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Agricultural Intensification in South Asia and Its Contribution to Greenhouse Gas Emission: A Review

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Abstract: This paper reviewed the agricultural intensification in South Asian region. The indications of intensification in terms of intensive use of chemical fertilizers (urea) and introduction of agro equipments like tractor were reviewed. From 1961 to 2005, Sri Lanka was in the top position to intensify agriculture. There has been a feedback loop between agricultural intensification and climate change. The observed positive outcome of agricultural intensification are mainly improved livelihood and secure food whereas enhanced emissions of greenhouse gases due to addition of nitrogen fertilizers (N inputs) was examined as one of the negative outcomes. Agricultural soil has been adding up major green house gases like methane (CH_4) and nitrous oxide (N_2O) to the atmosphere through tillage, fertilizer application and irrigation. From the review, N_2O emission from total arable land (in '000 ha) were analysed and estimated. The N_2O emission rate was found to be highest in Bangladesh and Sri Lanka (3 kg of N_2O-N ha^{-1}) followed by India and Pakistan (2 kg of N_2O-N ha^{-1}), assuming that crop intensification will demand urea application in all arable land in future.

Key words: Agricultural intensification, CH_4 and N_2O, livelihood, N inputs.

Introduction

Agricultural development has emerged as a key issue of development discourse in livelihood improvement and environment degradation in Asia. Shifting cultivation, the first stage of agricultural development was the most widespread agricultural system in South and Southeast Asia until the mid 20th century (Spencer, 1966). It involves basic tools and techniques, low level of inputs and subsistence level of production and consumption (Rasul and Thapa, 2003), which was unable to support growing population and their subsistence needs. The increasing population combined with government control over common property resources was putting pressure on shifting cultivators to reduce the fallow period (Palm et al., 1996; Gafur et al., 2000). Meantime, shifting cultivators deserve improved lifestyle which was not possible from the low return being provided by their practice of cultivation. Such circumstances forced farmers to seek for more productive agricultural system which otherwise could have brought a hunger and malnutrition situation in Asia. The "crisis" was realized by U.S. President's Science Advisory Committee and came up with a report in 1967. The report concluded that the scale, severity and duration of the world food crisis are so immense that a huge, long-range, pioneering effort in human history will be required to master it (IFPRI 2002). In response, Ford Foundation and Rockefeller initiated in establishing the international agricultural research system in order to transfer scientific

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advances. These advances including high yielding varieties, more use of chemical fertilizers, irrigation and other chemical inputs led to a remarkable yield in Asia in the late 1960s. Such a radical change from hunger situation to dramatic increased yield situation is coined as "Green Revolution".

Agricultural intensification is an important and escalating process for meeting the demands of an ever-growing population in South Asia. It has been defined in different ways (FAO, 2004; Hunt, 2000; Carswell, 1997; Boserup, 1965). However, the definition depends on the context and perception. In South Asian context, agricultural intensification is best defined as increase in the number of crops per unit area of land with higher inputs of agro-chemicals for better crop yield from the same amount of land (Dahal et al., 2008; Alauddin and Quiggin, 2008). In these situations, use of chemical fertilizers has increased by eight folds. It has been estimated that more than half of the total produced chemical fertilizers is used in the East, Southeast and South Asia (Yan et al., 2003). Although the positive impacts of intensification on society (Tiwari et al., 2008; Paudel, 2002; Carswell, 1997), for example, on farm production and income has been observed, there also have been negative implications on environment, and soil fertility and water quality (Dahal et al., 2008; Westarp et al., 2004; Ananda and Herath, 2003). Hence, the issue of positive and negative impacts of agricultural intensification is an important concern.

This paper focused on the objective of reviewing the signs and process of agricultural intensification in South Asian region to analyse the impact of intensification on climate change.

Indicators of Intensification Practices in South Asian Agriculture

There has been significant expansion of agricultural areas in South Asia (Nagdeve, 2006; Awasti et al., 2002; Upadhyay et al., 2005). The proportion of total land area in agricultural use was the highest in Bangladesh (around 73%) followed by India (around 59%) in 1961 (Table 1). In 2005, total land area in agricultural use in Bangladesh declined (69%) but still remained the highest

