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Carbon dioxide release due to change in land use in China mainland

Wang Xiaoke, Zhuang Yahui, Feng Zongwei

Research Center for Eco-Environmental Sciences, Chinese Academy of Sciences, Beijing 100085, China

Abstract — The carbon pool and emission of carbon dioxide from terrestrial ecosystems in China have been estimated. The carbon pool is $2.51\times10^9-25.2\times10^9$ ton C in vegetation, and 49.7×10^9 ton C in soil. The carbon dioxide release from terrestrial ecosystems is $0.0317\times10^9-0.195\times10^9$ ton C due to changes in land-use in recent years, mainly caused by deforestation and degradation of grassland. This carbon release due to changes in land-use is approximately 17% of the current carbon dioxide emission from fossil fuel combustion and cement production in China. As compared with the global carbon pool, the carbon pool in vegetation and in soil in China are 1.8% and 3.3% of the global figures, respectively.

Keywords: carbon pool; carbon dioxide release; terrestrial ecosystems.

1 Introduction

Carbon dioxide is the most important greenhouse gas which might lead to global warming. Its relative contribution to greenhouse effect is 60% according to the currently observed increment of its concentration in the atmosphere (Rhode, 1990). Many countries have estimated their carbon dioxide emissions and determined to share the responsibility for the global greenhouse effect. Since China is the most populous country in the world, her contribution to global carbon dioxide emissions should not be overlooked. The carbon dioxide emission from fossil fuel combustion and cement production in China have been estimated extensively (Barron, 1990; World Bank, 1992; Zhai, 1992; World Resources Institute, 1990; Sathave, 1991; Zhuang 1991; Chen, 1992). However, the flux of carbon dioxide from terrestrial ecosystems into the atmosphere due to changes in land-use and the carbon pool in terrestrial ecosystems have seldom been assessed. Xu (Xu, 1992) estimated the carbon dioxide release from forests in China to be -0.03×10^9 ton C/a. The negative value of carbon dioxide release implies that the carbon dioxide release due to deforestation has been offset by the recent afforestation activities. This seems to be too optimistic. It is well known, severe soil and climate limitations on biomass and productivity significantly confine areas appropriate for short-rotation plantation management in spite of large available land areas for afforestation. Good land is encroached by agriculture. On account of controversial policy and poor management, tree mortality associated with planted and replanted woodlands and forests are often substantial. The net productivity of the survived fraction is usually not quite high. Owing to human disturbance, gradual thinning of woodlands is not a scare incident. Furthermore, intensive reforestation activities and subsequent increased fertilizer demand for the implementation of short-rotation plantation would consume more energy, which is again derived from CO_2-generating energy sources, and hence would reduce the effectiveness of carbon dioxide sequestration in the biomass (Marland, 1986).

Based on the materials and data now available, this study estimates the carbon pools of terrestrial ecosystems in China and the carbon dioxide emissions from the terrestrial ecosystems due to land-use changes.

2 Carbon pool in terrestrial ecosystems

The total area of China is classified according to the land-use modes (Table 1). Nearly half of the territory involved is not covered by vegetation or soil, such as desert, glacier, residential areas. The carbon stored in these parts of land has been left out of account.

Table 1 Various land-use modes in China

Land-use mode	Area (10^6ha)	Percentage, %	Reference
Cultivated land	95.65	9.96	Chinese Agriculture Yearbook Editorial Board, 1992
Forest	124.65	12.98	Zhang, 1992
Grassland	312.00	32.50	Chinese Environmental Yearbook Editorial Board, 1990
Peat	11.00	1.15	Department of Geography Northwest Normal University, 1984
Lake and river	16.64	1.73	ibid
Glacier	4.70	0.49	ibid
Residential area	46.60	4.85	ibid
Desert	270.00	28.13	ibid
Others	78.76	8.21	
Total	960.00	100.00	ibid

The carbon pool in lakes and rivers has not been taken into consideration here, because of their relatively small proportions and because of lack of data of their biomass and net productivity.

