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Roles of urban vegetation on balance of carbon and oxygen in Guangzhou, China

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Abstract: The plant biomass and net primary production(NPP) of urban vegetation in Guangzhou were estimated by dimension analysis, tree truck volume, and harvest methods as well as relationship between biomass and NPP and so on. The biomass and NPP were respectively 2875150t and 1058122 t/a. They were respectively 392495t and 64948 t/a in the built-up area and 2482655t and 993147 t/a in the unbuilt-up area. It would make plant biomass, especially NPP decline obviously, if the unbuilt-up area were changed to the built-up area. The carbon content of plant was 1328649 for the total and 13.78 t/hm^2 for the mean, and amounts of carbon fixed and oxygen made by urban vegetation were respectively 4.80 t/(hm^2·a) and 12.79 t/(hm^2·a) for the mean and 462624 t/a and 1232430 t/a for the total, which were equal to 1.45 times and 1.04 times of those by human breathing. However, they were only equal to 7.61% and 4.97% of amount of carbon released and oxygen consumption in urban Guangzhou. The biomass and NPP of urban vegetation in Guangzhou only corresponded to 7.8% and 47.3% of those of southern subtropical evergreen broad-leaf forest in Dinghu Mountain. Therefore, the roles of Guangzhou urban vegetation in balance of carbon and oxygen would be increased greatly if it could be conserved and improved in some way.

Keywords: urban vegetation; carbon; oxygen; balance; Guangzhou

The greenhouse effect has been caused by the gradual increase of CO_2 concentration in the atmosphere due to the consumption of chemical fuel and the change of land use(Raynaud, 1993). Therefore, carbon cycling of earth has been a "heat point" of the global change. Vegetation, which includes that in urban areas, is an important storage pool in carbon cycling of the earth and an important foundation of the environment for urban sustainable development. Its function for the balance of carbon and oxygen could not be replaced. The role of urban vegetation on the balance of carbon and oxygen in Guangzhou has been studied by estimating storage, distribution and absorption of carbon and the making of oxygen by the vegetation, based on a study of plant biomass and primary production of the vegetation.

1 Study methods

1.1 Biomass and net primary production(NPP) of forest

In built-up areas the aboveground biomass of trees was estimated by dimension analysis (Guan, 1986). Belowground biomass was estimated by the ratios of aboveground and belowground biomass of various forest types (Fang, 1996a). The vegetation of 274.53 hm^2 and trees along 367 roads were surveyed. The diameters at breast high and heights of 156113 trees had been measured. The tree biomass was estimated based on these data.

In unbuilt-up area, the biomass of trees in forests was estimated by tree trunk volume (Brown, 1984; Fang, 1996a). The biomass of undergrowth in forests was similar to that of Massion pine forest and evergreen broad leaf forest in Liuxihe of Guangzhou. The value was 10 t/hm^2(Guan, 1989).

NPP of forest is related to biomass, condition and age of forest. The NPP and age of forest are usually reflected by forest biomass(Fang, 1996a). The formulas relating NPP and biomass in many forests have been established by Fang *et al*.(Fang, 1996a). The formulas for Massion pine forest ($Y = 5.565\ X^{0.157}$) and China fir forest ($Y = -0.018X + 9.059$) from Fang *et al*. (1996a) have been used in this paper. In addition, the formula of biomass and NPP of evergreen broad leaf forest have been established by authors using the data of southern subtropics of Guangdong and Yunnan(Chen, 1992; 1993; Peng, 1994; Dang, 1992). The formula is $1/Y = 2.6151/X + 0.0471 (p < 0.01)$. Here, Y is the NPP(t/(hm^2·a)) and X is the biomass(t/hm^2).

1.2 Biomass and NPP of shrubland and sparse woodland

The biomass of shrubland and sparse woodland varied from 9 t/hm^2 to 39 t/hm^2 in southern subtropics of China(Dong, 1986; Guan, 1998; Lai, 1988). The mean biomass of shrubland and sparse woodland was 19.76 t/hm^2 in this area. The NPP was calculated by the formula $1/Y = 1.27/X^{1.196} + 0.056$. Here,

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X and *Y* are the same as above.

1.3 Biomass and NPP of orchards

The mean biomass and NPP of orchards were 23.7 t/hm^2 and 9.2 t/($hm^2 \cdot a$) respectively (Fang, 1996a).

