International Journal of Ecology and Environmental Sciences 33(2-3): 91-103, 2007

Soil Degradation and Environment Quality in South Asia

R. LAL
Carbon Management and Sequestration Center, The Ohio State University, Columbus, OH 43210, USA
Email: Lal.1@osu.edu

ABSTRACT

South Asia, comprising seven countries, is a world within the world. This region is home to about 1.5 billion people or about one-fourth the world's population that lives on less than 5% of the earth's land area. The region has a total land area of 514 million hectares (Mha) of which 39.5% is arable, 9.6% is permanent pasture, and 15.2% is forest and woodland. The western region of South Asia is arid, and a large proportion of cropland is irrigated by canal and tube wells. Yet, rainfed agriculture is practiced widely on some 123 Mha or 56% of the cropland area in South Asia. Because of the high population density, the per capita cropland area and renewable fresh water resources are decreasing rapidly. Anthropogenic soil degradation is a serious problem throughout the region. Land area affected by different degradation processes is estimated at 55 Mha by water erosion, 24 Mha by wind erosion, 80 Mha by desertification, 17 Mha by salinization, 12 Mha by waterlogging, 11 Mha by nutrient depletion and large area by ground water depletion caused by excessive withdrawal for irrigation. The problem of soil erosion by water, especially severe in the lower and middle Himalayas and other regions with undulating terrains, is exacerbated by widespread deforestation, cultivation of steep slopes, and the perpetual use of extractive farming practices. The stagnation or even decline in productivity of the rice-wheat system, practiced on 12.5 Mha in the region, is attributed to soil degradation and nutrient imbalance. The use of traditional biofuels, crop residues and cattle dung used for cooking and heating, adversely impacts air quality and is a serious health hazard. Eutrophication of surface water and contamination of ground water are caused by indiscriminate use of agricultural chemicals, and discharge of industrial and urban effluents into rivers. The environmental problems are also caused by unprecedented and rapid economic development, especially in India. While improving education in rural areas is an important long-term strategy, the importance of conversion to a prudent land use and adoption of recommended practices of soil and crop management cannot be over-emphasized. Developing clean household cooking fuel is important to improving air quality and reversing soil degradation through use of crop residues and cattle dung as soil amendments.

Key Words: Soil Degradation, Sustainable Agriculture, Soil Quality, Soil Management, Food Security, Climate Change

INTRODUCTION

South Asia is a large region comprising seven countries: Afghanistan, Bangladesh, Bhutan, India, Nepal, Pakistan and Sri Lanka. The current population of about 1.5 billion is projected to be 1.6 billion by 2010, 1.8 billion by 2020, 2.0 billion by 2030, 2.2 billion by 2040 and 2.3 billion by 2050. The population may stabilize around 3 billion by 2100 (Table 1). India comprises a large proportion of the total population (Figure 1). It was 1.10 billion (74.3%) in 2005, and is projected to be 1.18 billion (73.8%) in 2010, 1.32 billion (72.1%) in 2020, 1.45 billion (73.3%) in 2030, 1.53 billion (69.9%) in 2040, and 1.59 billion (68.5%) in 2050 (WRI 2005). The rate of population growth differs among countries, and the current rate is about 4.1% in Afghanistan, 2.3% in Bangladesh and Bhutan, 1.7% in India, 2.4% in Nepal, 2.6% in Pakistan and 0.9% in Sri Lanka. There is an urgent need to stabilize population and reduce the growth rate in most countries of the region. Only the population of Sri Lanka will begin to decrease beyond 2040, and that of other countries must also stabilize in the near future.

Most of the population of the region lives in rural areas, and agriculture is the predominant profession of rural population. Most farmers are small landholders

Table 1. Population projections (millions) in South Asia between 2000 and 2050 (Recalculated from WRI 2005).

Year	Afghanistan	Bangladesh	Bhutan	India	Nepal	Pakistan	Sri Lanka	Total
2000	23.7	128.9	1.9	1021.1	24.4	142.6	19.8	1362.4
2005	29.9	141.8	2.2	1103.4	27.1	157.9	20.7	1483.0
2010	35.6	155.0	2.4	1183.3	29.9	175.2	21.6	1603.0
2015	41.4	168.2	2.7	1260.4	32.7	193.4	22.3	1721.1
2020	48.0	181.2	2.9	1332.0	35.7	211.7	22.9	1834.4
2025	55.4	193.8	3.2	1395.5	38.6	229.4	23.4	1939.3
2030	63.4	205.6	3.5	1449.1	41.4	246.3	23.7	2033.0
2035	71.8	216.7	3.7	1494.3	44.1	262.6	23.8	2117.0
2040	80.3	226.7	3.9	1534.4	46.7	278.0	23.9	2193.9
2045	88.8	235.5	4.2	1567.7	49.0	292.2	23.8	2261.2
2050	97.3	242.9	4.4	1592.7	51.2	304.7	23.6	2316.8

