table depth (Iqbal and Colbourn, 1984) are the major factors affecting the balance between the loss of N_2O by diffusion and its reduction to N_2. Acetylene is sometimes used in denitrification experiments to inhibit reduction of N_2O to N_2, in order to get the total denitrification product as N_2O, which is relatively easier to measure on a gas chromatograph. The effectiveness of acetylene as an inhibitor of N_2O reduction to N_2 may, however, decline with time.

Methods used for direct determination of denitrification gaseous fluxes from agricultural soils were based on ^{15}N tracer and acetylene inhibition techniques (Mahmood et al., 1998a) and measured on a gas chromatograph (Mahmood et al., 1998b). Various versions of acetylene inhibition e.g. soil cover and soil cores (Ryden et al., 1987; Mahmood et al., 1999) were used.

To estimate N_2O emissions from manure management, the number of heads of a livestock species was multiplied with annual average N excretion per head × fraction of total annual nitrogen excreted for each livestock species × emission factor for direct N_2O emissions from solid manure management (0.005) × 1.57 (i.e., conversion of N_2O–N to N_2O), based on IPCC guidelines (IPCC, 2006).

2.3 *Carbon dioxide*

The chief source of Carbon dioxide in agriculture is microbial decay of soil organic matter or burning of plant litter and organic residues (Smith, 2004; Janzen, 2004). The burning of wheat and rice straw is normally practiced in the areas by the farmers using mechanized harvesters, e.g., Combine Harvesters. The area and the biomass available for burning may fluctuate from year to year depending on the urgent need to harvest mechanically, such as imminent rainfall and the resources available to the harvester. The cane sheath and bagasse are burnt in the field for making brown sugar. The carbon dioxide emissions from the burning of straw were obtained by determining ratios of economic yield to residue yield which was multiplied by dry matter fraction of the residue and the proportion of residue available for burning. Table 1 gives these estimates. The CO_2 emission factors for different plant residues were adapted from IPCC (2006). These figures were then multiplied by the total areas of wheat, rice, sugarcane and maize to get total emissions from arable crops in Pakistan. The other GHGs evolved through the burning of plant residues (NO_x, SO_2) were estimated in the same manner.

Table 1. Parameters used in the calculation of GHG emissions from burning of crop residues.

Crop	Production to residue ratio	Dry matter fraction	Dry matter* burnt (%)
Wheat	1.75	0.83	25
Rice	1.76	0.85	25
Sugarcane	0.30	0.71	25
Maize	2.00	0.40	25

*1 kg of biomass burnt releases 1515 g of CO_2, 207 g of CH_4, 3.83 g of NO_x and 0.4 g of SO_2 (source: Andreae and Merlet, 2001).

Carbon dioxide is also produced by the decomposition of organic matter in the soil, a process known as soil respiration. The estimates of CO_2 produced through soil respiration in Pakistani soils were obtained from the published literature. The CO_2 emissions produced in the experimental treatments and those entrapped in soil cores were analyzed on a gas chromatograph (Mahmood et al., 2005).

3. Results and discussion

3.1 *Methane emissions*

3.1.1 *From enteric fermentation*

The methane emissions from enteric fermentation in ruminant livestock during 2005–06 are presented in Table 2. It is evident that as per IPCC guidelines (2006), out of all livestock species, the maximum CH_4 emission per head per year is by buffalo (55) followed by cattle (51) and camels (46). The minimum value is for sheep and goats (5). The corresponding emissions, during 2005–06, from buffalo, cattle and camels are 1.5652 Tg (46% of total), 1.301 Tg (38% of total) and 0.032 Tg (0.9% of total) per year. The low emissions from camels are due to their low number. The goats though have low emission factor but because of their large population are the third biggest contributor (9%) to the total emissions. Table 2 shows further that cattle and buffalo together account for more than 80% of total CH_4 emissions.

Singhal et al. (2005) reported the highest CH_4 emissions through enteric fermentation from indigenous cattle (48.5%) followed by buffalo (39%) and other livestock in India.