1.4 Biomass and NPP of crop

The biomass of crops was calculated by economic production and relative economic coefficients (Fang, 1996b). The NPP was estimated by biomass times multiple crop indexes.

1.5 Collection of plants and soil samples and analysis of carbon concentrations

Plant samples numbering 302 from different organs of dominant species and 93 soil samples from 23 profiles and 24 top soil sites are collected in the summer of 1996 and 1998. The samples were brought to laboratory as soon as possible after collection. The plant samples were washed by water, dried at 70℃ in an oven and then ground by mill. The soil samples were dried in air, ground and pass through an 8-mesh sieve. The large stones and roots were separated before proceeding. Potassium dichromate($K_2Cr_2O_7$) and sulphuric acid (H_2SO_4) were used in the digestion of soil and plants. The Walkley-Black Method was used to determine organic carbon concentrations of soil and plants.

2 Results and discussion

2.1 The biomass and NPP

The area of urban Gaungzhou was 114360 hm^2, of which the built-up area was 23913 hm^2. The vegetation area in built-up area was 5763 hm^2. In unbuilt-up area, there were 33600 hm^2 forest, 429 hm^2 shrubland and sparse woodland, 10883 hm^2 orchard, 45730 hm^2 cultivated land. The biomass and NPP were respectively 2875150t and 1058122 t/a in urban Guangzhou (Table 1). In unbuilt-up areas they were 2482655t and 933174 t/a which were equal to 6.3 times the biomass (392495t) and 15.3 times the NPP (64948 t/a) in the built-up area. In the unbuilt-up area, forest made up 76.9% of the biomass, although only occupied 37.1% of the land. Crops occupied 50.5% of the land, but only made up 12.4% of biomass. However, NPP of crops was relatively large and accounted for 53.8% of the NPP. Mean biomass in the built-up area was 2.48 times that of the unbuilt-up area, because vegetation in the former was mainly composed of trees. However, if it is calculated for the area based on the built-up area of 23913 hm^2 and unbuilt-up area of 120477 hm^2, mean biomass and NPP were respectively 16.14 t/ hm^2 and 2.72 t/($hm^2 \cdot a$) in the former and 20.61 t/ hm^2 and 8.24 t/($hm^2 \cdot a$) in the latter. This means that it would make plant biomass, especially NPP decline, if the unbuilt-up area were changed to built-up area.

Table 1 Biomass and NPP of urban vegetation in Guangzhou

Location	Vegetation area, hm^2	Biomass, t	NPP, t/a	Mean biomass, t/hm^2	Mean NPP, t/($hm^2 \cdot a$)
Built-up area					
Urban park	996	860896	12319	86.43	12.37
University	505	39215	6083	77.65	12.04
Roadside	295	26248	3423	88.98	11.60
Other	3967	240943	43123	60.74	10.87
Subtotal unbuilt-up area	5763	392495	64948	68.11	11.27
Forest	33600	1909731	355848	56.84	10.59
Shrubland & sparse woodland	429	8477	2826	19.76	6.59
Orchard	10837	256837	99700	23.70	9.20
Cultivated land	45730	307610	534800	6.73	11.69
Subtotal	90596	2482655	993174	27.40	10.96
Total	96359	2875150	1058122	29.84	10.98

2.2 Carbon storage and amounts of carbon fixed in NPP in urban vegetation

In the built-up area of Guangzhou, the carbon content of plant and carbon mass in the NPP were respectively 184983t and 29165 t/a, of which park vegetation accounted for 23.0% and 19.8%; university vegetation a further 10.0% and 9.4%; roadside vegetation 6.3% and 5.1%; other vegetation provided 60.7% and 65.7% respectively. In the build-up area, the carbon content of plants and carbon mass in NPP were respectively 1143666t and 443459 t/a, in which forest accounted for 78.2% and 36.9%; shrubland and sparse woodland 0.3% and 0.3%; orchard 10.0% and 10.0%; crops 11.5%

and 52.8%. In the vegetation of urban Guangzhou, the plants of the forest had the largest carbon content. Crops had only 9.9% of the total carbon content, but its carbon mass in the NPP was large and made up 49.5% of the total(Table 2).

In addition, soil was the most important carbon storage pool. Its carbon content was 12328 × 10^3t and equal to 9.3 times the carbon content of plants.