To visualize the carbon pool in soil, it is essential to establish numerical averages of carbon content in various types of soil. The following values have been adopted in our estimation: 79 ton C/ha for cultivated land soil, 131ton C/ha for forest soil, 80ton C/ha for grassland soil and 723 ton C/ha for peat (Woodwell, 1984). Hence,the total carbon pool in soil of China mainland is 49.6×10^9 ton C, as indicated in Table 2. The contributions of cultivated land, forest, grassland and peat are 15.2%, 32.9%, 50.3% and 1.60%, respectively.

Table 2 The carbon pools in soil and biomass in China mainland

(Unit: 10^9 ton C)

Land-use mode	Carbon in soil	Carbon in biomass	
		Long-lived	Short-lived
Cultivated land	7.56	–	0.690
Forest	16.3	2.10	0.042-0.060
Grassland	25.0	0.410-23.1(11.76)	0.117-1.17
Peat	0.795	–	–
Total	49.7	2.51-25.2(13.86)	0.849-1.920

Carbon pool in vegetation has also been estimated for each land-use mode. Here the carbon pool in vegetation is categorized into two types: the long-lived carbon pool, which can be preserved for a quite long period of time, such as volume reserve and the roots of perennial grass, and the short-lived carbon pool, which is stored in terrestrial ecosystems for less than one year and falls onto the ground or is harvested annually, such as the annual crops, the leaves and trimmed branches of woody plants and the above-ground parts of perennial grass. The short-lived carbon can be taken as a kind of carbon dioxide release from the vegetation. Only the long-lived carbon pool can lessen the greenhouse effect. Cooper (Cooper, 1982) has pointed out one of the paradoxes of forest management that forests managed for maximum sustained yield of biomass have a carbon content, averaged over the life of the stand, of only one-third that at maturity.

The carbon pool in the cultivated land was estimated from the grain yield. The total grain yield of China is known with some accuracy (Chinese Agriculture Yearbook Editorial Board, 1992). The average economic coefficient of grain is taken to be 0.5, and the carbon content in crop biomass is assumed to be 50%. The carbon pool in grain crop is 0.450×10^9 ton C in 1990. The total yield of economic crops, such as cotton, beet and sugarcane, is 0.0960×10^9 ton (Chinese Agriculture Yearbook Editorial Board, 1992). If an averaged economic coefficient of 0.2 is adopted for the economic crops, and the carbon content of these crops is taken as 50%, then the carbon pool in economic crops is equal to 0.240×10^9 ton C. The total carbon pool in vegetation on cultivated land is therefore 0.690×10^9 ton C, which belongs to the short-lived carbon pool.

Data collected from experimental plots in temperate zone in China suggest that the "good" land would support an annual net productivity of 12 – 16 tons of dry biomass per hectare, that "medium" land supports 6 – 12 tons dry biomass per hectare per year, and that the "poor" and "very poor" lands, comprised primarily of red soils and sandy or stony soils, produce 2 – 6 tons and <2 tons per hectare annually, respectively (Perlack, 1991). The volume reserve in forest, which is considered as the long-lived carbon pool, accounts for 8.09×10^9 m^3, according to the results of the third nation-wide forest resource survey carried out in the period of 1984 – 1988. A conversion factor of volume to carbon content of 0.26 is employed (Marland, 1988). Hence, the carbon stored in forest long-lived biomass is about 2.10×10^9 ton C. The short-lived carbon increment lies between 0.042×10^9 ton C/a and 0.060×10^9 ton C/a (Ministry of Forestry of China, 1990).

Based on his surveys, Jiang (Jiang, 1989) estimated the grass yield of grassland in China mainland to be 750 – 7500 kg/ha. The ratio of the underground portion to the above-ground biomass is adopted to be in range of 3.5 (Zhu, 1991) and 19.72 (Chen, 1981). If the carbon content of grass is taken to be 50%, the short-lived carbon pool in the above-ground biomass of grassland in China is $0.117 \times 10^9 - 1.17 \times 10^9$ ton C, while the long-lived carbon pool in the underground biomass is $0.410 - 23.1 \times 10^9$ ton C.

From the above figures, we can summarize that the carbon pool in vegetation in China is $2.51 \times 10^9 - 25.2 \times 10^9$ ton long-lived C and $0.849 \times 10^9 - 1.92 \times 10^9$ ton short-lived C, and that the total carbon pool in terrestrial ecosystems in China mainland is $53.0 \times 10^9 - 76.7 \times 10^9$ ton C.