There has been an increasing trend in the emissions during the past decade (Fig. 3) due primarily to the gradual increase in the livestock population. The emissions increased from 2.615 Tg yr^{-1} in 1996–97 to 3.383 Tg yr^{-1} in 2005–06, a 29.4% increase. The increase has been more pronounced from 2000–01 to 2005–06. A province-wise time series trend of methane emissions (1976–2006) is also shown in Appendix-A.

3.1.2 *From Manure management*

The results (Fig. 4) show a linear increase in CH_4 emissions from 2000–01 (0.246 Tg yr^{-1}) to 2004–05 (0.272 Tg yr^{-1}), a 10.6% increase followed by a further sharp increase during 2005–06 (0.290 Tg yr^{-1}). The increase in 2005–06 relative to the previous year was 6.6%. This coincides with the increasing number of livestock population during this period.

Table 2. CH_4 emissions from different livestock species during 2005–06 in Pakistan.

Species	Emission factor (kg CH_4 head^{-1} yr^{-1})	Population (Million)	Emission (Tg yr^{-1})	Percent of Total
Cattle	51	25.5	1.301	38.5
Buffalo	55	28.4	1.562	46.2
Sheep	5	25.5	0.128	3.8
Goat	5	61.9	0.310	9.2
Camel	46	0.7	0.032	0.9
Horses	18	0.3	0.005	0.1
Asses	10	4.3	0.043	1.3
Mules	10	0.3	0.003	0.1
Total			**3.383**	

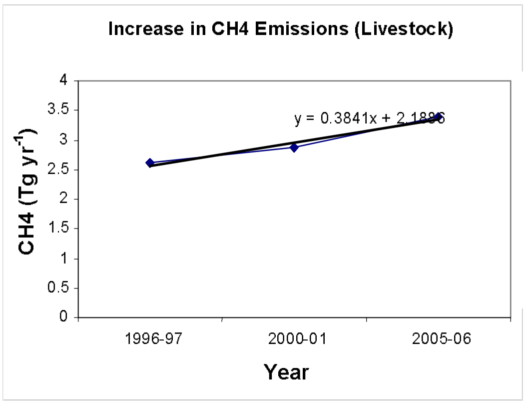

Fig. 3. Methane emissions from all livestock species from 1967–97 to 2005–06 in Pakistan.

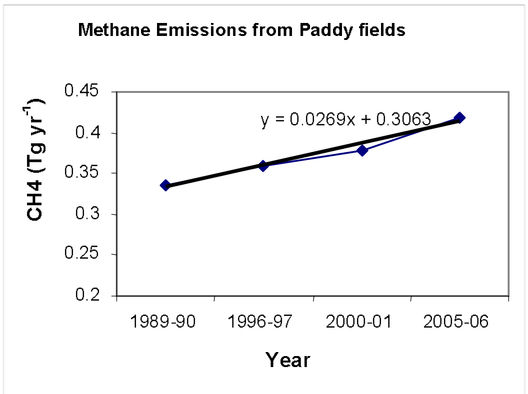

Fig. 5. Methane emissions from rice cultivation from 1989–90 to 2005–06.

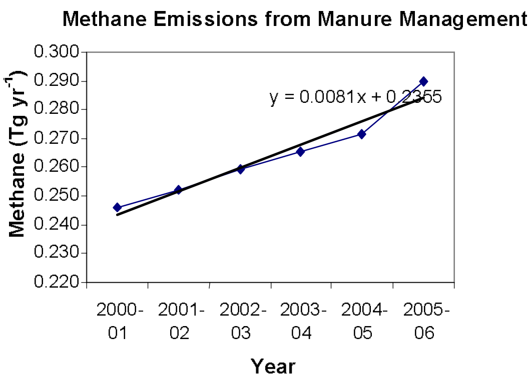

Fig. 4. Methane emissions from manure management during 2000–01 to 2005–06.