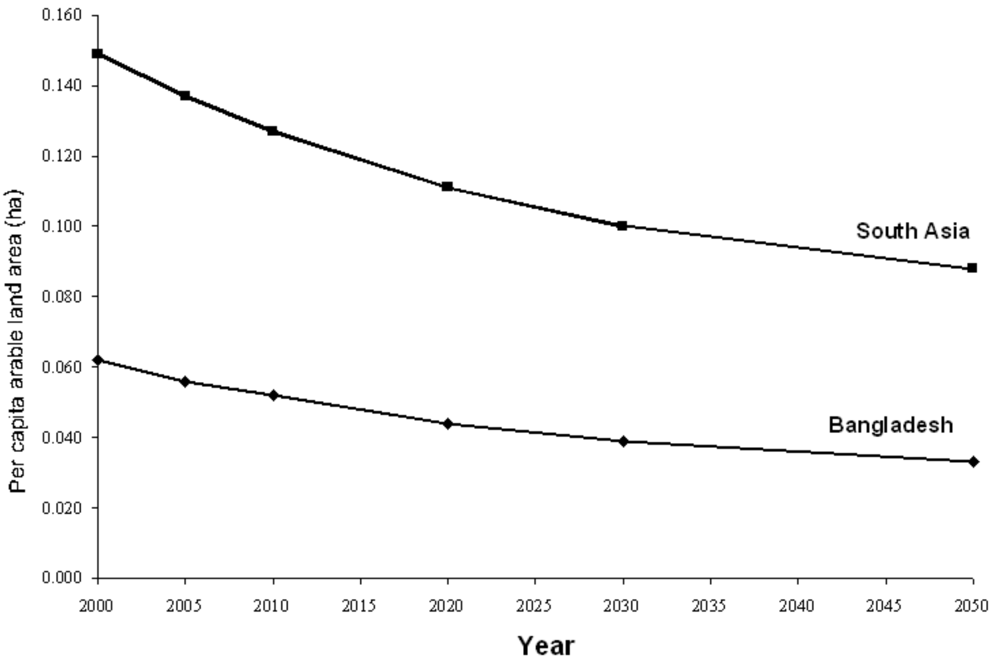

Figure 1. Projected growth of population in South Asia (redrawn from WRI 2005).

with farm size of 0.5 to 2 ha, and use extractive prac-tices of subsistence farming. The region is also home to more than half of world's hungry, malnour-ished and poor people living on less than \$1 day^{-1} income (Rogers et al. 2006). Furthermore, the region is undergoing a rapid economic development, urbanization, and land use change with short and long-term impacts on soil and environmental degradation. Therefore, the focus of this manuscript is the South Asian region, with the specific objectives to: (i) review land use and agricul-tural status, (ii) assess factors and causes of soil degra-dation by different processes (iii) evaluate the projected food demand and technological options to advance food security, and (iv) describe strategies of minimizing risks

Table 2. Predominant land uses (Mha) in South Asia (FAO and WRI 2005).

Country	Total Area	Land Area	Agricultural	Arable	Permanent Pasture	Forest and Woodland
Afghanistan	65.2	65.2	38.0	7.9	30.0	1.4
Bangladesh	14.4	13.0	9.0	8.0	0.6	1.3
Bhutan	4.7	4.7	0.5	0.15	0.4	3.0
India	328.7	297.3	180.8	161.7	11.1	64.1
Nepal	14.7	14.3	4.2	3.2	1.7	3.9
Pakistan	79.6	77.1	25.1	21.4	5.0	2.4
Sri Lanka	6.6	6.5	2.4	0.9	0.4	1.9
Total	513.9	478.1	260.0	203.3	49.2	78.0

Table 3. Per capita cropland area (ha) in South Asia* (calculated from FAO 2005).

	Per Capita Land Area in Different Years					
Country	2000	2005	2010	2020	2030	2050
Afghanistan	0.330	0.260	0.220	0.160	0.120	0.080
Bangladesh	0.062	0.056	0.052	0.044	0.039	0.033
Bhutan	0.079	0.069	0.063	0.052	0.043	0.034
India	0.158	0.147	0.137	0.121	0.112	0.102
Nepal	0.131	0.118	0.107	0.090	0.077	0.063
Pakistan	0.150	0.136	0.122	0.100	0.087	0.070
Sri Lanka	0.045	0.043	0.042	0.039	0.038	0.038
Region	0.149	0.137	0.127	0.111	0.100	0.088

* These calculations are based on the assumption that the arable land area of 2000 will remain unchanged

of environmental pollution and soil degradation while implementing programs of agricultural intensification. Being a large country, covering 74% of the total population in 2005 and 64% of the total area, most examples of land use and soil management will be drawn from India.

Climate, Land Use and Soil Resources

The region is appropriately described as the world within the world. The climate, land resources, terrain, physiography and ethnic and cultural heritage of the population are highly diverse. The climate of Afghanistan, Pakistan and of one-fourth of the northwestern part of India is predominantly arid. In contrast, climate of Bangladesh, Bhutan, Nepal, eastern India and Sri Lanka is humid. Almost 40% of the total land area of the region is under cropping, which is a reflection of the very high population density (Table 2). Yet, the per capita land area in the region is among the lowest in the world. For the region as a whole, the current per capita land area of 0.137 ha is projected to decrease to 0.10 ha by 2030, and <0.09 ha by 2050 (Table 3). The least per capita land area in the region is in Bangladesh. It was 0.06 ha in 2000 and is projected to be 0.05 ha in 2010, and merely 0.03 ha in 2050 (Figure 2). Thus, all demands (e.g., food, feed, fiber, fuel) of the present and future population in Bangladesh have to be met on a very small land area, which may be further jeopardized by the sea level rise due to the projected climate change. Thus, agricultural intensification of existing land resources through adoption of recommended management

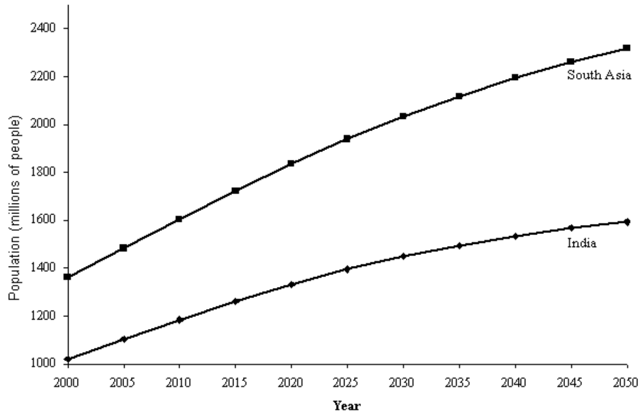

Figure 2. Temporal changes in per capita land area in South Asia (redrawn from FAO 2005, WRI 2005).

Table 4. Per capita renewable fresh water resources (m^3) of South Asia (recalculated from Garner Outlaw and Engelman 1997).

Country	1995	2050
Afghanistan	2,543	815
Bangladesh	19,936	10,803
Bhutan	53,672	18,326
India	2,244	1,360
Nepal	7,923	3,170
Pakistan	3,435	1,310
Sri Lanka	2,410	1,600

practices (RMPs) is an absolute necessity. Continuation of low-input systems, which are extractive farming practices based on mining of soil fertility, is no longer an option in the context of ever increasing population and accentuating demand on limited soil resources.