3 Carbon dioxide release from terrestrial ecosystems due to changes in land use

3.1 Cultivated land

The area of cultivated land in China is decreasing at a rate of 1% per year. This part of land is used for construction of buildings and roads, or is converted into fallow land, grassland and forest. Here, the carbon stored in soil has been assumed unchanged. Since the annual grain yield in recent years fluctuates not much, the carbon dioxide release from vegetation due to deduction of cultivated land is not taken into account.

3.2 Forest

The carbon dioxide release from forest has been estimated either from the annual timber consumption or from the change of forest area.

The annual volume production, as mentioned above, is taken to be $160-230\times10^6$ m^3/a, while the timber consumption has been estimated to be 294×10^6 m^3/a (Ministry of Forestry of China, 1990), 300×10^6 m^3/a (Forestry Division Office, 1990), $301\times10^6 m^3/a$ (Chinese Forestry Yearbook Editorial Board, 1991), and $340\times10^6 m^3/a$ (Zhai, 1992). So the net deficit of timber ranges from 64.4×10^6 to 180×10^6 m^3/a. In order to meet the demand of timber in this country, the Ministry of Forestry simply took it for granted to have more volume harvested than the forests can produce. If the conversion factor of timber to carbon is taken as 0.26 and the portion of timber employed as construction materials and reserved as a long-lived pool of carbon is taken to be 42%, then the carbon release from the remaining 58% of the consumed volume, i. e., the short-lived carbon, is $0.00971\times10^9-0.0271\times10^9$ ton C/a.

If the volume reserve in mature forest is taken as $78.6m^3/ha$ (Ministry of Forestry of China, 1990), the area of mature forests and woodlands shrinks at a rate of $0.819\times10^6-2.29\times10^6$ ha per year. The carbon pool in the soil of these harvested lands is also decreasing. If this deduction is 52 ton C/ha (from 131 ton C/ha in forest soil to 79 ton C/ha in cultivated land soil), the carbon stored in the soil of recently harvested forests decreases at a rate of $0.0426\times10^9-0.119\times10^9$ton C/a, which is, in fact, a kind of carbon dioxide emission from terrestrial ecosystems into the atmosphere.

Judging from the results of the second (1977—1981) and third (1984—1988) nation-wide forest resources surveys, the total forest area in China has increased by 5.88×10^6 ha, while volume reserve decreased by $308\times10^6 m^3$ in a period of 7 years. From one side, the newly afforested land in the long run will store 0.306×10^9 ton C more than the farmland, because the average carbon content in the soil of this part of land will increase gradually from 79 ton C/ha to 131 ton C/ha. However, this amount of carbon will be sequestered in a fairly long period, say, 7—14 years for the short and normal rotation, but not in one single year. Consequently, the average rate of carbon dioxide adsorption is $0.00312\times10^9-0.00624\times10^9$ ton C/a. From the other side, the deduction of volume reserve due to overharvesting mature forests would release 0.0464×10^9 ton C in a period of 7 years under the assumption that 58% of the timber consumed is short-lived. The average rate of carbon dioxide release is 0.00663×10^9 ton C/a. The net release of carbon dioxide due to change in forest area is $0.000390 \times 10^9 - 0.00351 \times 10^9$ ton C/a. These figures are positive, that means the newly planted and replanted woodlots still cannot compensate the lost mature forests. From Table 3, it can be seen that the total range of the sum of emission from vegetation and from soil lies between $+0.000390 \times 10^9$ and $+0.135 \times 10^9$ ton C/a.

Table 3 The CO_2 release from forest in China

Unit: 10^9 ton C/a

	Release from vegetation	Release from soil	Total release
Estimation #1 (timber)	+0.00971 – +0.0271	+0.0426 – +0.119	+0.0523 – +0.135
Estimation #2 (forest area)	+0.00663	−0.00312 – −0.00624	−0.000390 – +0.00351
Total range of estimation	+0.00663 – +0.0271	−0.00624 – +0.119	+0.000390 – +0.135

3.3 Grassland

One fourth of the grassland area in China has degraded, and the degrading rate is about 1.3×10^6 ha/a (Chinese Environment Yearbook Editorial Board, 1991). The grass productivity of the degraded grassland decreased by 30% – 50%. Here it is assumed that the carbon stored in degraded soil is 30% less than that in the normal soil, and that the carbon content in normal grassland soil is 80 ton/ha in average. Thus, the degraded grassland soil released 0.0312×10^9 ton C/a into the atmosphere due to degradation. If the carbon stored in underground biomass decreased at the same rate as the deduction of grass productivity, the degrading grassland releases $0.0005 \times 10^9 - 0.0288 \times 10^9$ ton/a. The total release from grassland is $0.0317 \times 10^9 - 0.0600 \times 10^9$ ton C/a due to degradation.

