SHORT REPORT

The method of measuring carbon sinks based on the changes in oxygen concentration in forest canopy

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Measuring forest carbon sinks is becoming a popular topic as the need of many countries' carbon neutrality plans. This study demonstrated a simple and accurate method of forest carbon sinks measurement. By observing the daily average oxygen concentration in the canopy, the results showed that it presented a parabolic distribution from spring to fall in a year. The forest finished the cycle from releasing oxygen and sequestrating carbon dioxide to using oxygen and releasing carbon dioxide in this period. The calculated carbon sequestration of the forest was 101.39 t/hm²/y, and the carbon sink was 15.09 t/hm²/y. By calculating the changes in oxygen concentration in a growth cycle, the carbon sink was 16.29% of the carbon sequestration.

Keywords: **f**orest carbon sinks; measurement; average oxygen concentration; carbon sequestration.

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Introduction

Forest carbon sinks represent the ability of forest ecosystems to absorb and store carbon dioxide by quantifying the mass of carbon dioxide fixed by plants [1, 2]. It is an important indicator for assessing the impact of global climate change, management measures, and human disturbance on forest ecological function, growth, and survival [3-5]. Therefore, accurate quantification of carbon sinks is essential for the effective assessment of forest function dynamics. However, the most common way to measure the changes in carbon sequestration right now is the Stock-Difference method, which calculates the forest gross primary productivity (GPP) rather than net ecosystem productivity [6]. The Gain-loss method [7] is based on monitoring the changes of carbon dioxide in the air, which not only has large errors but also cannot be verified by the test and measurement. Therefore, an accurate, accessible, low-cost, short-period observation method is useful for observing forest functional dynamics and convenient to promote in the forestry, agriculture, grass industry, and other related industries.

The objectives of this study were to propose a method to calculate carbon sinks by observing oxygen concentration change based on the material conversion process in photosynthesis and to apply this method to observe the change of carbon sink function in the growing season of the poplar plantation. Furthermore, the accuracy of this proposed method was verified in corn fields in northern China by harvesting whole crops.

Materials and methods

Overview of the research area

The research was conducted in Beijing Gongqing Forestry Farm (Beijing, China), which is located in the northeast of Beijing (166.40 E and 40.10 N) with the altitude of 25 meters. The soil type is sandy soil, and the forest type is planted forest. The main tree species are poplars (*Populus × euramericana*). The average tree height of poplars was 21 meters, the average canopy height was 12 meters, and the average tree age was 25 years. The study region has a warm temperate semi-humid continental monsoon climate with four distinct seasons. It is dry and windy in spring, hot and rainy in summer, cool and crisp in autumn, and cold and dry in winter. The annual average temperature is 11.5°C and the annual sunshine time is about 2,750 hours with the average annual rainfall of about 625 mm. It belongs to a relatively arid area.

Experimental setup

Forest carbon sink was observed by a 30 meters high measuring tower which was set in the center of the 160-hectare forest. An oxygen concentration detector was installed 15 meters high of the measuring tower to ensure that the detector was in the middle of the canopy. Corn carbon sequestration was measured by another oxygen concentration detector installed in the center of a 10 × 25 m^2 cornfield. The detector was raised in the position to ensure that the detector was always located at the middle-upper part of the cornstalk as the growing up of the corn. The error value of the oxygen concentration detectors were adjusted to less than ± 0.5%.

The two oxygen concentration detectors continuously measured the oxygen concentration (% Vol.) for one day and night every 5 minutes. The daily average oxygen concentrations of the forest and cornfield were then calculated. Since trees only begin to grow and release oxygen at a temperature higher than their biological zero and the biological zero of poplar is more than 10°C, the starting point of data recording in spring was set on March 10 because the average temperature of Gongqing Forestry Farm from March 10^{th} to March 24^{th} is 10.17°C. The endpoint of data recording in autumn was set at the time point when the oxygen concentration was higher than that on the starting point in spring, which was on October 5^{th}. The duration of the measurement in the forest was from January 1^{st}, 2020, to December 31^{st}, 2020. In a cornfield, this duration was from May 1^{st}, 2020, to July 14^{th}, 2020. The sowing time of corn was May 1^{st}, 2020, and the harvest time of corn was July 14^{th}, 2020.