In addition to prime farm land, renewable fresh water resources of the region are also scarce (Table 4). Countries with severe constraints of water availability, not only for irrigation but also for use by people and livestock, are Afghanistan, India and Pakistan. These three countries, with a total population of 1.3 billion in 2005 and projected to be 2.0 billion by 2050, will have per capita fresh water supply of merely 815 m^3, 1360 m^3 and 1310 m^3 by 2050 in Afghanistan, India and Pakistan, respectively (Table 4). Fresh water resources are also being polluted by discharge of urban and industrial effluents in rivers.

Similar to the per capita land area, the region is also characterized by extremely low per capita irrigated land area (Table 5). While the irrigated agriculture has been practiced in the region for several millennia, high demographic pressure has stressed the irrigation resources to the limit. The per capita irrigated land area, the ecosystem with high and assured crop yields, is merely 0.03 ha in several countries and rapidly declining with increase in population. The irrigated agriculture is also jeopardized by salinization, depletion of ground water, pollution/ contamination of water, and lack of availability of new water resources for further expansion of irrigation at affordable cost. Indeed, the percent of cropland area under irrigation is among the highest in the world (Table 6). As much as 80% of the cropland in Pakistan and 55% in Bangladesh is under irrigation (Table 6). Future expansion of irrigated cropland would be extremely difficult and expensive.

Table 5. Irrigated Area (Mha) in South Asia (Recalculated from FAO 2005, Kaosaard and Rerkasem 2000)

Country	1975	1985	1995	1998	2003	Per capita in 2003 (ha)
Afghanistan	2.4	2.6	2.8	2.8	2.7	0.09
Bangladesh	1.4	2.1	3.2	4.2	4.7	0.03
India	33.7	41.8	50.1	54.8	55.8	0.05
Nepal	0.2	0.8	0.9	1.1	1.2	0.04
Pakistan	13.6	15.8	17.2	18.1	18.2	0.11
Sri Lanka	0.5	0.6	0.6	0.7	0.7	0.03

Table 6. Percent of cropland area under irrigation (WRI 2005).

Country	% Irrigated
Afghanistan	29.6
Bangladesh	54.5
Bhutan	24.2
India	33.6
Nepal	34.5
Pakistan	80.5
Sri Lanka	33.3

Energy Use and Fossil Fuel Combustion

Being a developing region with low GDP, the use of primary energy is amongst the lowest in the world (Table 7). Total primary energy consumption was merely 5.1 Quads (quadrillion BTU or 10^{15} BTU) in 1980 (1.8% of the world), 9.7 Quads (2.8% of the world) in 1990, 16.1 Quads (4.0% of the world total) in 2000, and 16.9 Quads (4.0% of the world total) in 2003. The fact that about one-quarter of the world population relies on only 4% of the world's energy consumption is a reflection of the extreme poverty and low standard of living. With rapid economic growth in some countries, the fossil fuel consumption is increasing rapidly (Table 8). Total CO_2-C emission (Tg C yr^{-1}) for the region was < 25 in 1950, about 35 in 1960, 60 in 1970, 107 in 1980, 210 in 1990, 357 in 2000 and 733 in 2002 (Table 8). In addition to fossil fuel, the main source of household energy use in South Asia is the traditional fuel comprising of fuel wood, crop residues and cattle dung. The total amount of traditional fuel used in India was 374 Tg in 1995 (Table 9, Venkataraman et al. 2005). These traditional biofuels set in motion degradative trends in the quality of soil, water and air resources (Figure 3). Rather than using as soil amend-ments, removal of crop residues and dung as residential fuel depletes soil organic carbon (SOC) pool, creates a negative nutrient budget; degrades soils structure, increases susceptibility to soil erosion and reduces agronomic/biomasss productivity. Decline in soil quality also leads to eutrophication/ contamination of water resources because of increase in non-point source pollution (Figure 3). Incomplete combustion of the biomass leads to emission of soot, and numerous noxious gases with adverse impact on human health (Venkataraman et al. 2005).

Table 7. Primary energy consumption (Quads) in South Asia.

Country	1980	1990	2000	2003
Afghanistan	0.03	0.11	0.023	0.02
Bangladesh	0.13	0.25	0.50	0.62
Bhutan	0.0001	0.013	0.017	0.018
India	4.16	8.02	13.50	14.03
Nepal	0.008	0.018	0.058	0.062
Pakistan	0.63	1.18	1.85	1.91
Sri Lanka	0.09	0.11	0.19	0.20
Regional Total	5.05	9.70	16.14	16.86
World Total	283.4	347.3	399.7	421.5

Source: www.eia.doe.gov/pub/international/eaf/table1.xls

Soil Degradation

Predominant soils of the region are Inceptisols (88.1 Mha), Entisols (82.0 Mha), Alfisols (73.4 Mha), Aridisols (63.2 Mha), Vertisols (60.3 Mha), Ultisols (41.6 Mha), shifting sands (32.8 Mha), rocks (32.8 Mha), Mollisols (19.1 Mha), Histosols (1.2 Mha) and Gelisols (0.3 Mha) (Eswaran et al. 1999). Alfisols, Aridisols and Vertisols are extremely susceptible to erosion by water and/or wind. Alfisols are prone to crusting and compaction, and Vertisols have extremely low infiltration rate (Lal 2006). In addition, Inceptisols are also prone to secondary salinization especially when irrigated without provision for adequate drainage. Anthropogenic soil degradation is a serious problem throughout the region. Estimates of soil degradation by different processes include 55.4 Mha affected by water erosion, 23.6 Mha by wind erosion, 11 Mha by fertility depletion, 4.7 Mha by waterlogging, and 9.3 Mha by salinization (Table 10).

The problem of soil degradation is exacerbated by fragile soils of high erodibility, harsh climate with torrential monsoonal rains and desiccating westerly winds in the arid/dry western regions, and perpetual use of extractive farming practices based on removal of crop residues and dung, excessive/uncontrolled grazing, and

Table 8. Total CO_2-C emission (Tg C yr^{-1}) by fossil fuel consumption in South Asia (Marland and Andres 2004).