Table 4 The total CO_2 release from terrestrial ecosystems in China due to land-use changes

Land-use mode	CO_2 release, $\times 10^9$ ton C/a		Percentage of anthropogenic emission, %
	Range	Average	
Cultivated land	no account	–	no account
Forest	0.000390 – 0.135	0.0677	10
Grassland	0.0317 – 0.0600	0.0459	6.8
Total	0.0321 – 0.195	0.114	17

Note: The anthropogenic carbon dioxide emission from fossil fuel combustion and cement production is 0.678×10^9 ton C/a (Chen, 1992)

Table 4 gives the total amount of carbon dioxide released from terrestrial ecosystems in China due to changes in land use. It is $0.0321 \times 10^9 - 0.195 \times 10^9$ ton C/a, and is about 17% of the annual emission from fossil fuel combustion and cement production. It is interesting to note that the carbon dioxide released from terrestrial ecosystems due to land-use changes on a global scale is about 20%–30% of the emission form fossil fuel combustion and cement production (McCracken, 1990).

Table 5 China's share in the global carbon pool interrestrial ecosystems

Land-use mode	Area			Carbon pool in vegetation			Carbon pool in soil		
	China	World	China's share, %	China	World	China's share, %	China	World	China's share, %
	$\times 10^6$ km^2			$\times 10^9$ ton C			$\times 10^9$ ton C		
Cultivated land	0.9565	14.41	6.6	–	7.0	–	7.56	111	6.8
Forest	1.2465	40.33	3.1	2.10	765.0	0.27	16.3	755	2.2
Grassland	3.120	32.53	9.6	11.8	33.3	35.3	25.0	233	10.7
Peat	0.110	2.00	5.5	–	13.4	–	0.795	145	0.55
Others	4.167	40.93	10.2	–	8.3	–	–	271	–
Total	9.600	130.2	7.4	13.9	827.0	1.66	49.7	1515	3.3

Table 6 China's share in the world carbon dioxide flux from terrestrial ecosystems

Land-use mode	Carbon pool in vegetation			Carbon pool in soil		
	China	World	China's share,	China	World	China's share,
	$\times 10^9$ ton C		%	$\times 10^9$ ton C		%
Cultivated land	–	*	–	–	1.54	–
Forest	0.017	5.6	0.3	0.056	1.86	0.3
Grassland	0.012	–	–	0.031	–	–
Others		0.2	–	–	1.29##	–
Total	0.029	5.8	0.5	0.087	4.6	1.8

* It is included in the row "others"; # all non-agricultural uses are included

Table 5 shows the carbon pools in terrestrial ecosystems both in China and in the world, while Table 6 gives the carbon dioxide fluxes from the ecosystems in China and in the world. From these tables one can have a view of China's share in the global carbon pool and carbon dioxide flux. In view that the actual quantities of carbon dioxide absorbed by the terrestrial biomass and by the ocean on the global scale are still determined, and that changes in land-use including deforestation tend to complicate the issues even further, our preliminary estimation might initiate further detailed study on the interaction of carbon dioxide with terrestrial ecosystems.

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For more information, please contact:

For Chinese participants: Prof. Rusong Wang, Special Committee for Sustainable Development, 19 Zhongguancun Rd., Beijing 100080, China. Fax:86-1-256-2775;Tel:86-1-256-1871;E-mail:Wangrs@bepc2.IHEP.AC.CN

For foreign participants: Mr. ENG-Leong Foo, UNESCO Microbial Resources Center, MTC-Karolinska Institute, S 171 77 Stockholm, Sweden.Fax:08-331547;Tel:08-728-7145;E-mail:eng-leong.foo@mtc.ki.se