Measurement of forest carbon sinks

During Photosynthesis, plants absorb carbon dioxide and release the same amount of substance of oxygen. Their amount of substance is equal to the mass divided by the molar mass. Therefore, the value of plant carbon sequestration can be calculated by the following formula.

$$M_{co2} = \sum v\,phs(mr_{co2}/mr_{o2})$$

where M_{co2} is the mass of plant fixed carbon dioxide. $\sum v$ is the accumulation value of oxygen concentration difference during a period. ρ is the oxygen density 1.43kg/m^3. h is the average height of the photosynthetic part of the plant. s is the area of the plant. mr_{co2} is the molecular weight of CO_2 of 44. mr_{o2} is the molecular weight of O_2 of 32.

Statistical analysis

For testing the difference of the temperature difference of each 15-day period, an analysis of one-way ANOVA was performed.

Results

Diurnal variation of forest canopy oxygen concentration

This research analyzed and processed the change of oxygen concentration in the whole day on April 14th, 2020 (Figure 1). The daily variation of oxygen concentration value showed a wave model. On April 14th, 2020, the lowest oxygen concentration in a day and night was from 5:30 am to 7:30 am with the lowest oxygen concentration value of 20.39% (Vol.). The highest oxygen concentration value in a day and night was from 1:00 pm to 3:00 pm, and the highest oxygen concentration value was 21.23% (Vol.).

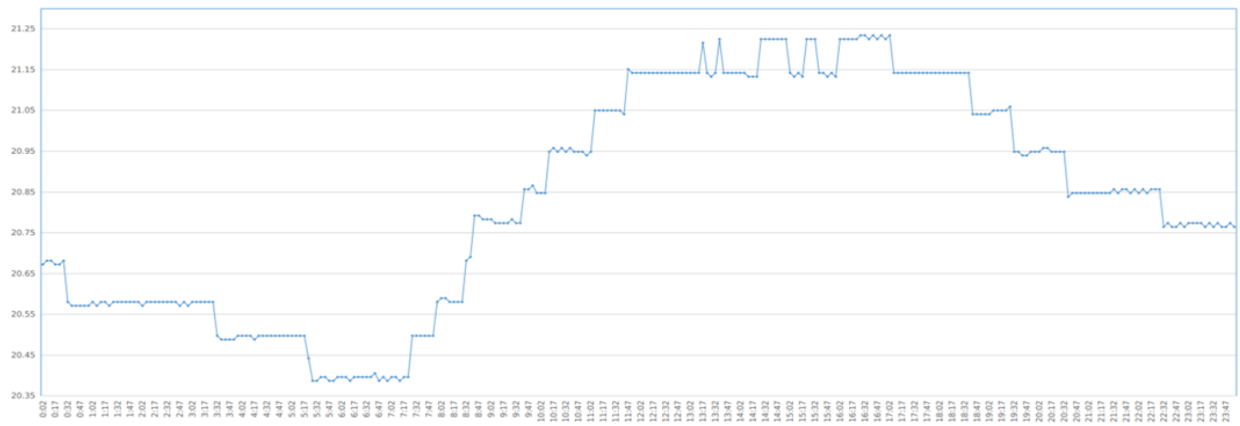

Figure 1. The change of oxygen concentration on April 14th, 2020.

Table 1. Forest carbon sinks meter.

Date (2020)	Cell	Average oxygen concentration (% Vol.)	Difference in the average value of oxygen concentration every 15 days (% Vol.)	Summation of average difference of oxygen concentration (% Vol.)	Canopy height (m)	Area (m^2)	Mass of sequestrated CO_2 (kg/hm²)	Mass of released CO_2 (kg/hm²)	Forest Carbon Sinks (kg/hm²)
3/10-3/24	1	20.56			12				
			0.08						
3/25-4/08	2	20.64			12				
			0.11						
4/09-4/23	3	20.75			12				
			0.07	0.43					
4/24-5/08	4	20.82			12				
			0.01						
5/09-5/23	5	20.83			12				
			0.08						
5/24-6/07	6	20.91			12				
			0.08						
6/08-6/22	7	20.99			12				
			-0.11						
6/23-7/07	8	20.88			12	10,000	(0.43 × 1.43 × 12 × 10,000 × 44)/32 = 101,458.5	(-0.36 × 1.43 × 12 × 10,000 × 44)/32= -84,942	16,516.5
			-0.02						
7/08-7/22	9	20.86			12				
			0						
7/23-8/06	10	20.86			12				
			-0.03	-0.36					
8/07-8/21	11	20.83			12				
			-0.02						
8/22-9/05	12	20.81			12				
			-0.04						
9/06-9/20	13	20.77			12				
			-0.14						
9/21-10/5	14	20.63			12				

The difference between the lowest and the highest oxygen concentrations on April 14th, 2020 was about 4.12%.