Table 1: Land endowment, arable land and permanent crops in South Asia

Year	*Land area in '000 ha*	*Agricultural land*		*Permanent Crops*		*Arable land*	
		in '000 ha	*as % of land area*	*in '000 ha*	*as % of agricultural land*	*in '000 ha*	*as % of agricultural land*
Bangladesh							
1961	13017	9480	73	275	3	8605	91
2005	13017	9011	69	460	5	7951	88
India							
1961	297319	174907	59	5180	3	155806	89
2005	297319	180180	61	10000	6	159650	89
Nepal							
1961	14300	3531	25	25	1	1806	51
2005	14300	4222	30	130	3	2357	56
Pakistan							
1961	77088	21881	38	150	1	16731	77
2005	77088	27070	35	795	3	21275	79
Sri Lanka							
1961	6474	1723	27	943	55	595	35
2005	6463	2356	37	1000	43	916	39
Bhutan							
1961	4700	341	7	13	4	80	24
2005	4700	592	13	18	3	159	27
Maldives							
1961	30	5	17	2	40	2	40
2005	30	14	47	9	64	4	29

Source: FAOSTAT 2007

percentage of total land area in agricultural use. In contrast, Pakistan, Nepal and Sri Lanka had only around 30% of land area in agricultural use in 1961 but it has increased over a period of time. Maldives also shows the similar trend. Bangladesh and India also have the highest proportion of arable to agricultural land (around 90%) which decreased by around 3% by 2005. But in contrast, the ratio has increased in Nepal, Pakistan, Sri Lanka and Bhutan. According to Alauddin and Quiggin (2008), Bangladesh has practiced highest degree of intensification compared to India, Pakistan, Nepal and Sri Lanka. For example, rice production increased in all countries with production in Bangladesh, India, Pakistan and Sri Lanka more than doubled between 1961 and 2005. The ratio of permanent crops to agricultural land is significantly higher in Sri Lanka (around 50%) compared to Bangladesh, India, Nepal, Pakistan and Bhutan. All these changes could be attributed to Asian Green Revolution which began in the early 60s.

The green revolution in Asia refers to the development and flow of a series of fertilizer-responsive, short maturing and high-yielding modern varieties of crops. It also introduced tractors and other mechanized irrigation. Table 2 shows the number of tractors per one thousand hectares of arable land in South Asia from 1961 to 2005. Sri Lanka experienced the highest rise in the use of tractors from 1961 (around eight) to 2005 (around 23) among other South Asian countries. There was a gradual increase in the use of tractors in Pakistan, India and Nepal. In Bangladesh, the use of tractors peaked during 1980s, and then decreased until 2005. In Sri Lanka tractor uses increased until early 1980s, then decreased until early 1990s and again increased from mid 1990s. The reason behind decrease in use of tractors in Sri Lanka after early 1980s could be due to open up of the economy. Before liberalization, agriculture support policies created implicit and open subsides to agricultural assets like tractors. When Sri Lanka opened up economy during 1977, then subsides were removed, thus making capital inputs more expensive (Alauddin and Quiggin, 2008).

Input intensification is an important indicator to agricultural intensification in South Asia. Sri Lanka used highest amount of urea from 2002 to 2005 followed by Bangladesh and Pakistan as seen from Table 3. The use of urea in Nepal is lower but on an average the annual chemical fertilizer use has increased by 22% over the last four decades (Dahal et al., 2008).

Relationship between Agricultural Intensification and Climate Change

It has been viewed that agricultural intensification need not always have the negative outcome, but it certainly helps the socio-economic uplift and improves both quantity and quality of livelihood (Dahal et al., 2009; Tiwari et al., 2008; Dahal et al., 2008; Paudel 2002; Carswell, 1997). In Nepalese context, where more than 80% of people's livelihood is based on agriculture, the ever-increasing population demand for food and other necessities certainly increases pressure on agricultural land through intensive use of land and agro-chemicals. The major components of intensified agriculture are chemical fertilizers, pesticides, tillage and irrigation that have been identified as factors contributing climate gases to the atmosphere. The increased use of chemical fertilizers in intensified agriculture has been adding up major green house gases like methane (CH_4) and nitrous oxide (N_2O) to the atmosphere (Figure 1). Net CH_4 production has been found to be increasing in the high-input cropping system. In such systems, there is increased

Table 2: Trends in number of tractors per one thousand hectares of arable land in South Asia

