Oxygen production potential of trees in India

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This study deals with the oxygen production potential of India taking baseline data from ISFR 2019. The Indian forests have an oxygen production potential of 7896.14 million tonnes (mt) and the annual potential was 28.04 mt yr\(^{-1}\) for 2019. Considering oxygen production potential of the top 10 tree species from forests and those outside forests, Shorea robusta (Sal) and Mangifera indica (Mango) ranked first, i.e. 657.87 and 214.39 mt respectively. The fast-growing agroforestry tree species exhibit a net oxygen production rate in the range of 1.03–34.15 tonnes ha\(^{-1}\) yr\(^{-1}\). Bamboo being a fast-growing and higher biomass-producing species showed oxygen production of 27.38 mt yr\(^{-1}\). Overall this provides huge scope for establishing oxyparks in India.

Keywords: Agroforestry, bamboos, oxygen production potential, oxyparks.

OXYGEN is one of the important elements necessary for the survival of every species in this planet. Forests and trees are the major source of oxygen and an important reservoir of carbon dioxide. They meet half of the oxygen demand, producing 26 billion tonnes per year and are thus referred to as ‘oxygen factories’\(^1\). Among the different types of forest, tropical forests, and savannas account for 34% and 26% of global photosynthesis and amazon rainforests hold one-half of the world’s tropical rainforests\(^2\). Since 1990, the area of naturally regenerating forests has been decreasing due to deforestation, but the area of planted forests has increased by 123 million ha\(^3\). However, the Indian scenario shows an increasing trend in terms of forest and tree cover (80.73 million hectares), which is 24.56% of the total geographical area of the country\(^4\). The decrease in the number of trees/plants can result in a decrease in oxygen production\(^5\). Therefore, in this study we estimate the oxygen production potential of India under the following sub-headings: (a) Annual production potential of oxygen based on forest carbon, (b) Oxygen production potential of Indian forests (state-wise), (c) Top ten tree species of Indian forests and trees outside forests (TOF), (d) Agroforestry tree species, (e) Bamboo species. The baseline data were collected from the Indian State of Forest Report (ISFR) by Forest Survey of India (FSI), Dehradun\(^4,5\) and net oxygen release was calculated based on organic carbon produced by trees or local plants\(^6-8\).

\[\text{Net } \text{O}_2 \text{ release (tonnes ha}^{-1} \text{ yr}^{-1}) = \frac{\text{Net carbon sequestration (tonnes ha}^{-1} \text{ yr}^{-1}) \times 32}{12}. \]  

(Note: 32 is the molecular weight of oxygen and 12 is the molecular weight of carbon.)

Based on the wood density of different species according to FAO estimates (http://www.fao.org/3/w4095e/w4095e0c.htm), the mass of the species was calculated. In simple terms

\[\text{Wood density} = \text{Biomass/Volume}.\]

\[\text{Biomass} = \text{Volume} \times \text{wood density}.\]

The obtained biomass of trees from volume provides the aboveground biomass. Therefore, to calculate belowground biomass, the aboveground biomass is multiplied with the IPCC-driven universal conversion factor of 0.26. Then, the total dry biomass is multiplied by carbon content (50% of wood is carbon) to obtain the carbon sequestration of woody species.

The results indicate that the net oxygen production potential was 28.04 million tonnes per year, of which aboveground oxygen production (25.37 mt yr\(^{-1}\)) was more than belowground oxygen production (2.67 mt yr\(^{-1}\)) (Figure 1).

The total oxygen production potential of Indian forests is 7896.14 million tonnes (mt). Arunachal Pradesh (1151.40 mt) ranks first, followed by Madhya Pradesh (613.29 mt) and Jammu and Kashmir (582.13 mt), whereas the least oxygen production potential is from the Union Territories of Daman and Diu (0.12 mt), Chandigarh (0.22 mt) and Puducherry (0.20 mt). The production potential of oxygen is linked to greenery, growing season, stems per unit area, age, geographical area and forest cover of a state. Moreover, the area of very dense forest (21,095 km\(^2\)) and medium dense forest (30,557 km\(^2\)) in Arunachal Pradesh is more in comparison with the other states\(^4\). Therefore, if forest canopy is increased and sustained over a period, net carbon dioxide will be removed and more oxygen will be produced\(^6\). Figure 2 shows the state-wise oxygen production potential in India.