3.1.3 *From Rice fields*

The data on methane emissions from rice fields are presented in Fig. 5. The data show that there was a gradual increase in emissions from the year 1989–90 to 1999–2000 after which there was a decline for 3 years and then again an increase up until 2005–06. In Pakistan, the period of 1999–2002 was marked by a severe drought resulting in lower amounts of surface water available for rice irrigation which resulted in lower yields (Government of Pakistan, 2006). This might have led to a corresponding decrease in CH_4 emissions. ALGAS (1998) reported CH_4 emission from rice cultivation in Pakistan of 526 Gg yr^{-1}. These values are slightly higher than those reported in Fig. 5. The difference may be due to adoption of an emission factor of 130 kg CH_4 ha^{-1} d^{-1} compared to 200 kg CH_4 ha^{-1} d^{-1} used by ALGAS (1998).

3.1.4 *From burning of crop residues*

Estimates of CH_4 emitted from the burning of wheat, rice, sugarcane and maize residues during 1996–97 to 2005–06 are presented in Table 3. In the case of wheat and sugarcane, the emissions increased gradually but slightly, whereas emissions from burning of maize residue were more or less stable until 2003–04 after which there was a sudden increase. In case of rice, a dip in emissions was noticed in 2001–02 and 2002–03. This coincides with the severe drought conditions prevailing in Pakistan during this period. The highest CH_4 emission was recorded for wheat (0.016 to 0.21 Tg ha^{-1} d^{-1}) followed by sugarcane (0.006 to 0.008 Tg ha^{-1} d^{-1}), rice (0.004 to 0.006 Tg ha^{-1} d^{-1}) and maize (0.0008 to 0.0019 Tg ha^{-1} d^{-1}). The dif-

Table 3. GHG emissions (Tg yr^{-1}) from burning of crop residues in Pakistan.

Year	Crop	CO_2	CH_4	NO_x
1996–97	Wheat	9.160	0.0163	0.0232
	Rice	2.439	0.0043	0.0062
	Sugarcane	3.381	0.0060	0.0085
	Maize	0.452	0.0008	0.0011
	Total	**15.432**	**0.0275**	**0.0390**
2000–01	Wheat	10.197	0.0179	0.1031
	Rice	2.721	0.0049	0.0069
	Sugarcane	3.518	0.0063	0.0089
	Maize	0.524	0.0009	0.0013
	Total	**16.961**	**0.0299**	**0.1202**
2005–06	Wheat	11.938	0.0215	0.1207
	Rice	3.143	0.0056	0.0079
	Sugarcane	3.575	0.0064	0.0090
	Maize	1.079	0.0019	0.0027
	Total	**19.734**	**0.0354**	**0.1404**

ferences might be due to rate of residue decomposition and its composition. Gupta et al. (2004) reported CH_4 emissions from the burning of rice and wheat straw in India to be 110 Gg (0.011 Tg) in 2000, which are close to our values of wheat residues.

3.2 *Nitrous oxide emissions*

3.2.1 *From arable crops*

Substantial data have been reported on denitrification losses from different agro-ecosystems, but few studies exist to ascertain the significance of denitrification losses from irrigated croplands under semi-arid tropical conditions. Denitrification is a microbial process in which nitrate (NO_3), released from the applied fertilizer or produced from mineralization of native soil organic matter, is reduced to nitrite (NO_2) which is in turn reduced to nitrous oxide (N_2O). Under suitable conditions, nitrous oxide is further reduced to free nitrogen. The latter two denitrification products, being gases, escape into the atmosphere reducing the fertilizer efficiency. Oxygen, NO_3, and organic carbon are the major factors controlling the denitrification process at the cellular level, whereas soil moisture, organic amendment, fertilizer management practices, and edaphoclimatic conditions are important factors affecting the denitrification process by controlling the dynamics of O_2, NO_3, and organic C.

