Oxygen production potential of trees in urban areas: a reality check?

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Trees are referred to as the lungs of the earth for their oxygen releasing potential, via photosynthesis. Air quality in urban areas has deteriorated and it is impacting the well-being of human life. The oxygen spa or artificial oxygen environment is portrayed as an alternative to air pollution. Against this backdrop, there are voices supporting to increase the tree cover in urban areas, thereby increasing oxygen availability. Increasing tree numbers to remove air pollutants is a logical argument, but improving the air quality by increasing the oxygen concentration by growing more trees needs introspection. Thus the question – How much oxygen is produced by different tree species and how to quantify it? According to atmospheric researchers the oxygen concentration of the atmosphere has not changed for quite a long time. Also, oxygen production from the terrestrial ecosystems is less compared to the marine and aquatic ecosystems. Moreover, there are numerous benefits from urban trees or urban greenspaces, so do we really need to worry about oxygen production or release from urban trees?

Keywords: Oxygen release, photosynthetic rate, trees, urban greenspaces, valuation.

AIR pollution, poor air quality and high particulate matter ($PM_{2.5}$, PM_{10}) concentration are some of the common phrases frequently found in the headlines of newspapers across the globe[1,2]. Consequently, news articles about oxygen bars, oxygen cylinders and oxygen spa are found subsequently in the newspapers[3,4]. Industrial revolution and urbanization have deteriorated the air quality which has great implications on human well-being. This fact is not controversial, i.e. air pollution is real. However, there are debates on portraying oxygen spa or artificial oxygen environment as an alternate to air pollution. Medical professionals are not yet decisive on the concept of oxygen spa. On the other hand, environmentalists insist on planting more trees and increasing the green cover of cities as a remedy for issues related to air pollution. The proponents of tree planting often use statements like – 'trees give oxygen and we need oxygen to live'.

Even in the 1970s, there was ambiguity on the depletion of oxygen in the atmospheric air. Broecker[5] commented that the possibility of depleting atmospheric oxygen was impossible even if all the fossil fuel reserves were burnt out. However, the article also pointed out that there was a good chance for the depletion of oxygen (dissolved oxygen) in the aquatic ecosystem due to anthropogenic activity. He quotes 'There are hundreds of other ways that we will hazard the future of our descendants before we make a small dent in our oxygen supply'[5]. The oxygen concentration in the atmosphere is 21% and it has not changed much[6]. Approximately 2.5 billion years ago, the condition was different; there existed an atmosphere devoid of oxygen[7]. Geologists and atmospheric researchers point out a time period when the increase in oxygen concentration of the earth's atmosphere happened, and termed it as the Great Oxygenation Event. Till date, researchers are working on this area for better clarity[8].

Irrespective of the uncertainty on the time period of the Great Oxygenation Event, scientists agree that photosynthetic oxygen released from terrestrial as well as oceanic autotrophs has shaped life on the planet. In the context of deteriorated air quality in urban areas, planting trees is a more potent way of tackling air pollution, as a pro-environmentalist advocates. Studies have quantified and proven that trees can remove sulphur dioxide (SO_2), particulate matter (PM_{10}) and ozone (O_3) (refs 9–11). It may seem natural for the trees to sequester CO_2 and other gases, but trees as such have limits. There are variations in the extent of remediation between different tree species. The varying level of air pollutants will have an impact on the growth of trees too, i.e. their metabolic processes, both photosynthesis and respiration. It depends on individual tree species and its ability to tolerate the stress[12].