Years \ *Countries*	*Bangladesh*	*India*	*Nepal*	*Pakistan*	*Sri Lanka*	*Bhutan*
1961	0.0872	0.1991	0.0997	0.3287	7.7916	NA
1965	0.1082	0.3034	0.1246	0.3866	9.1967	NA
1970	0.2345	0.6228	0.4066	1.0956	16.6667	NA
1975	0.3439	1.3967	0.8769	1.8226	18.5429	NA
1980	0.3936	3.2587	1.1075	4.8701	19.2353	NA
1985	0.316	3.7238	1.2169	7.7533	17.2577	0.1364
1990	0.2386	6.0697	2.1863	12.9725	17.8286	0.4425
1995	0.1988	8.3763	2.4096	14.5345	19.2263	0.7692
2000	0.1237	13.0236	2.4096	15.3389	19.7207	0.8357
2005	0.1956	17.1312	2.3759	19.7745	23.3624	0.6289

Source: FAOSTAT 2008

Table 3(a) and (b): Trends in urea use (kg of urea per hectare of arable land) in South Asia

(a)

Years \ Countries	*Bangladesh*	*India*	*Nepal*	*Pakistan*	*Sri Lanka*	*Bhutan*
2002	281	117.1	NA	NA	410.8	3.3
2003	251.9	119.9	26.7	207.9	315.5	3.8
2004	253.2	130.7	45.8	221.5	352.5	5.8
2005	258.4	138.7	9.6	243.4	404.9	4

Source: FAOSTAT, 2008

(b)

Country	*Fertilizer use (kg/ha)*	
	1980	*2000*
Bangladesh	46	149
India	35	106
Nepal	10	32
Pakistan	53	126
Sri Lanka	180	268

Source: FAOSTAT, 2008

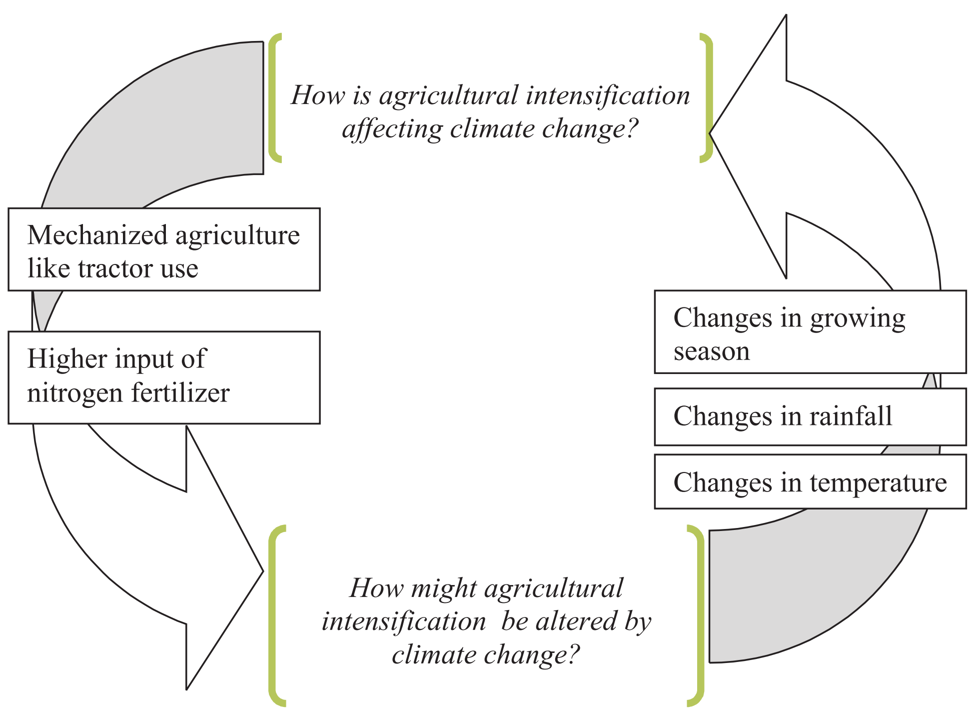

Figure 1: Relationship between agricultural intensification and climate change.

soil respiration and results in anaerobic conditions. Such anaerobic condition is favourable for degradation of organic matter during which CH_4 is produced. Paddy is cultivated in 42.24 million hectare area, the largest in Asia, in the Indian subcontinent (Bhatia et al., 2004). It has also been found that rice cultivation with water logging system is the major source of CH_4 emission. About 23 % of total CH_4 emissions in India in 1995 were from rice cultivation as rice is a dominant crop in South East Asia. N_2O emission from agricultural system, including direct and indirect emissions, accounts for 6.3 Tg per annum (Yan et al., 2003). Direct emission refers to the emission from agricultural soil and animal system whereas indirect emission refers to the emission from agriculture soil through loss of nitrogen to aquatic system and atmosphere (Bhatia et al., 2004). Most of the N_2O

from soils is produced mainly by two biological processes, namely nitrification and denitrification. Similarly, frequent tillage in soil exposes soil surface, which releases carbon dioxide that is presented as sequestered in soil particles. In addition, high inputs of fertilizers with frequent tillage accelerate the emission.