In Pakistan, where crop husbandry largely depends on flood irrigation, fertilizer-N recovery is often poor and ranges from 58% (in cotton-wheat system, Mahmood et al., 2000) to 67% (in wheat maize system, Mahmood et al., 1998b). As the substrate for the denitrification process (i.e., NO_3) is provided chiefly by the nitrogenous fertilizers, hence the evolution of N_2O is closely related to the amounts of N-fertilizer applied. The differences in emissions of N_2O as a function of N application rate have been amply demonstrated in the case of wheat and maize, and cotton. Denitrification was measured under the semiarid subtropical field conditions of Faisalabad in central Punjab province of Pakistan from the arable soil layer of irrigated wheat-maize cropping system fertilized with urea at 50 or 100 kg N ha^{-1} yr^{-1}, each applied in combination with 8 or 16 ha^{-1} yr^{-1} of farmyard manure. Denitrification loss ranged from 3.7 to 5.7 kg N ha^{-1} during the growing season of wheat (150 d) and from 14.0 to 30.3 kg N ha^{-1} during the maize growing season (60 d) (Mahmood et al., 2005). On the other hand, under irrigated cotton fertilized with urea at 173 kg N ha^{-1} and exposed to high summer temperatures and heavy monsoon rains, the denitrification loss, including the N_2O entrapped in soil, was as high as 65 kg N ha^{-1} (Mahmood et al., 2000).

The cotton fields during the fallow periods usually produce greater amounts of N_2O than those during the cotton growing season because the NO_3 produced during the fallow period is all available for denitrification in the absence of crop uptake. Total N_2O emissions from cotton fields fertilized with 100 kg N ha^{-1} as urea, from 95 integrated sampling dates, were estimated to be 324.4±359.5 g N ha^{-1} from the growing season (May to October) compared to 647.9±508.5 g N ha^{-1} for the fallow period (November to April), making a yearly total emission of 972.3±868.0 g N ha^{-1}. This amount corresponds to less than 1% of the applied fertilizer-N (unpublished data, Mahmood, 2006). Data from 1996–97 to 2005–06 showed a minute change in N_2O emissions from soils under major crops due to denitrification (Fig. 6).

The emissions on the national scale can be correlated with total use of nitrogenous fertilizers on arable crops. The uses of N-fertilizer and potential N_2O emissions are presented in Fig. 7. It is to be pointed out that about 75% of the fertilizer is used for cotton; hence

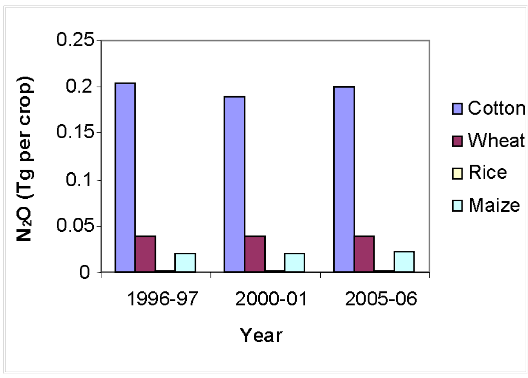

Fig. 6. N_2O emissions from soils under major crops due to denitrification.

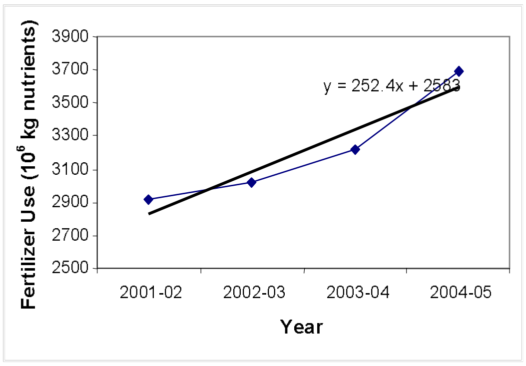

Fig. 7. Fertilizer usage trend in Pakistan during the past 4 years.

the emissions from cotton could be much higher. The factors like the proportion of N_2O in the denitrification product, appropriate conditions for denitrification, availability of water, etc., however, play important roles in controlling N_2O emissions.

3.2.2 *From manure management*

The N_2O emissions from manure management gradually increased from 1996–97 to 2005–06 (Fig. 8). The emissions, in general, were small compared to those from arable crops and will be neglected.