Year	Afghanistan	Bangladesh	Bhutan	India	Nepal	Pakistan	Sri Lanka	Total
1950	0.023	-	-	18.171	0.007	-	0.444	-
1960	0.113	-	-	32.883	0.022	-	0.616	-
1970	0.452	0.926	0.001	52.861	0.062	5.132	0.981	60.415
1980	0.468	2.163	0.006	94.786	0.148	8.637	0.905	107.113
1990	0.713	4.192	0.035	185.016	0.172	18.566	1.026	209.72
2000	0.247	8.168	0.108	316.223	0.928	28.772	2.779	357.225
2002	0.168	9.412	0.109	332.667	1.048	29.612	2.823	733.064

Table 9. Estimate of the traditional biofuel use (Tg C yr^{-1}) in India and Asia in 1995 (modified from Venkatraman et al. 2005).

Country/Region	Fuel wood	Cattle dung		Crop residue	Total
		Range	Average		
India	109-409	35-108	20-67	164-584	374
Asia	800-930	130-200	430-565	1360-1675	1018
World	1324-1615	150-410	442-707	1916-2732	2324

Table 10. Extent and severity of soil degradation (Mha) in South Asia (modified from FAO 1994).

Country	Water Erosion	Wind Erosion	Fertility Decline	Waterlogging	Salinization	Groundwater Depletion
Afghanistan	11.2	2.1	-	0	1.3	0
Bangladesh	1.5	0	6.4	0	0	0
Bhutan	0.04	0	0	0	0	0
India	32.8	10.8	3.2	3.1	4.1	-
Nepal	1.6	0	-	0.6	0	0
Pakistan	7.2	10.7	-	1.0	3.8	0.01
Sri Lanka	1.1	0	1.4	0	0.05	0
Total	55.4	23.6	11.0	4.7	9.3	0.01

lack of modern off-farm inputs. Excessive irrigation, especially with poor quality water, has been the cause of secondary salinization in the Indo-Gangetic Basin and elsewhere in the region. Use of traditional biofuels is one of the principal causes of soil degradation. Of the 6.8 billion Mg of oil equivalent of energy consumed from biosolids on the global scale, South Asia consumes about 250 million Mg of oil equivalent (Table 11). However, most of the biosolid energy consumed in South Asia is in the form of traditional residential biofuels. Improved biofuels (e.g., ethanol or methane) are not yet widely used in South Asia.

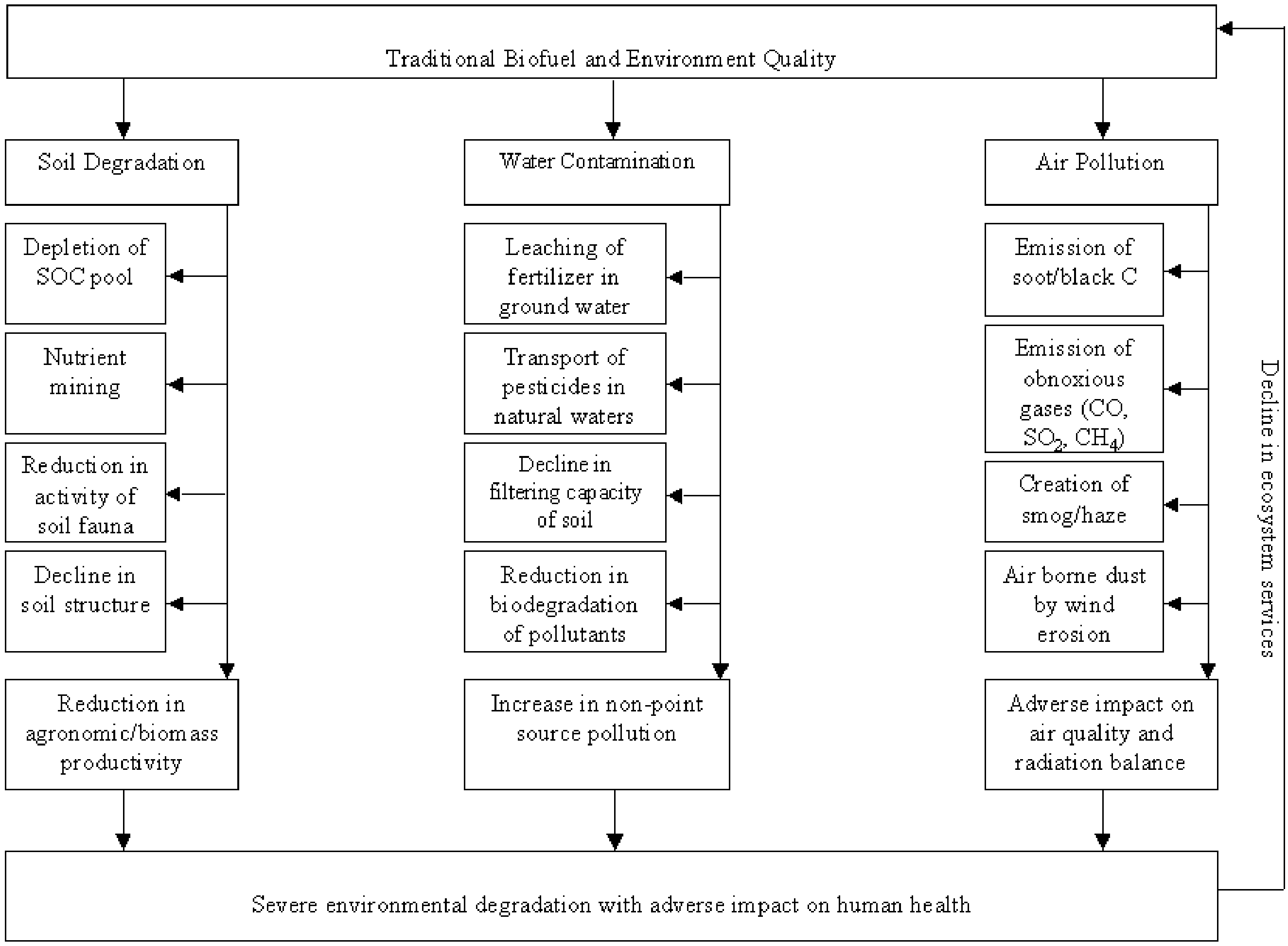

Figure 3. Adverse impacts of traditional biofuels on soil, water, and air quality and decline in ecosystem services

Table 11. Energy produced form biosolids in South Asia (Earth Trends 2003).