2.3 Gross primary production (GPP) and amounts of carbon mixed in GPP and oxygen made in urban vegetation

GPP was estimated from the NPP. It has been reported that NPP/GPP was 0.3 in mature forest; 0.5—0.55 in developing forest and 0.55—0.65 in grassland(Fang, 1996c). In this study 0.5 was used as the ratio of NPP/GPP for forest because forest in urban Gaungzhou was mainly developing forest. The median value 0.6 was used as ratio for grassland. The carbon mass in GPP was also estimated based on that in NPP.

The amount of oxygen making was estimated by the equation $CO_2 + H_2O = CH_2O + O_2$, which meant that when 12.011g of carbon was absorbed by plant photosynthesis, 31.9988g of oxygen was made. According to calculation, the GPP was 1921458 t/a, carbon mass in GPP was 841892 t/a and amount of oxygen made in plant photosynthesis was 2242788 t/a in urban vegetation of Guangzhou. However, some of oxygen made in plant photosynthesis had been consumed by its respiration. In fact, only 54.95% of oxygen made in GPP could provide to human(Table 3).

Table 2 Carbon content of plants, soil and carbon mass of NPP in urban vegetation of Guangzhou

Location	Plant carbon content, t	Soil carbon content, t	Mean plant carbon content, t/hm^2	Mean soil carbon content, t/hm^2	Carbon mass in NPP, t/a	Mean carbon mass in NPP, t/(hm^2·a)
Built-up area						
Urban park	42559	164000	42.73	164.6	5789	5.81
University	18417	40000	36.47	79.2	2742	5.43
Roadside	11666	25000	39.55	84.7	1480	5.02
Other	112341	506000	28.32	127.6	19154	4.83
Subtotal unbuilt-up area	184983	735000	32.10	127.5	29165	5.06
Forest	894015	5544000	26.61	165.0	160116	4.76
Shrubland & sparse woodland	3768	54000	8.78	125.9	1222	2.85
Orchard	114164	1376000	10.53	127.0	43120	3.98
Cultivated land	131719	4619000	2.88	101.0	229001	5.01
Subtotal	1143666	11593000	12.62	128.0	433459	4.78
Total	1328649	12328000	13.78	127.9	462624	4.80

Table 3 Gross primary production and amounts of fixed carbon and oxygen making in urban vegetation of Gaungzhou

Location	GPP, t/a	Mean GPP, t/(hm^2·a)	Carbon mass in GPP, t/a	Oxygen made in GPP, t/a	Oxygen made in NPP, t/a	Mean oxygen made in NPP, t/(hm^2·a)
Built-up area						
Urban park	24282	24.38	11426	30441	15422	15.48
University	11976	23.71	5404	14396	7305	14.46
Roadside	6819	23.12	2948	7834	3943	13.37
Other	5453	21.54	37969	101154	51026	12.86
Subtotal unbuilt-up area	128530	22.30	57747	153825	77696	13.48
Forest	696543	20.73	313792	835943	426549	12.69
Shrubland & sparse woodland	5652	13.17	2444	6511	3255	7.59
Orchard	199400	18.40	86240	229743	114872	10.60
Cultivated land	891333	19.49	381669	1016766	610058	13.34
Subtotal	1792928	19.79	784145	2088963	1154734	12.74
Total	1921458	19.94	841892	2242788	1232430	12.79

2.4 The amount of carbon released and oxygen consumed

Population was 4054958 in urban Guangzhou. The amounts of coal, petroleum, natural gas consumed were 6394059t, 1619141t and 171870t respectively (Statistical Department of Guangzhou, 2000). The amount of released carbon was calculated by below formulas:

(1) Amount of carbon released for burning coal (t/a) = amount of coal consumption (t/a) × 0.982 × 0.73257;

(2) Amount of carbon released for burning petroleum (t/a) = amount of petroleum consumption (t/a) × 0.982 × 0.73257 × 0.813;

(3) Amount of carbon released for burning natural gas (t/a) = amount of natural gas consumption (t/a) × 0.982 × 0.73257 × 0.561. Here, 0.982 is efficiency of effective oxidation. 0.73257 is carbon concentration of standard coal. 0.813 is released carbon ratio of petroleum/coal when emitted energy is the same. 0.561 is released carbon ratio of natural gas/coal when emitted energy is the same.

(4) Amount of carbon released for human breathing (t/a) = human population × 0.079. Here, 0.079 is mean value of carbon released for one person a year.