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Table 1. Oxygen production potential of top 10 species from Indian forests and trees outside forests (TOF)

| Species                  | Growing stock (million cubic metre) | Carbon sequestration (million tonnes) | Oxygen production potential (million tonnes) |
|--------------------------|-------------------------------------|--------------------------------------|---------------------------------------------|
| Forests                  |                                     |                                      |                                             |
| Shorea robusta           | 543.81                              | 246.67                               | 657.87                                      |
| Tectona grandis          | 194.54                              | 67.41                                 | 179.78                                      |
| Terminalia tomentosa     | 165.71                              | 80.39                                 | 214.39                                      |
| Pinus roxburghii         | 156.52                              | 64.09                                 | 170.94                                      |
| Abies pindrow            | 129.20                              | 32.56                                 | 86.83                                       |
| Anogeissus latifolia     | 124.12                              | 61.77                                 | 164.75                                      |
| Pinus wallichiana        | 119.27                              | 36.07                                 | 96.19                                       |
| Cedrus deodara           | 118.71                              | 43.38                                 | 115.69                                      |
| Lannea coromandelica     | 101.41                              | 34.50                                 | 92.01                                       |
| Picea smithiana          | 94.45                               | 23.80                                 | 63.48                                       |
| TOF                      |                                     |                                      |                                             |
| Mangifera indica         | 207.24                              | 77.03                                 | 205.44                                      |
| Azadirachta indica       | 133.23                              | 57.92                                 | 154.46                                      |
| Madhuca latifolia        | 81.46                               | 37.98                                 | 101.28                                      |
| Cocos nucifera           | 63.93                               | 20.14                                 | 53.71                                       |
| Borassus flabelliformis  | 62.42                               | 38.14                                 | 101.73                                      |
| Acacia arabica           | 52.34                               | 23.08                                 | 61.56                                       |
| Butea monosperma         | 45.65                               | 13.80                                 | 36.82                                       |
| Tamarindus indica        | 42.50                               | 20.08                                 | 53.56                                       |
| Pinus wallichiana        | 42.45                               | 12.84                                 | 34.24                                       |
| Ficus religiosa          | 40.07                               | 16.91                                 | 45.11                                       |

Figure 2. Oxygen production potential (mt) in different states of India.

The oxygen production potential of the top ten tree species from forests ranged from 63.48 mt (Picea smithiana) to 657.87 mt (Shorea robusta). For trees outside forest (TOF), Mangifera indica (214.39 mt) had the highest oxygen potential, followed by Azadirachta indica (154.46 mt), Borassus flabellifer and Madhuca latifolia (Table 1). M. indica (mango) is considered as the ‘King of fruits’ and is commercially cultivated in the tropical regions of the world. However, A. indica (neem) is considered a versatile tree species, which is distributed throughout India. It is both a naturally grown and cultivated species on roadsides, field boundaries and associated with rituals.

Agroforestry is gaining importance for expanding greeneries and increasing tree cover outside the forests. It is considered as ‘low hanging fruit’ due to its various outputs of both tangible and intangible benefits. Therefore, based on net carbon sequestration rate reported by various researchers, the most prominent agroforestry tree species were chosen to calculate the oxygen production potential (Table 2). In India, Populus deltoides and Eucalyptus tereticornis are widely cultivated due to their importance in pulp and paper production and sustainable wood supply. Both these fast-growing trees have high oxygen production potential around 33 tonnes ha⁻¹ yr⁻¹. The net oxygen production rate ranges from 1.04 to 34.15 tonnes ha⁻¹ yr⁻¹. Again this depends on location, number of trees, diameter distribution, annual timber increment, tree health, age and management techniques.

Bamboo is one of the fast-growing multipurpose species widely adapted to different climatic conditions, comprising 125 indigenous species and 11 exotic species. It also releases 35% more oxygen than an equivalent volume of other trees. Nath et al. compiled numerous published information and reported average biomass of bamboo as 124 tonnes ha⁻¹ (with a range 60–242 tonnes ha⁻¹). They also found that mean carbon storage and sequestration rate ranged from 30 to 121 Mg ha⁻¹ and 6 to 16 Mg ha⁻¹ yr⁻¹ respectively. This highlights that bamboo has a huge potential to capture CO₂ and produce more oxygen than other tree species. It is considered as a major oxygen...
Table 2. Net oxygen production rate (tonnes ha\(^{-1}\) yr\(^{-1}\)) of important agroforestry tree species in India