3.3 *Carbon dioxide emissions*

The CO_2 emissions from the burning of wheat, rice, sugarcane and maize plant residues are presented in Table 3. In the case of wheat, the emissions showed a slight increase during the past decade but in the case of rice, sugarcane and maize, the emissions tended to be stable. The highest CO_2 emission was recorded from wheat crops (9.16 to 11.94 Tg yr^{-1}) followed by sugarcane (3.38 to 4.45 Tg yr^{-1}), rice (2.43 to 3.14 Tg yr^{-1}) and maize (0.45 to 1.08 Tg yr^{-1}). However, when carbon fixation by the crops and accumulation of crop residue in the root zone is taken into account, the net value becomes zero. Carbon dioxide emissions

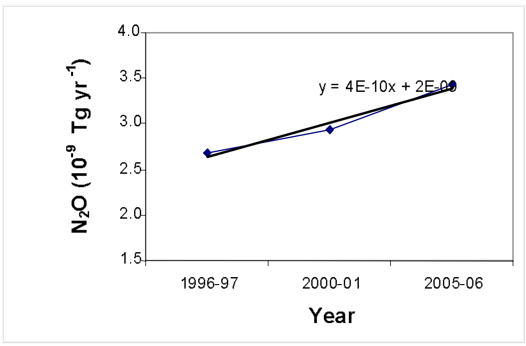

Fig. 8. N_2O emission from manure management during 1996–97 to 2005–06.

from burning of crop residues were, therefore, not considered further.

3.4 CO_2 *produced by soil respiration*

Soils are the largest carbon pool in terrestrial ecosystems containing two-thirds of the total carbon in the terrestrial ecosystems. The release of carbon or its accumulation depends on the standing stock of carbon in vegetation, soil, humus and litter that further depends on land use and land cover changes.

Mahmood et al. (2005) determined soil respiration, or total CO_2 efflux in relation to denitrification, from wheat-maize copping system under semi-arid conditions of Punjab, Pakistan. They reported that average soil respiration during the wheat growing season (at water-filled pore space $<60\%$) was significantly higher (12.3 kg C ha^{-1} d^{-1}) in the treatments receiving urea at the rate of 100 kg ha^{-1} and farmyard manure at the rate of 16×10^3 kg ha^{-1} than in other fertilizer treatments (11.0–11.3 kg C ha^{-1} d^{-1}), whereas during the maize growing season, the rate was similar among fertilized treatments. In another study (Mahmood et al., 1998a), the average soil respiration rate during the maize season (19.4 kg C ha^{-1} d^{-1}) was 1.6 times higher than the average rate during the wheat season (11.8 kg C ha^{-1} d^{-1}). The soil respiration rate from an irrigated cotton field at Faisalabad, Pakistan during the 1996 growing season ranged from 16.0 to 217.2 kg C ha^{-1} d^{-1}; the mean (50.4 kg C ha^{-1} d^{-1}) was slightly higher than that recorded for the 1995 growing season (Mahmood et al., 2000). Figure 9 shows CO_2 emissions from the soil under major crops in Pakistan.

Sharma and Rai (2007) reported that crop production typically results in a reduction of soil carbon, larger than wastelands, due to increased soil disturbance and organic matter loss. On the other hand, a considerable amount of plant biomass goes into the soil as a result of growth of roots and as crop residue and litter. Sharma and Rai (2007) reported that total vegetation C was significantly higher in open cropped areas of temperate and subtropical belts in comparison to the mandarin agro-forestry system due to high weedy biomass in the former land use.

The net result of carbon loss and fixation in the stabilized land use systems is almost zero. The carbon release values in the present study were, therefore, not considered further.