Country	10^6 Mg of oil equivalent
Afghanistan	-
Bangladesh	7.5
Bhutan	-
India	198.0
Nepal	6.9
Pakistan	23.5
Sri Lanka	4.2
Total	240.1
World	6753.3

Table 12. Increase in rice yields (Mg ha^{-1}) between 1977 and 2005 in South Asia (Adapted from Kaosaard and Rerkasm 2000, FAO 2005).

Country	1977	1997	1999	2000	2001	2005
Afghanistan	2.0	1.8	2.0	-	-	-
Bangladesh	1.9	2.6	3.2	3.3	3.3	3.6
India	1.9	2.9	3.0	2.9	3.0	3.0
Nepal	1.9	2.3	2.5	2.6	2.7	2.7
Pakistan	2.4	2.8	3.0	3.0	3.0	2.9
Sri Lanka	2.1	3.4	3.3	3.2	3.2	3.5
Asia		2.6	3.8	3.9	3.9	3.9-

Table. 13. Increases in wheat yield (Mg ha^{-1}) between 1977 and 2005 (Adapted from Kaosaard and Rerkasm 2000, FAO 2005).

Country	1977	1997	1999	2000	2001	2005
Afghanistan	1.2	1.1	1.2	-	-	-
Bangladesh	1.6	2.0	2.2	2.2	2.4	2.0
India	1.4	2.5	2.6	2.7	2.7	2.7
Nepal	1.1	1.6	1.7	1.8	1.8	2.1
Pakistan	1.4	2.1	2.2	2.5	2.3	2.6
Asia	1.6	3.0	2.7	2.5	2.5	-

Use of improved biofuels in India and elsewhere in South Asia would involve conversion of biosolids into ethanol, biodiesel or CH_4 gas. Rather than using crop residues, biofuel feedstocks need to be produced from biofuel plantations of specifically identified species adaptable to local soils and ecological conditions. Biofuel plantations can be established on marginal/ degraded soils by several native species including Jatropha (*Jatropha carcos*), Mahua (*Madhuca* spp.), Karanj (*Pongamia pinata*), Mesquite (*Prosopis juliflora*), Neem (*Azadirachta indica*) etc. Some perennial grasses are also suitable to reclaiming salt-affected soils, such as the Karnal or Kallar grass (*Leptachloa fusca*) (Hedge et al. 2004a, Shrinivasa 2004, Kanniganti 2004, Kalbag 2004, Pratibhan et al. 2004, Hedge et al. 2004b, Takawale 2004, Ilorkar and Banginwar 2004). There are several research and development issues which need to be addressed to promote biofuel production in developing countries (Lal 2006, Girard and Fallot 2006).

Food Demand and Natural Resources

There was a strong increase in agronomic production of food crops in South Asia through the so-called "Green Revolution" which was ushered during the 1970s. For example, rice production in South Asia was merely 47 million Mg in 1950, and progressively increased to 67 million Mg in 1960, 84 million Mg in 1970, 105 million Mg in 1980, 144 million Mg in 1990 and 175 million Mg in 2000 (Lal 2004, FAO 2005). Total rice production in South Asia increased by 3.7 times over the 5 decade period ending in 2000. To a large extent, the increase in rice production occurred through increase in crop yield per hectare. The data in Table 12 show that rice grain yield increased by 50 to 60% between 1977 and 2005 (Borlaug 2002, Lal 2004). Despite the impressive gains, however, rice yields in the South Asian region are still low. In comparison with the average yield of rice in China or Asia, there is a large potential to increase rice yields in all countries of South Asia. Improving water management and enhancing soil fertility are amongst several strategic options of increasing rice grain yield. Direct seeding, without puddling, in specifically prepared soil may save time and labor. Similar to rice, there was also a strong increase in wheat yield throughout the region (Table 13). The yield of wheat almost doubled between 1977 and 2005. Consequently, the rate of growth of cereal production exceeded that of the population in India between 1950 and 2000 (Roy 2003). These impressive increases in crop yields were attributed to growing improved varieties with input of fertilizers under irrigated conditions. There was a drastic increase in fertilizer consumption in South Asia between 1961 and 2003 (Tables 14 and 15). Total fertilizer consumption in South Asia increased from less than 0.5 million Mg in 1961 to more than 21 million Mg in 2003, an increase by a factor of 42. Such a drastic increase in fertilizer consumption contrasts with little use and no growth in fertilization consumption over the same period in sub-Saharan Africa (Figure 4). Indeed, there was a linear relationship between cereal production and fertilizer consumption in India (Figure 5), and elsewhere in developing countries (Bumb and Hammond 2006). More the energy input, in the form of fertilizers and irrigation, more was the grain production. The Green Revolution was an energy-intensive farming strategy.

Similar to the positive impact of fertilizer input, there was also a strong positive correlation between the area under irrigation and total cereal production in India (Figure 6). Adverse impacts of drought due to vagaries or uncertainties of monsoon rains were partly alleviated by rapid expansion of cropland area under irrigation. In some cases, however, irrigation proved to be a mixed blessing. Excessive irrigation with poor quality water increased risks of secondary salinization and depletion of the ground water.