Technically, air pollution is the addition of undesirable, harmful gases and substances in the air, either naturally or through man-made activities. Pertinently, air quality in urban areas becomes worse sometimes that it is unfit for breathing. As stated earlier, atmospheric oxygen

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Table 1. Methods for measuring photosynthetic oxygen evolution in plants

Methods	Mechanism	Reference
The Clark electrode Leaf disc electrode Joliot-type electrode	Polarography	19, 26, 40
Optical O_2 sensor	Photoluminescence quenching	41
Genetically encoded O_2 sensor	The sensitivity of fluorescence protein to O_2	42
Photoacoustic spectroscopy	Photobaric contribution due to oxygen evolution	43–45
EPR (electron paramagnetic resonance) Oximetry	Paramagnetic property of the O_2	46, 47
LSI (large-scale integration)-based biosensor	Based on the amperometric sensor array system	48
Fibre optic O_2 probe	Fluorescence quenching	19
Differential zirconium analyzer Differential fuel cell analyzer	Galvanic sensors	25
Membrane inlet mass spectroscopy	Mass spectroscopy	49, 50
Dual-frequency phase modulation technique Pulse ratio technique	Based on luminescence lifetime	24

concentration has not changed at all, but only the addition of other gases like carbon monoxide, SO_2 and pollutants make it unfit[13,14]. Some literature mention about the decrease in oxygen concentration inside urban areas[15,16]. Even though there is uncertainty about the former statement, increasing the number of trees to remove air pollutants and to improve air quality by increasing the oxygen concentration at the local level is a logical argument. Thus the question: How much oxygen is produced by different tree species and how to quantify?, remains a researchable issue.

Estimating photosynthetic oxygen production

Photosynthesis is a biochemical process which provides energy for the sustenance of life on the earth. During this process, oxygen is released as a by-product which has changed the evolutionary history of the planet itself[17]. Similarly, photorespiration process in plants ensures their growth and development. Thus photosynthesis and respiration are vital physiological processes which have intrigued researchers. Attempts for measuring photosynthetic and respiration rates in different autotrophs have been the focus of plant physiological research even today[18]. In physiological research, it is assumed that the photosynthetic rate in the plant is equal to the gas exchange rate, i.e. CO_2 and O_2 flux. Thus, early researchers like Otto Warburg attempted to measure the gas exchange rate as a means to quantify the photosynthetic rate in plants[19].

There were attempts to measure photosynthetic oxygen in 1937 from isolated chloroplast[20]. Through a similar experiment, Mehler and Brown[21] using isotope tracer $^{18}O_2$ also proved that oxygen released during photosynthesis comes from the splitting of a water molecule. There were other important works on measuring photosynthetic oxygen during the 1980s (ref. 22). Scientifically, oxygen measurements are done at two media – one aqueous (liquid phase) and another one at the gaseous phase. There are robust methodologies to measure dissolved oxygen in freshwater as well as marine ecosystems. However, there is a wide distinction between photosynthetic oxygen release and the former. Many researchers developed methods and tools to measure photosynthetic oxygen release which are listed in Table 1. There have been few good reviews in this aspect as well[18,19,23–26].

Despite numerous developments, there remain some unanswered questions. For instance, there was a research paper titled 'Measurement of gross photosynthesis, respiration in the light, and mesophyll conductance using $H_2{}^{18}O$ labeling' in the *Journal of Plant Physiology*[27]. Commenting on this article as a significant contribution, Holloway-Phillips[28] pointed out that the *in vivo* measurement of oxygen fluxes based research had declined in the last 20 years. Another research work also attempted real-time imaging of oxygen using large scale integration biosensor method, but it focused on the measurement in excised leaves. Overall, it seems that each of these different methods for estimation or determination of oxygen release from autotrophic organisms, have their own advantages and disadvantages. Despite research for more than 100 years on photosynthetic oxygen release, there is uncertainty. Thus, one can be skeptical about estimating the oxygen production of urban trees.