| Species               | Age (yr) | Tree density (trees ha\(^{-1}\)) | Net carbon sequestration rate (tonnes ha\(^{-1}\) yr\(^{-1}\)) | Net oxygen production rate (tonnes ha\(^{-1}\) yr\(^{-1}\)) | Reference |
|-----------------------|----------|----------------------------------|---------------------------------------------------------------|------------------------------------------------------------|-----------|
| *Populus deltoides*   | 8        | 500                              | 12.61                                                         | 33.67                                                      | 11        |
| *Eucalyptus tereticornis* | 8        | 1111                             | 12.79                                                         | 34.15                                                      | 11        |
| *Dalbergia sissoo*    | 14       | 312                              | 2.15                                                          | 5.74                                                       | 12        |
| *T. grandis*          | 15       | 2500                             | 5.42                                                          | 14.47                                                      | 13        |
| *Melia spp.*          | 10       | 640                              | 3.94                                                          | 10.52                                                      | 14        |
| *Terminalia arjuna*   | 10       | 690                              | 9.54                                                          | 25.47                                                      | 15        |
| *Pongamia pinnata*    | 8        | 258                              | 2.75                                                          | 7.34                                                       | 15        |
| *Alnus nepalensis*    | 21       | 458                              | 4.68                                                          | 12.50                                                      | 16        |
| *Dendrocalamus strictus* | 20       | 100                              | 5.46                                                          | 14.59                                                      | 17        |
| *M. indica*           | 10       | 400                              | 0.38                                                          | 1.03                                                       | 18        |
| *Prosopis cineraria*  | 19       | 45                               | 0.46                                                          | 1.24                                                       | 19        |
| *Casuarina equisetifolia* | 20       | 1600                             | 9.30                                                          | 24.83                                                      | 20        |
| *Embelica officinalis* | 12       | 100                              | 0.47                                                          | 1.25                                                       | 21        |

Net carbon sequestration rate alone has been taken from the above-mentioned references.

Table 3. Baseline oxygen production (mt) and annual oxygen production (mt yr\(^{-1}\)) from bamboo resources in India

| Bamboo                | Green weight of bamboo* (A) | Dry biomass** (B = A × 0.45) | Carbon storage (C = B × 0.50) | Oxygen production potential (D = C × 2.67) |
|-----------------------|-----------------------------|------------------------------|-------------------------------|----------------------------------------|
| **Baseline oxygen production potential from bamboo** |                           |                              |                               |                                        |
| Reserve Forest        | 277.59                      | 124.91                       | 62.46                         | 166.76                                 |
| TOF                   | 19.73                       | 8.88                         | 4.44                          | 11.85                                  |
| **Total**             | 297.32                      | 133.79                       | 66.90                         | 178.61                                 |
| **Annual oxygen production potential from bamboo** |                           |                              |                               |                                        |
| Reserve Forest        | 88.83                       | 39.97                        | 19.99                         | 53.36                                  |
| TOF                   | 2.32                        | 1.04                         | 0.52                          | 1.39                                   |
| **Total (difference of 2017 and 2019)** |                           | 41.02                        | 20.51                         | 54.76                                  |
| Per year              | 45.57                       | 20.51                        | 10.25                         | 27.38                                  |

*Bamboo resources of India, ISFR*. **Factor of dry matter content in bamboo**

source and an ‘Oxygen Park’ of bamboo has been established at Tamil Nadu Agricultural University (TNAU), Coimbatore. A fully grown bamboo species generates 300 kg of oxygen every year per person\(^2\). The calculated oxygen production potential of bamboo was 178.61 mt, both from Reserve Forest and TOF in India, whereas oxygen production potential per year was 53.36 mt from Reserve Forests and 1.39 mt from TOF respectively. However, annual production of oxygen from bamboo was 27.38 mt yr\(^{-1}\) (Table 3).

Holistically, the emerging oxygen crisis and increasing CO\(_2\) concentration is a common phenomenon all over the world. In order to mitigate this, the focus must be shifted to encourage the proportion of urban vegetation coverage. Moreover, after the initiation of the Millenium Development Goals, several efforts are also made to quantify the services provided by tree species.