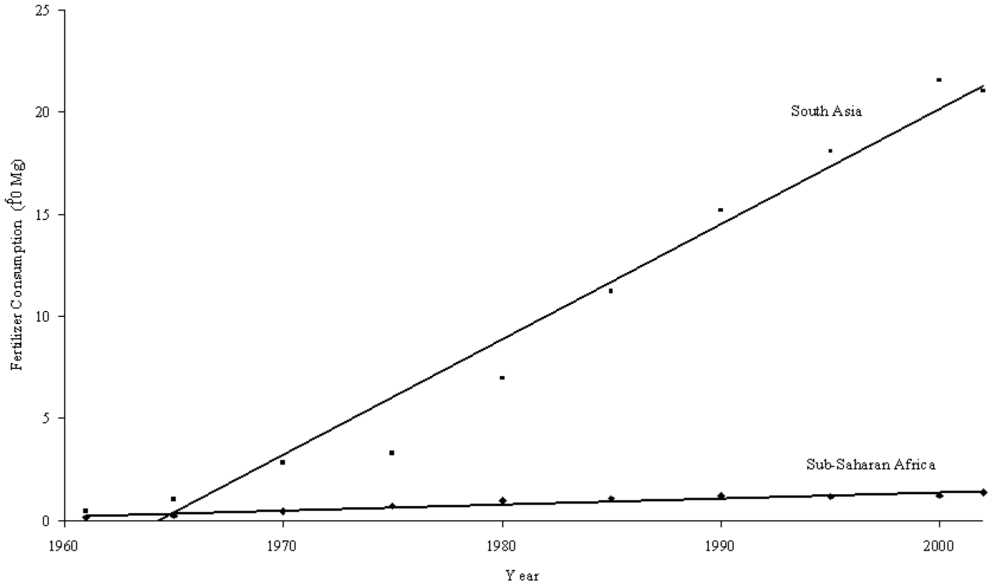

Figure 4. Total Fertilizer Use in South Asia vs. Sub-Saharan Africa (10^6 Mg/yr) (redrawn from IFDC 2004)

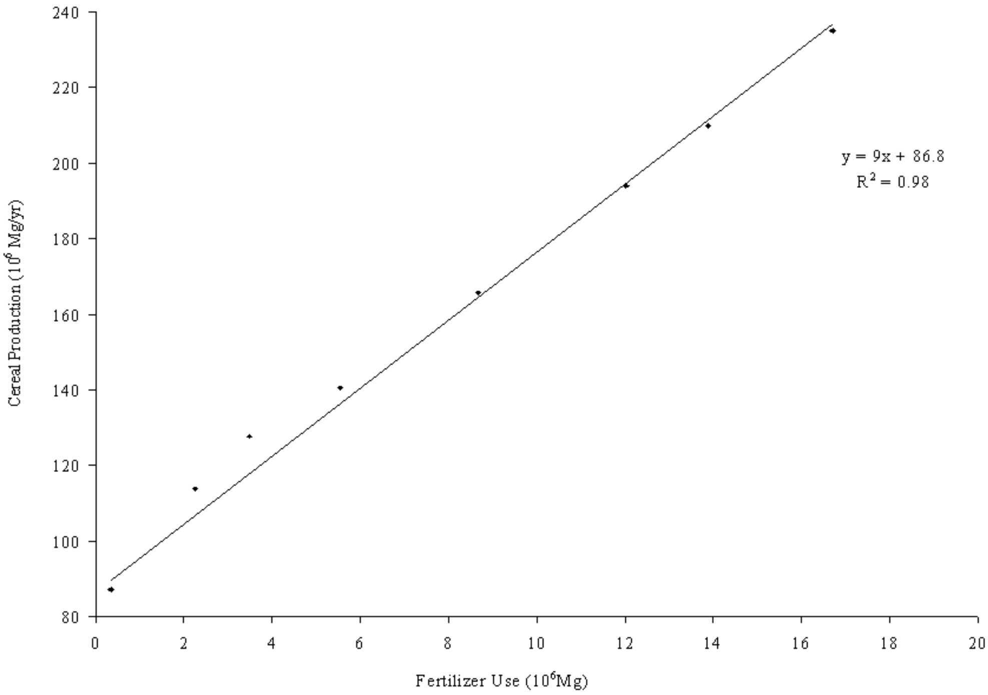

Figure 5. Cereal production in India in relation to fertilizer Use Between 1961 and 2003 (Replotted from the data of FAO 2005, and IFDC 2004).

Table 14. Fertilizer consumption (10^6 Mg yr $^{-1}$) in South Asia from 1961 to 2003 (Modified from IFDC 2004).

Year	Nitrogen	Phosphate	Potash	Total in South Asia	Total in sub-Saharan Africa
1961	0.354	0.084	0.057	0.484	0.16
1970	1.914	0.637	0.283	2.834	0.44
1980	5.002	1.653	0.712	7.368	0.96
1990	9.892	3.813	1.502	15.208	1.25
2000	14.559	5.223	1.732	21.516	1.24
2003	14.250	4.906	1.875	21.035	1.38

Table 15. Total fertilizer consumption (10^6 Mg yr $^{-1}$) in South Asia in 2002 (FAO, 2004).

Country	Fertilizer Consumption
Afghanistan	0.21
Bangladesh	1.42
Bhutan	0
India	16.12
Nepal	0.89
Pakistan	2.96
Sri Lanka	0.28

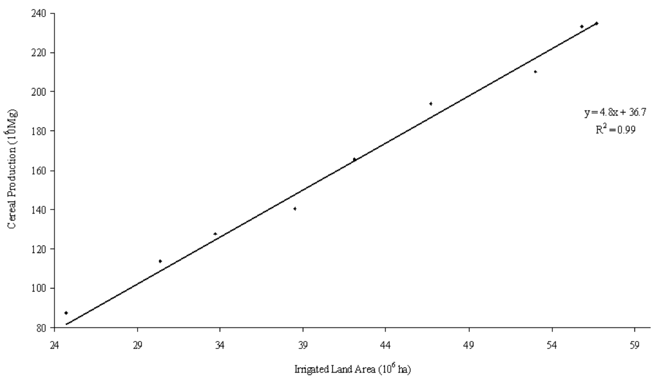

Figure 6. Cereal production in India in relation to increase in irrigated land area between 1961 and 2000 (Replotted from the data of FAO 2005).

It was this unprecedented increase in food production in South Asia which proved many doomistic prophecies (e.g., Ehrlich 1971) wrong. For example, the mass starvation predicted by William and Paul Paddock (1967) in their book, "Famine 1975: America's Decision, Who Will Survive" was proven baseless. Paddock brothers stated that: "By 1975, a disaster of unprecedented magnitude will face the world. Famines greater than any in history, will ravage the undeveloped nations. A swelling population is blotting up the earth's food. United States' surplus are virtually exhausted. Birth control programs are failing. Our technology will be unable to increase food production in time to avert the death of tens of millions of people by starvation. This is the greatest problem facing mankind." While hunger and malnutrition still persist in the region, the doomistic forecast was proven entirely wrong.