3.5 NO_x *emissions*

Table 3 shows NO_x emissions from burning of wheat, rice, sugarcane and maize residues. Although NO_x are not greenhouse gases, they are the major product from burning of crop residue. Except for wheat, where there was a slight increasing trend, no

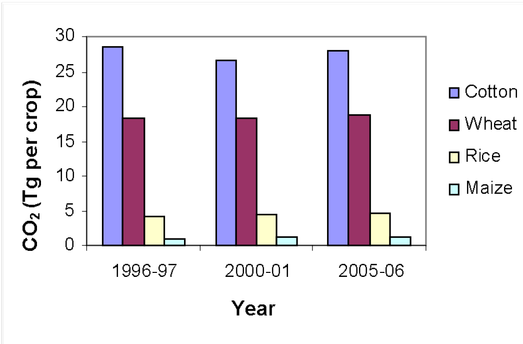

Fig. 9. CO_2 emissions from the soil under major crops.

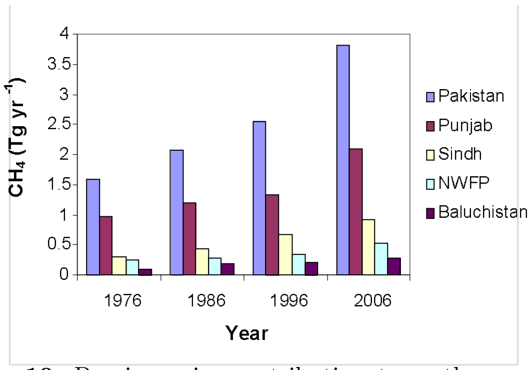

Fig. 10. Province-wise contribution to methane emissions from livestock.

systematic pattern of NO_x emission was noticed for these crops. The highest concentration was recorded for wheat (0.023 to 0.12 Tg yr^{-1}) while in the other three crops, the emissions were less than 0.011 Tg yr^{-1}. In India, Gupta et al (2004) reported NO_x emissions from rice and wheat straw burning to be 84 Gg (0.0084 Tg) in 2000.

3.6 *Province-wise contribution to emissions*

The CH_4 emissions from enteric fermentation during the past three decades (1976–2006) from four provinces on Pakistan; Punjab, Sindh, North West Frontier Province (NWFP) and Baluchistan, are presented in Fig. 10. The emissions showed a slight increase in Pakistan (as described earlier) with component increases in Punjab and Sindh provinces up to 1996, after which there was a surge in emissions up until 2006. This increase in methane emission, primarily due to increase in the number of livestock, is in line with IPCC (2007) findings. The increasing trend in case of NWFP and Baluchistan was, however, slight.

The provincial contribution to CH_4 emissions from enteric fermentation during 2006 are given in Table 4. The Punjab province contributed to the maximum extent (55%) to national emissions followed by Sindh (24%), NWFP (14%) and Baluchistan (7%). This contribution is primarily based on number and nature of livestock reared, availability of fodder and availability of water. The Punjab and Sindh provinces are abound in buffalo and cattle (cow) whereas NWFP has higher number of cattle and goats, and Baluchistan greater number of cattle, goat and sheep (Appendix A).

4. Conclusions

The total GHG emissions by source are summarized in Table 5. The highest emissions were of methane, followed by N_2O, from arable soils. Among CH_4 emissions, the greatest share was of enteric fermentation followed by that of rice cultivation, manure management and residue burning. The large increase in enteric and manure methane emissions is attributed to the proliferating dairy industry showing an impressive growth rate of 4.3% (Government of Pakistan 2007). The main driver of increasing N_2O emissions is the use of N fertilizers which is on the increase in Pakistan, as shown in Fig. 7, to keep up with the increasing demand for food resulting from rapid population growth (presently at the rate of 1.8%). The N_2O emissions from agricultural soils could be higher than those given in the Table when weighted against fertilizer use. These emissions are slightly higher than those reported in Pakistan's Initial National Communication on Climate Change (Government of Pakistan 2003), which were determined in 1993–94, but lower than those reported by India's Natcom (2002).

The increased greenhouse gas concentrations from the Agriculture Sector, in combination with those from the other sectors, have contributed to changes in cli-

Table 4. Provincial contribution of CH_4 from enteric fermentation during the year 2006.