The relationship between daily average oxygen concentration and daily maximum temperature

The daily maximum temperature from March 10th to October 5th (Figure 2), and the daily

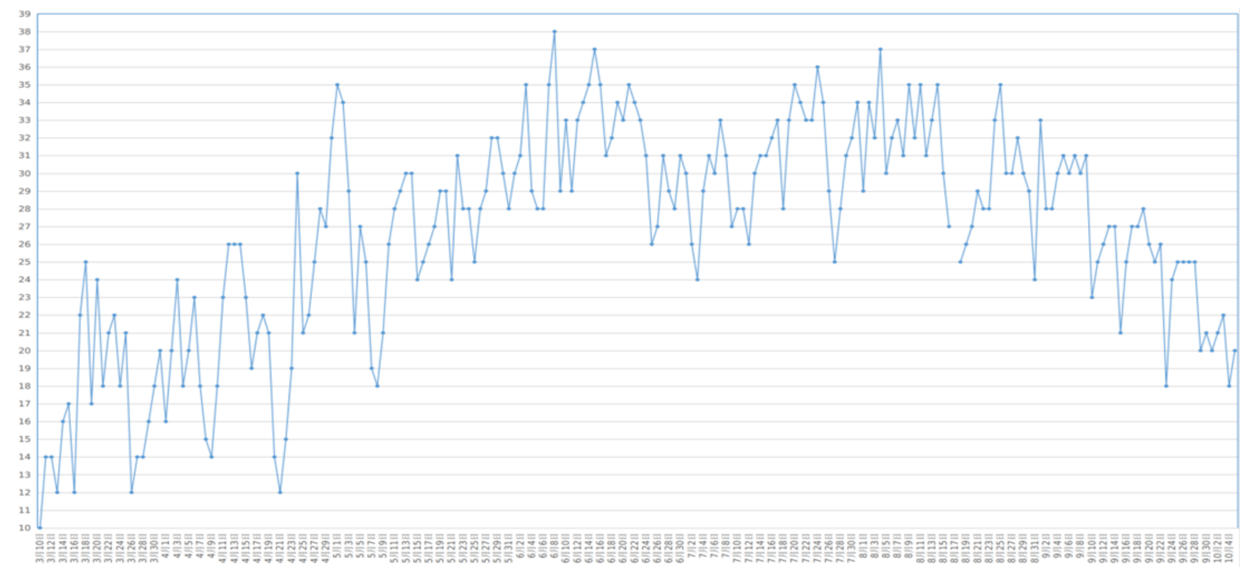

Figure 2. Daily maximum temperature curve from March 10th to October 5th.