Environmental Issues and Sustainability of Green Revolution Technologies

Despite impressive gains in agronomic production, there is no cause for complacency. Continuous growth in population and possible change in food habits, from basically vegetarian to more animal-protein based diet, will increase the demand for food production. The total food grain production in India increased from 82 million Mg yr $^{-1}$ in 1960-61 to 212 million Mg yr $^{-1}$ in 2003-04 (Table 16). However the rate of increase in food grain production is presently lagging behind the total demand. Consequently, the per capita cereal production in India has declined from a peak of 235 kg ha^{-1} yr^{-1} in 1995 to a low of 205 kg ha^{-1} yr^{-1} in 2002 (FAO 2005). Increasing per capita cereal production,

Table 16. Production of food crops (10^6 Mg yr $^{-1}$) in India between 1960 and 2004 (Adapted from FAO 2006).

Crop	1960-61	1970-71	1980-81	1990-91	2000-01	2003-04
Rice	34.6	42.2	53.6	74.3	85.0	87.0
Wheat	11.0	23.8	36.3	55.1	69.7	72.1
Sorghum	9.8	8.1	10.4	11.7	7.5	7.3
Corn	4.1	7.5	7.0	9.0	12.0	14.7
Millet	3.3	8.0	5.3	6.9	6.8	11.8
Chick Pea	6.3	5.2	4.3	5.4	3.9	5.8
Pigeon Pea	2.1	1.9	2.0	2.4	2.2	2.4
Groundnut	4.8	6.1	5.0	7.5	6.4	8.3
All cereals	69.3	96.6	119.0	102.1	185.7	196.8
All pulses	12.7	11.8	10.6	14.3	11.0	15.2
Total Food grains	82.0	108.4	129.6	176.4	196.8	212.0

Table 17. Expected food demand (10^6 Mg yr $^{-1}$) in India between 2000 and 2020 (Adapted from Radhakrishna and Reddy 2002, FAO 2006).

Commodity	2000	2005	2010	2015	2020
Rice	78.3	88.1	98.0	108.5	118.9
Wheat	54.2	63.1	72.1	82.2	92.4
Other cereals	13.1	13.6	14.1	14.8	15.6
All cereals	145.1	163.1	181.1	201.1	221.1
Pulses	10.6	12.6	14.6	17.1	19.5
Total Food Grains	155.6	175.7	195.7	218.2	240.6

Table 18. Trends in yields (kg ha $^{-1}$) of major field crops in India between 1960 and 2004 (Recalculated from FAO 2006).

Crop	1961	1971	1981	1991	1995	2001	2004
Rice paddy	1570	1750	1943	2615	2692	3135	2925
Wheat	810	1310	1615	2270	2540	2690	2620
Cereals	960	1115	1404	1923	2115	2440	2385
Maize	960	925	1150	1350	1600	2000	2075
Jute	970	1000	1270	1650	1650	2000	2000
Coarse grains	500	580	770	810	925	1115	1115
Pulses	510	500	500	600	650	575	635
Fiber crops	270	300	300	420	420	420	440
Oil Crops	150	190	200	230	270	270	275

with stagnating yields of the rice-wheat system, will be a major challenge for the coming decades. The expected food grain demand may be as much as 240 million Mg or more by 2020 (Table 17). Trends of increase in grain yield of different crops show stagnant yields in pulses, fiber crops and oil crops (Table 18). Crop yields are especially low in rainfed crops, throughout South Asia.

There are numerous other environmental issues which need to be addressed. Important among these are the excessive use of water for irrigation by outdated and inefficient method of flood irrigation. Degradation of soil and water resources, exacerbated by extractive farming practices, remains to be a challenge which must be addressed. Risk of soil erosion and depletion of SOC pool may also be confounded and aggravated by the projected climate change. In this regard, finding alternatives to soil for brick making and crop residue/ dung for household cooking residential fuel will be a challenge to scientists and policy makers during the first half of the 21st century.

With decreasing total cropland area, the per capita cropland area is also decreasing. Thus, there is a strong need for revisiting the Green Revolution technologies. With soil and water resources already stressed, future increases in grain production must occur by intensification of existing cropland through increase in use efficiency of input (e.g., fertilizer, irrigation, energy for tillage). There is also a strong need for value addition to farm produce. The surplus rice and wheat grains, estimated at 5 to 8 million Mg yr^{-1} in Punjab and Haryana states of India, must be utilized through development of post-harvest technologies. These grains can be used for food products (e.g., rice crispies, samolina, starch) or for ethanol and other industrial products. Wastage of these grains amounts to utter misuse of precious soil and scarce water resources.

CONCLUSIONS

Those holding neo-Malthusian views will be proven wrong also during the 21st century as they were during the 19th and 20th century. There is a tremendous scope for further increase in crop yields, especially in India, through adoption of RMPs, irrigated and rainfed agriculture. A holistic approach of ecosystem management, to harness its potential by managing soil and water related constraints, is essential to sustainable management of natural resources.

There have been problems of soil degradation and water pollution in some regions where the "Green Revolution" technologies were adopted. However, the problem is not with the technologies. It has been the improper use of technologies which caused the problems. It is the unbalanced fertilization using N without P and K, improper use of pesticides, excessive use of flood irrigation, unnecessary plowing, burning or removal of crop residues, mining of surface soil for brick making, and using cattle dung as household fuel rather than manure which have caused soil degradation, depleted ground water, and polluted the environment. The solution to these problems is in determining: (i) when, at what rate, in which formulation and by what method to apply fertilizers?, (ii) when, how much and how to apply irrigation?, (iii) how much, how and, if at all, to plow?, and (iv) how to use crop residues and biosolids as soil amendments?

The issue is how countries in South Asia are going to feed themselves without jeopardizing the soil resources which are already under great stress? Soil scientists, in collaboration with agricultural engineers and plant scientists, need to develop technologies for delivering nutrients and water directly to roots of genetically modified or improved varieties through soil-specific management or precision farming.

REFERENCES

Borlaug, N.E. 2002. Feeding a world of 10 billion people: The Miracle Ahead. pages 29-59, In: Bailey, R. (Editor) Global Warming and Other Ecomyths: How the Environmental Movement Uses False Science to Scare Us to Death. Forum, Prina Publishing, New York.