It had been understood that N_2O emission from rice field was insignificant. However, practices of aerating rice fields at least once during the growing season resulted in considerable N_2O emission (Yan et al., 2003). N_2O evolved from soils either by oxidation of ammonium to nitrate by nitrifying micro-organisms under aerobic condition or by reduction of nitrate by denitrifying micro-organisms under anaerobic conditions (Bremner, 1997). The process is accelerated when soils are treated with ammonium or ammonium yielding fertilizers. As a result, emission of N_2O from soil is increased. A very few studies on N_2O and CH_4 emissions have been done in South Asia whereas researches are intensively carried out in China (Yan et al., 2003).

The other scenario of impact of climate change on agriculture may be primarily through changes in temperature, rainfall pattern, growing season and area that climate change will affect agriculture. In Asian context, the effects of climate change will exacerbate stresses on agricultural production, particularly in low and mid latitude countries. For example, in the Indo-Gangetic Plains, wheat production will be adversely affected. Rice yields will also decrease due to increased night time temperatures (Yohe et al., 2008). As crop yields decline, there will be less supply of food in the market and prices will be higher. Poor people will not have enough access to food and they will be the ones who will suffer the most from malnutrition. This creates a situation of food insecurity.

Estimation of Direct Contribution of Urea to N_2O Emissions

There have been different methods for the estimation of fertilizer induced emission from the cultivated land (Eichner, 1990; Bouwman, 1996). However, there are a number of uncertainties in both the methods described by Eichner (1990) and Bouwman (1996). One of those uncertainties is that the method described by Eichner (1990) gave lower N_2O emission estimation than method given by Bouwman (1996), i.e. N_2O emission caused by application of urea fertilizer calculated by Eichner (1990) was lower by a factor of 3 than calculated from Bouwman (1996). Since in this paper, we consider urea as a main fertilizer used in South Asia, therefore, the equation (1) given by Bouwman (1996) was used for the estimation of N_2O emission in this paper.

$$E = 1 + 0.0125 * F \quad (1)$$

Where, E is the emission rate and F is the fertilizer application rate. The method is very simple and based on background emission of 1 kg N_2O-N ha^{-1} y^{-1} and fertilizer induced N_2O emission of 1.25% of the N application. The potential of urea derived N_2O emission rate based on the urea application rate in the year 2005 was estimated assuming that crop intensification will demand urea application in all arable land (Table 4). The result estimated N_2O emission rate (kg of N_2O-N per ha per year) from different South Asian countries range from 1 (Nepal and Bhutan) to range 3 (Bangladesh and Sri Lanka).

Table 4: Estimates of urea derived N_2O emission assuming crop intensification will demand urea application in all arable land in future in South Asian regions

Countries	*Amount of N in urea (F) (kg of N ha^{-1})*	*Urea derived N_2O emission[a] (kg of N_2O-N ha^{-1})*	*E from total arable land in '000 ha (kg of N_2O-N)*
Bangladesh	119	3	19878
India	64	2	287370
Nepal	5	1	2357
Pakistan	112	2	51060
Sri Lanka	186	3	3023
Bhutan	2	1	162

Source: Table 3a and Bouwman (1996)

[a] Using equation for cultivation soil: The emission rate $E = 1^b + 0.0125 * F$ (assuming that crop intensification will demand urea application in all arable land in future)

[b] The value of 1 kg N ha^{-1}

Conclusion

Expansion and intensification of agricultural land is widely recognized as one of the most significant human alteration to global climate change. In South Asian context, there has been distinct increase in the agricultural crop land with intensification process. The intensive use of chemical fertilizers, introduction of agro equipment like tractors and other mechanized irrigation inputs represent the signs of intensification practices in South Asia. Agricultural intensification has a positive impact on livelihood security in terms of better socio-economic condition and food security. When socio-economic condition is improved and food is secure, farmers may not have compulsion to acquire food through the unsustainable practices. However, agricultural intensification also has potential negative implications on climate change. The key elements of agricultural intensification, use of N fertilizer and tractor will potentially increase N_2O emission in future. In order to have a better understanding of the implications due to agricultural intensification, more specific knowledge of the linkages between agricultural intensification and climate change is needed.

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