1. Affék, A. et al., Potentials to provide ecosystem services – analytical approach. In Ecosystem Service Potentials and their Indicators in Postglacial Landscapes, Elsevier, 2020, pp. 133–289; doi:10.1016/b978-0-12-816134-0.00006-7.
2. Beer, C. et al., Terrestrial gross carbon dioxide uptake: global distribution and covariation with climate. Science, 2010, 329, 834–838.
3. Global Forest Resource Assessment. 2020; http://www.fao.org/forest-resources-assessment/2020/en/ (accessed on 19 April 2020).
4. FSI, Indian State of Forest Report. Forest Survey of India, Dehradun, 2019.
5. FSI, Indian State of Forest Report. Forest Survey of India, Dehradun, 2017.
6. Zhang, L. J., Li, W. L., Jiang, C. Y. and Zang, S. Y., Examining the century dynamic change of forest oxygen production in Heilongjiang Province, China. Int. J. Environ. Sci. Technol., 2015, 12(12), 4005–4016.
7. Ma, J. Y., Yin, K. and Lin, T., Analysis of the carbon and oxygen balance of a complex urban ecosystem: a case study in the coastal city of Xiamen. Acta Sci. Circumst., 2011, 31(8), 1808–1816.
8. Chen, B. and Shan, L., Valuing ecological services of green space of West Lake scenic area in Hangzhou. J. Zhejiang Univ. Agric. Life Sci., 2009, 35(6), 686–690.
9. Nowak, D. J., Hoehn, R. and Crane, D. E., Oxygen production by urban trees in the United States. Arboricult. Urban For., 2007, 33(3), 220–226.
10. Chavan, S. B. et al., National Agroforestry Policy in India: a low hanging fruit. Curr. Sci., 2015, 108(10), 1826–1834.
11. Chavan, S. B., Modelling biomass and carbon sequestration potential in poplar (*Populus deltoides*) and eucalypts (*Eucalyptus tereticornis*) based agroforestry systems. Ph.D. thesis submitted to Chaudhary Charan Singh Haryana Agricultural University, Hisar, 2019.
12. Newaj, R., Chavan, S. B., Badre Alam and Dhyani, S. K., Biomass and carbon storage in trees grown under different agroforestry
systems in semi-arid region of central India. Indian For., 2016, 142(7), 642–648.
13. Jain, A. and Ansari, S. A., Quantification by allometric equations of carbon sequestered by Tectona grandis in different agroforestry systems. J. For. Res., 2013, 24(4), 699–702.
14. Chauhan, S. K., Singh, S., Sharma, S., Sharma, R. and Saralch, H. S., Tree biomass and carbon sequestration in four short rotation tree plantations. Range Manage. Agrofor., 2019, 40(1), 77–82.
15. Sen, T. and Chauhan, S. K., Biomass partitioning and carbon storage in short rotation tree species. In ISTS-IUFRO Conference on Sustainable Resource Management for Climate Change Mitigation and Social Security, Chandigarh, 2014.
16. Devi, B. et al., Carbon allocation, sequestration and carbon dioxide mitigation under plantation forests of north western Himalaya, India. Ann. For. Res., 2013, 56(1), 123–135.
17. Kaushal, R. et al., Predictive models for biomass and carbon stock estimation in male bamboo (Dendrocalamus strictus L.) in Doon valley, India. Acta Ecol. Sin., 2016, 36(6), 469–476.
18. Naik, S. K., Sarkar, P. K., Das, B., Singh, A. K. and Bhatt, B. P., Biomass production and carbon stocks estimate in mango orchards of hot and sub-humid climate in eastern region, India. Carbon Manage., 2019, 10(5), 477–487.
19. Tanwar, S. P. S. et al., Carbon sequestration potential of agroforestry systems in the Indian arid zone. Curr. Sci., 2019, 117(12), 2014.
20. Madhusudanan, S., Patil, N. S., Jha, S. and Aneesh, S., Short rotation forestry as a viable option for GHG mitigation. Indian J. Ecol., 2011, 38(Spec. Issue), 15–19.
21. Chavan, S. B. et al., Trees for life: creating sustainable livelihood in Bundelkhand region of central India. Curr. Sci., 2016, 111(6), 994–1002.
22. Siraj, M. A., 2014; https://www.thehindu.com/features/homes-and-gardens/green-living/bamboo-power/article5900988.ece (accessed on 12 May 2021).
23. Nath, A. J., Lal, R. and Das, A. K., Managing woody bamboos for carbon farming and carbon trading. Global Ecol. Conserv., 2015, 3, 654–663.
24. The Hindu, 2019; https://www.thehindubusinessline.com/news/national/oxygen-park-with-beema-bamboo-established-at-tnau/article30123754.ece
25. Banik, R. L., Growth, behaviour and silviculture of bamboos. In Bamboos in India (eds Kaushik, S. et al.), ENVIS Centre on Forestry, National Forest Library and Information Centre, Forest Research Institute, Dehradun, 2015.

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