Bumb, B.L. and Hammond, L.L. 2006. Fertilizers: mineral. pages 691-697, In: Lal, R. (Editor) Encyclopedia of Soil Science. Dekker/Taylor and Francis, Boca Raton, FL.

Earth Trends, 2003. http://earthtrends.wi.org/researchable_db/variablenotes_static.cfm?varid=2864 themeid=6

FAO, 1994. Land Degradation in South Asia: Its Severity, Causes and Effects on People. World Soil Resources Report 789. FAO, Rome, Italy. 100 pages.

FAO, 1997. FAO State Database. FAO, Rome, Italy.

FAO, 2005. Production Yearbook in Agriculture, FAO, Rome, Italy. 260 pages.

FAO, 2006. Rapid Growth of Selected Asian Economics: Lessons and Implications for Agriculture and Food Security: China and India. Policy Assistance Series 1/2. Rome, Italy, 82 pages.

Ehrlich, P.R., 1971. The Population Bomb. Balantine Books, New York. 201 pages.

Gardner-Outlaw, T. and Engelman, R. 1993. Sustaining Water, Easing Scarcity: A Second Update. Population Action International, Washington, D.C.

Girard P. and Fallot, A. 2006. Review of existing and emerging technologies for the production of biofuels in developing countries. Energy for Sustainable Development X(2): 92-108.

Hedge, N.G., Daniel, J.N. and Dhar, S. (Editors) 2004a. Jatropha and Other Perennial Oil Seed Species. Proceedings of the National Workshop, 5-8 August 2003, Pune, India, BAIF Development Research Foundation, Pune, India, 160 pages.

Hedge, G.V., Miremath, S.M. and Keremane, B.G. 2004b. Potential of tree-borne oil seed species. Pages 114-118, In: Hedge, N.G., Daniel, J.N. and Dhar, S. (Editors) Jatropha and Other Perennials Oil Seed Crops. BAIF Development Research Foundation, Pune, India.

Ilorkar, V. M. and A. D. Banginwar 2004. Distribution and status of tree-borne oil seed species in Vidarbha. Pages 144-146, In: Hedge, N.G., Daniel, J.N. and Dhar, S. (Editors) Jatropha and Other Perennials Oil Seed Crops. BAIF Development Research Foundation, Pune, India.

International Fertilizer Development Center (IFDC). 2004. World Fertilizer Consumption. Muscle Schoals, AL. 90 pages.

Kalbag, S.S. 2004. Trials on Karanj and Jatropha as energy sources. pages 96-97, In: Hedge, , N.G., Daniel, J.N. and Dhar, S. (Editors) Jatropha and Other Perennials Oil Seed Crops. BAIF Development Research Foundation, Pune, India.

Kanniganti, C. 2004. Why Jatropha oil is the answer compared to other oils? Pages 81-83, In: Hedge, N.G., Daniel, J.N. and Dhar, S. (Editors) Jatropha and Other Perennials Oil Seed Crops. BAIF Development Research Foundation, Pune, India.

Kaosa-ard, M.S., and Rerkasem, B. 2000. The Growth and Sustainability of Agriculture in Asia. Oxford University Press, Hong Kong. 303 pages.

Lal, R., 2006a. Dryland farming in South Asia. pages 527-576, In: Dry Land Farming. ASA Monograph, American society of Agronomy, Madison, WI, USA.

Lal, R. 2006b. Land area for establishing biofuel plantations. Energy for Sustainable Development X(2): 67-79.

Lal, R. 2004. Soil and water resources of South Asia in an uncertain climate. pages 19-35, In: Lal, R., Hobbs, P.R., Uphoff, N. and Hansen, D.O. (Editors) Sustainable Agriculture and the International Rice-Wheat System. Marcel Dekker, New York.

Marlan G., and Andres, R.J. 2004. Global Co_2 Emissions from Fossil Fuel Burning, Cement Manufacture and Gas-flaring: 1751-2003: ORNL, Oakridge, TN. 4 pages.

Paddock, W. and Paul, p. 1967. Famine 1975: America's Decision, Who Will Survive? Little, Brown, Boston. 276 pages.

Pratibhan, K.T., Paramathma, M., Khanna, U., Jagatram, M. and Kumaran, K. 2004. Screening superior genotypes for higher oil content and colonal propagation of Mahna (*Madhuca latifolia*) pages 108-113, In: Hedge, N.G., Daniel, J.N. and Dhar, S. (Editors) Jatropha and Other Perennials Oil Seed Crops. BAIF Development Research Foundation, Pune, India.

Radhakrishna, R. and Reddy, V.K. 2002. Food Security and Nutrition. Pages 201-220, In: Vision 2020. Government of India, Development Report, New Delhi, India.

Rogers, P.P., Jalal, K.F. and Boyd, J.A. 2006. An Introduction to Sustainable Development. Harvard University Press, Boston, 404 pages.

Roy, A.H. 2003. Fertilizer needs to enhance production: Challenges facing India. pages 53-68, In: Lal, R., Hansen, D.O., Uphoff, N. and Slack, S. (Editors) Food Security and Environment Quality in India. CRC/Lewis Publishers, Boca Raton, FL.

Shrinivasa, U. 2004. Could non-edible oils serve India as biofuels in the new Millenium? Pages 27-30, In: Hedge, N.G., Daniel, J.N. and Dhar, S. (Editors) Jatropha and Other Perennials Oil Seed Crops. BAIF Development Research Foundation, Pune, India: 27-30.

Takawale, P.S. 2004. *Calophyllum inophyllum* – non- edible oil-yielding tree species. Pages 130-132, In: Hedge, N.G., Daniel, J.N. and Dhar, S. (Editors) Jatropha and Other Perennials Oil Seed Crops. BAIF Development Research Foundation, Pune, India.

U.N. 2005. Population Challenges and Development Goals. United Nations Population Division, New York. 57 pages.

Venkatraman, C., Habib, G., Eiguren-Fernandez, A., Miguel, A.H. and Friedlander, S.K. 2005. Residential biofuels in South Asia: carbonaceous aerosol emissions and climate impacts. Science 307: 1454-1456.

WRI 2005. World Resources Data - Earth Trends. World Resources Institute, Washington, D.C.