	CH_4 emissions (Tg yr^{-1})	Share in Pakistan (%)
Punjab	2.100	55
Sindh	0.910	24
N.W.F.P	0.524	14
Baluchistan	0.273	7
Pakistan	**3.807**	**100**

Table 5. Source-wise total emissions of GHGs (Tg yr^{-1}) in Pakistan during 2006.

	CH_4	N_2O
Enteric fermentation	3.383	–
Manure Management	0.29	–
Rice Cultivation	0.419	0.0023
Agricultural Soils	–	0.2627
Burning of crop Residues	0.0354	–
Total	**4.1273**	**0.265**

APPENDIX A

Methane Emissions from Enteric Fermentation (Tg yr^{-1})

		1976	1986	1996	2006
Punjab	Cattle	0.4135	0.4497	0.4785	0.7852
	Buffalo	0.4388	0.6133	0.7206	1.0934
	Sheep	0.0402	0.0334	0.0307	0.0569
	Goat	0.0388	0.0539	0.0765	0.1075
	Camel	0.0155	0.0148	0.0086	0.0203
	Horses	0.0051	0.0044	0.0033	0.0066
	Asses	0.0114	0.0166	0.0195	0.0294
	Mules	0.0003	0.0004	0.0006	0.0008
	Subtotal	**0.9637**	**1.1863**	**1.3382**	**2.1001**
Sindh	Cattle	0.1456	0.1976	0.2787	0.3933
	Buffalo	0.1009	0.1771	0.3088	0.3947
	Sheep	0.0091	0.0131	0.0186	0.0260
	Goat	0.0212	0.0338	0.0487	0.0671
	Camel	0.0066	0.0100	0.0104	0.0165
	Horses	0.0017	0.0014	0.0011	0.0022
	Asses	0.0037	0.0050	0.0069	0.0099
	Mules	0.0000	0.0001	0.0001	0.0001
	Subtotal	**0.2888**	**0.4380**	**0.6733**	**0.9099**
NWFP	Cattle	0.1530	0.1675	0.2161	0.3247
	Buffalo	0.0419	0.0699	0.0767	0.1177
	Sheep	0.0184	0.0080	0.0141	0.0219
	Goat	0.0234	0.0145	0.0338	0.0440
	Camel	0.0044	0.0032	0.0030	0.0057
	Horses	0.0005	0.0006	0.0008	0.0012
	Asses	0.0038	0.0045	0.0053	0.0082
	Mules	0.0003	0.0002	0.0006	0.0007
	Subtotal	**0.2457**	**0.2685**	**0.3505**	**0.5240**
Baluchistan	Cattle	0.0349	0.0590	0.0684	0.1023
	Buffalo	0.0018	0.0035	0.0089	0.0101
	Sheep	0.0254	0.0556	0.0542	0.0855
	Goat	0.0222	0.0365	0.0468	0.0674
	Camel	0.0098	0.0161	0.0156	0.0002
	Horses	0.0004	0.0005	0.0008	0.0011
	Asses	0.0024	0.0037	0.0038	0.0061
	Mules	0.0000	0.0000	0.0001	0.0001
	Subtotal	**0.0969**	**0.1748**	**0.1986**	**0.2727**
Pakistan	Cattle	0.7469	0.8738	1.0416	1.6055
	Buffalo	0.5834	0.8637	1.1150	1.6159
	Sheep	0.0931	0.1101	0.1176	0.1903
	Goat	0.1057	0.1386	0.2058	0.2858
	Camel	0.0363	0.0441	0.0375	0.0426
	Horses	0.0078	0.0069	0.0060	0.0112
	Asses	0.0214	0.0297	0.0356	0.0536
	Mules	0.0006	0.0007	0.0014	0.0017
Total		**1.5952**	**2.0676**	**2.5605**	**3.8067**

matic parameters, mainly temperature and precipitation, in the Indus Basin of Pakistan. The mean temperature increase recorded in Pakistan during the past century was 0.6°C (Mitchell and Jones, 2005), which is of the same order as the average global temperature during the same period (IPCC, 2007).

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