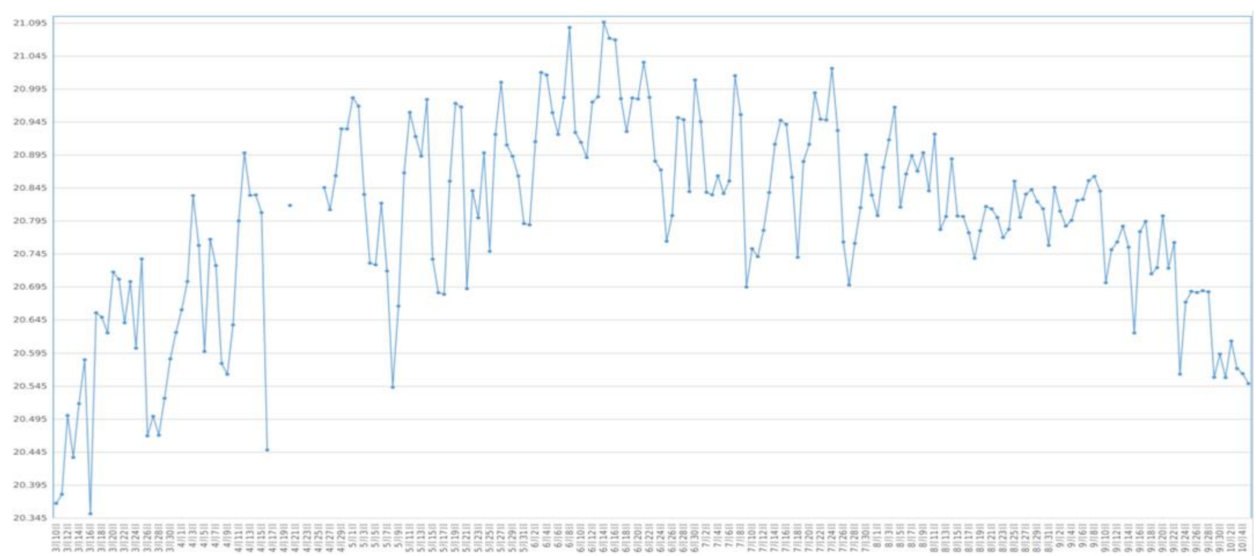

Figure 3. Daily average oxygen concentration from March 10th to October 5th.

average of oxygen concentration from March 10th to October 5th (Figure 3) were analyzed. The average daily oxygen concentration in the canopy was basically consistent with the changing trend of daily maximum temperature, and the oxygen concentration increased or decreased with the rise and fall of temperature. The changing trend of oxygen concentration during a growth period showed the form of low in spring and autumn, and high in summer.

The changes in average oxygen concentration in time frame of 15 consecutive days

According to the analysis results of the one-way ANOVA, the temperature differences of each 15-day time frame were significant. Therefore, the average value of oxygen concentration every 15 days was taken as a unit oxygen concentration value (Table 1). The first time frame as the starting point was from March 10th to 24th in spring. The average oxygen concentration was

Table 2. Corn carbon sequestration meter.

Date	Cell	Average oxygen concentration (% Vol.)	Difference in average value of oxygen concentration every 15 days (% Vol.)	The height of cornstalk (m)	Area (m^2)	Mass of sequestrated CO_2 (kg)
5/1-5/15	1	20.85				
			0.03	0.6		0.57
5/16-5/30	2	20.88				
			0.21	1.5	16	9.91
5/31-6/14	3	21.09				
			0.03	2.1		1.98
6/15-6/29	4	21.12				
			-0.09	2.2		
6/30-7/14	5	21.03				

20.56% Vol., and gradually increased from spring to summer with the highest point appearing in the seventh unit, which was from June 8^{th} to 22^{nd} in summer with the average oxygen concentration of 20.99% Vol. After that, the average oxygen concentration gradually decreased from summer to autumn. The last unit was the fourteenth unit, which was from September 21^{st} to October 5^{th} in autumn, and the average oxygen concentration was 20.63% Vol.

The measurement of forest carbon sinks and corn carbon sequestration

The carbon sequestration of forest in a growth cycle was 101,458.5 kg/hm², which was equivalent to 101.46 t/hm². The emission of carbon dioxide was 84,942 kg/hm², which was equivalent to 84.94 t/hm². The forest carbon sink was 16,516.5 kg/hm², which was equivalent to 16.52 t/hm² (Table 1). The forest carbon sink was 16.29% of carbon sequestration.

The total carbon sequestration mass of corn during growth was 12.46 kg/hm², which was equivalent to 7.79 t/ hm². The corn harvested from the observation point (16 m^2) obtained 23 kg of dry matter, including root, stem, leaf, and corn. Based on the content of organic carbon in each part, the total mass of carbon sequestration was calculated as 9.95 kg, and the measured carbon sequestration of corn accounted for 79.86% of the theoretical carbon sequestration (Table 2). The measured carbon sequestration was lower than the theoretical carbon sequestration. It was because the fact that the carbon sequestration of roots and other plants in the soil could not be fully collected.

Discussion

The diurnal variation of forest canopy oxygen concentration was closely related to air temperature

The photosynthetic rate of trees in the growing season is closely related to the temperature [8-10]. The lowest temperature in spring occurred at 5:00 - 7:00 am. In this period, the trees had the lowest photosynthetic rate of the day and the oxygen concentration in the air dropped to a minimum. The highest temperature appeared from 13:00 - 15:00. In this period, the photosynthetic rate of trees reached the strongest level of the day, and the oxygen concentration in the air also reached the highest level.