(5) Amount of carbon released for soil respiration (t/a) = area of vegetation type × mean value of its soil respiration rate. Here, mean value of soil respiration rate except root respiration is 2.88t $C/(hm^2 \cdot a)$ for forest and orchard, 2.55t $C/(hm^2 \cdot a)$ for shrubland and sparse woodland and 2.45 for cultivated land (Raich, 1992; 1989).

According to Zhong Ye Zun Zheng *et al*. (Zhong, 1986), the amount of oxygen consumed was calculated by below formulas:

(1) Amount of oxygen consumed for burning coal (t/a) = amount of coal consumption (t/a) × 32/12;

(2) Amount of oxygen consumed for burning petroleum (t/a) = amount of petroleum consumption (t/a) × 24/7;

(3) Amount of oxygen consumed for burning natural gas (t/a) = amount of natural gas consumption (t/a) × 160/44;

(4) Amount of oxygen consumed for human breathing (t/a) = human population (person) × 0.292.

In addition, the oxygen consumed for soil respiration is estimated based on carbon released for soil respiration in this study. That is:

(5) Amount of oxygen consumed for soil respiration (t/a) = amount of carbon released for soil respiration (t/a) × 2.664. Here, 2.664 are oxygen equivalent value when one equivalent carbon is released as CO_2.

In urban Guangzhou the amount of carbon released was 6078686t, of which coal and petroleum respectively made up 75.7% and 15.6% while population only accounted for 5.3%. The amount of oxygen consumed was 24790094t, of which the largest contribution was also made by coal, which accounted for 68.8% of the total. The second largest was petroleum, which was 22.4% of the total. Population only accounted for 4.8% of that. The amounts of carbon released and oxygen consumed by petroleum, coal and natural gas made up 92.4% and 93.7% of total in urban Guangzhou because a large amount of fuel was consumed. Population only made up a little of carbon release and oxygen consumption (Table 4).

Table 4 Amounts of carbon released and consumption of oxygen (of burning of fossil fuel as well as breathing of human and soil) on urban Gaungzhou in 1999

Item	Coal	Petroleum	Natural gas	Population	Soil respiration	Total
Population (person) or fuel, t	6394054	1619141	171870	4054958		
Released carbon, t	4599778	946969	69362	320342	142235	6078686
Oxygen consumed, t	17050810	5551340	624982	1184048	378914	24790094

2.5 The role of urban vegetation on balance of carbon and oxygen

The contents of carbon and oxygen in the atmosphere of urban Gaungzhou are estimated according to the method as follow:

For CO_2: 355 ppm × (12/29) × 1.03 kg/cm^2 × 1443.6 km^2 = 2.18×10^6 t.

For O_2: 210000 ppm × (16/29) × 1.03 kg/cm^2 × 1443.6 km^2 = 1.72×10^9 t.

Here, 355 ppm and 210000 ppm are concentrations of CO_2 and O_2 in atmosphere respectively. 12 and 16 are atomic weight of carbon and oxygen respectively. 1.03 kg/cm^2 is atmospheric mass. 1443.6 km^2 is the urban area of Guangzhou.

The carbon contents in plants and soils of urban vegetation were 0.61 times and 5.7 times of that in the atmosphere respectively. The amounts of carbon fixed and oxygen made by urban vegetation were equal to 1.45 times and 1.04 times those by human breathing. However, they were only equal to 7.61% and 4.97% of the amounts of carbon released and oxygen consumption in urban Gaungzhou. Fortunately, the amount of oxygen consumption only corresponded to 1.44% of the oxygen content in atmosphere where the oxygen content is large.

Mean plant biomass and NPP were 29.84 t/hm^2 and 10.98 t/(hm^2·a) respectively(Table 1), which corresponds to 7.8% and 47.3% of those of southern subtropical evergreen broad-leaf forest on Dinghu Mountain (Peng, 1994), where the biomass and NPP were 380 t/ hm^2 and 23.2 t/(hm^2·a) respectively. Therefore, the roles of Guangzhou urban vegetation in the balance of carbon and oxygen would be increased greatly if it could be conserved and improved in some way.

In addition, the urban area is a point of region. The balance of carbon in the urban area depends, in part, on the air exchange with the surround area. The air of urban Guangzhou is replaced on average 3995 times per annual based on built-up area of 15 km width and mean wind speed of 1.9 m/s. Therefore, there were no serious problem in the balance of carbon and oxygen in urban Guangzhou. But, urban Guangzhou was certainly an important source for the release of carbon and consumption of oxygen in Guangdong and southern China.

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