Estimating oxygen production in trees

There are works that quantify the oxygen production in trees exclusively, even in terms of monetary benefits[10,29–33]. There are two approaches widely followed for quantifying oxygen production in trees:

(i) Net primary productivity (NPP) is measured using a portable photosynthesis measurement system and the values are used to compute the total assimilation per day. Using the principle of converting the total assimilation amount into the quantum of CO_2 fixed, the quantum of oxygen released is computed using the formula given below

$$QO_{2\,avg} = Y \times P_{avg} \times (1–0.2) \times 32/1000, \quad (1)$$

where $QO_{2\,avg}$ is the average amount of oxygen released by a plant per day (g d^{-1}), Y the leaf area and P_{avg} is the average net assimilation rate per unit area (m mol m^{-2} d^{-1}) (ref. 32).

(ii) An empirical equation to determine the amount of oxygen produced based on the carbon sequestered

$$\text{Net } O_2 \text{ release (kg yr}^{-1}\text{)} = \text{net C sequestration (kg yr}^{-1}\text{)} \times (32/12) \text{ (ref. 10).} \quad (2)$$

Both the approaches quantify the net oxygen released by a tree after accounting for the oxygen consumed during the respiration process. There is a wide difference between these two approaches. The first method quantifies the net oxygen production at that instant as its measurements depend upon the actual number of leaves and other leaf traits such as transpiration rate, stomatal conductance, intra-cellular CO_2 concentration and other parameters. And the latter only quantifies oxygen produced so far till that moment as its measurements depend upon the net carbon sequestered in the past. It also assumes that the trees having high net carbon sequestration must also have net oxygen production. Further, the major disadvantage of the empirical equation method is that it does not account for the nature of tree, growth rate, tree architecture or leaf area. For instance, the fast growing trees like Casuarina will usually have high net oxygen production based on the empirical approach. In real-time, there will be a need to estimate the oxygen production potential of trees rather than estimating the oxygen released so far by the tree.

Critical issue: need of the hour

The scientific attempts for measuring photosynthesis and photorespiration rate are centuries old. Researchers have been working on methodologies for precise and accurate estimation. Oxygen released from trees or the oxygen production potential of trees has not been a scientific question so far, except for few studies (as stated earlier). However, questions arise on the logic behind the valuation of trees based on their oxygen release or production, due to lack of consent on the methodology itself. This needs to be addressed specifically as there is misinformation about certain tree species having high oxygen production potential. More pertinently, in the legal case relating to the Bengal Flyover Project where the local administration proposed felling of 356 trees for constructing bridges, and the Chief Justice of India mooted the concept of valuing trees based on their oxygen release potential[34]. Subsequently, the apex court reiterated the same and refused to permit to fell nearly 2940 trees for Krishna–Govardhan road project[35]. Usually, trees are compensated based on their timber or biomass value which is determined either through allometric equations or yield tables, and sometimes based on actual biomass measurement itself. More systematic method for estimating the net present value of trees is also practiced in Indian context[36]. The argument is not about methodology of valuating trees but valuating trees based on their utility as sources of oxygen. Moreover, there are numerous other benefits from urban trees or urban greenspaces, so do we really need to worry on the oxygen production or release from urban trees? Also, does the oxygen produced by the trees really improve the quality of air that we breathe? This question arises because there are studies reporting that the air quality in urban areas is poor due to pollutants like SO_2, $PM_{2.5}$, or PM_{10}, but there are not enough studies to support that oxygen concentration in urban areas is lesser compared to surroundings of an urban greenspace except for Ginzburg *et al.*[16].

Similarly, there is a belief in India that certain trees have high oxygen production potential like *Ficus bengalensis*, *Ficus religiosa*, *Azadirachta indica*, etc. There is a need for scientific studies in this aspect so as to prevent the dominance of certain tree species in urban tree planting programmes. Of late, researchers are arguing for increasing diversity among urban trees to enhance the utility value of urban greenspaces and urban forests[37–39]. Also the concept of prioritizing tree species for urban planting based on their utility can be misleading in many situations, as it should be site-specific rather than a blanket recommendation. In all good-faith, local tree species should be the first choice in urban tree planting programmes, unless there is a systematic evaluation of trees for their utility values like $PM_{2.5}$ removal or oxygen production potential which should be supported scientifically.

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