The two stages of forest growth cycle: carbon sequestration and carbon release

From spring to summer, the photosynthetic rate of trees increased with the increase in temperature and the average oxygen concentration in the canopy increased gradually. It showed that, during this period, the rate of photosynthesis of trees was higher than the respiration rate. It was the stage of releasing oxygen and absorbing carbon dioxide. April 9th to April 23rd was the fast-growing period of poplar branches and leaves, and it was also the period with the fastest increase in oxygen concentration. From summer to autumn, the photosynthetic rate of trees decreased with the decrease in temperature, and the average oxygen concentration in the canopy gradually decreased, which showed that, during this period, the rate of photosynthesis of trees was lower than respiration [11, 12]. It was the stage of consuming oxygen and releasing carbon dioxide.

The fast-growing period of corn was also the peak of carbon sequestration

According to the measurement results, the carbon sequestration from May 31st to June 14th was 9.91 kg, accounting for 79.53% of the total measurement. Based on the observation data, this stage was the fastest period of high growth and sturdy growth of corn, and it was also the stage with the largest increase in oxygen concentration. The results were in full agreement with the actual situation.

Conclusion

The measurement method shown in this paper could distinguish the total photosynthesis and total respiration of forests, which was very convenient for calculating the net productivity of forests. The validity and accuracy of the formula could be proved by the corn experiment. Therefore, the method of carbon sequestration measurement based on the variation law of oxygen concentration in the canopy was simple, accurate, and real-time. It was applicable not only to forests but also to crops, grasslands, wetlands, and other scenes requiring carbon sequestration measurement

References

1. UNFCCC. Kyoto Protocol to the United Nations Framework Convention on Climate Change, 2019. Disponível em: <https://unfccc.int/resource/docs/convkp/kpeng.pdf>.
2. Yang Y, Shi Y, Sun W, Chang J, Zhu J, Chen L, *et al*. 2022. Terrestrial carbon sinks in China and around the world and their contribution to carbon neutrality. Sci China Life Sci. 65:861-895.
3. Pan Y, Birdsey R, Fang J, Fang J, Houghton RA, Kauppi PE, et al. 2021. A large and persistent carbon sink in the world's forests. Science. 333:988–993.
4. Gampe D, Zscheischler J, Reichstein M, O'Sullivan M, Smith WK, Sitch S, *et al*. 2021. Increasing impact of warm droughts on northern ecosystem productivity over recent decades. Nat Clim Change. 11:772–779.
5. Sitch S, Friedlingstein P, Gruber N, Jones SD, Murray-Tortarolo G, Ahlström A, *et al*. 2015. Recent trends and drivers of regional sources and sinks of carbon dioxide. Biogeosciences. 12:653–679.
6. Forestry Carbon Sequestration Editorial Board. 2016. Forestry Carbon Sequestration: practice in Beijing. China Forestry Publishing House (In Chinese).
7. Li NY, Lv J. 2009. Carbon Inventory Methods. China Forestry Publishing House (In Chinese).
8. Horst SVJVD, Pitman AJ, Kauwe MGD, Ukkola A, Abramowitz G, Isaac P. 2019. How representative are FLUXNET measurements of surface fluxes during temperature extremes? Biogeosciences. 16(8):1829–1844.
9. Urban J, Ingwers MW, McGuire MA, Teskey RO. 2017. Increase in leaf temperature opens stomata and decouples net Photosynthesis from stomatal conductance in *Pinus taeda* and *Populus deltoides* x nigra. J Exp Bot. 68(7):1757–1767.
10. Liu J, Zhang R, Xu X, Fowler JC, Miller TEX, Dong T. 2020. Effect of summer warming on growth, photosynthesis, and water status in female and male *Populus cathayana*: Implications for sex-specific drought and heat tolerances. Tree Physiol. 40(9):1178–1191.
11. De Kauwe MG, Medlyn BE, Pitman AJ, Drake JE, Ukkola A, Griebel A, *et al*. 2019. Examining the evidence for decoupling between Photosynthesis and transpiration during heat extremes. Biogeosciences. 16(4):903–916.
12. Griebel A, Bennett LT, Metzen D, Pendall E, Lane PNJ, Arndt SK. 2020. Trading water for carbon: Maintaining photosynthesis at the cost of increased water loss during high temperatures in a temperate forest. J Geophys Res-Biogeo. 125:e2019JG005239.