STUDY OF THE STORED CARBON IN AGE-WISE PLANTATIONS IN THE SOUTH BENGAL FOREST DIVISIONS

PROJECT FUNDED UNDER GREEN INDIA MISSION

OFFICE OF THE PRINCIPAL CHIEF CONSERVATOR OF FOREST
(RESEARCH, MONITORING AND DEVELOPMENT)
DEPARTMENT OF FOREST,
GOVERNMENT OF WEST BENGAL

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PREFACE

In the present *era*, people are taking multi-dimensional actions that are gradually changing the morphology, physiology, and anatomy of the planet Earth and its climate in large scale. The single human activity that is most likely to have a large impact on the climate is the burning of "fossil fuels" such as coal, oil and natural gas. These fuels contain carbon. Burning them liberates carbon dioxide gas in the atmosphere. Since the early 1800s, when people started burning large amounts of coal and oil, the amount of carbon dioxide in the earth's atmosphere has increased by nearly 30%, and average global temperature appears to have risen between 1° and 2°F. Forest vegetations can serve as an effective escape route from such situations owing to their ability to scrub carbon dioxide for carrying out photosynthesis.

The forests of South Bengal divisions dominated by Akashmoni, Eucalyptus and Sal are potential sink of carbon. When lost or destroyed, they not only shut down the process of sequestering carbon, but also release their deposits of carbon and become new sources of carbon emissions which can last for centuries. Recent scientific syntheses have documented the global total estimated emissions from degraded and converted forest ecosystems each year at between 300 and 900 million tonnes of carbon dioxide. Considering this alarming bell, a research programme entitled "….**STUDY OF THE STORED CARBON IN AGE-WISE PLANTATIONS IN THE SOUTH BENGAL FOREST DIVISIONS**…." was initiated by the Office of the PCCF (Research, Monitoring and Development) on and from 17th March, 2022. The focal theme of the project is to evaluate the age-wise carbon sequestration potential of the plantations of Quick Growing Species (QGS) and Sal under South Bengal Forest Divisions in the state of West Bengal.

The Office of the PCCF (Research, Monitoring and Development) acknowledges the sincere efforts given by Dr. Abhijit Mitra, Director, Research (Hony), Techno India University, West Bengal and his team members along with all the officers and staffs of the West Bengal Forest Department for their contributions in completing the project.

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List of acronyms

AGB	Above Ground Biomass
AGC	Above Ground Carbon
ARD	Afforestation, Reforestation and Deforestation
BGB	Below Ground Biomass
CFC	Chlorofluorocarbons
COP	Conference of the Parties
GHGs	Green House Gases
GPP	Gross Primary Production
GPS	Global Positioning System
HFCs	Hydrofluorocarbons
KP	Kyoto Protocol
NBP	Net Biome Productivity
NEP	Net Ecosystem Productivity
NPP	Net Primary Productivity
PFCs	Perfluorocarbons
PGPR	Plant Growth Promoting Rhizobacteria
PPMV	Parts Per Million Volume
QGS	Quick Growing Species
SF6	Sulphur hexafluoride
SOC	Soil Organic Carbon
UNEP	United Nations Environment Programme
UNFCCC	United Nations Framework Convention on Climate Change

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A. Executive Summary

1) Climate change is a bitter truth of the present century which has cropped up mostly due to man-made sourced GHG emissions. The rapid pace of industrialization, urbanization and change of land use pattern has resulted in an exponential rise of carbon dioxide level in the near surface atmosphere of the planet Earth.

2) There are various roadmaps to reduce the levels of GHGs in the atmosphere like use of non-conventional energy, switching over to green energy sector etc., but most of these routes are financially not suited to developing and under developed nations. Hence, scrubbing carbon dioxide from the atmosphere through plantations / forest vegetation is a cost-effective method to retard the pace of carbon dioxide rise in the atmosphere.

3) The producer community of the planet Earth is a potential sink of carbon dioxide as they are capable of photosynthesis in which atmospheric carbon dioxide is locked in the form of glucose / starch in almost zero-cost except that which are spent for plantation and maintenance of the planted floral species. Carbon is stored in five pools, namely above-ground biomass (AGB), below-ground biomass (BGB), leaf litter, dead wood and soil carbon stock in forest ecosystems. Below-ground biomass is an important carbon pool for many vegetation types and land-use systems and accounts for about 20% to 26% of the total biomass. The greatest proportion of root biomass occurs in the top 30 cm of the soil surface. Revegetation of degraded land leads to continual accumulation of below-ground biomass, whereas any disturbance to topsoil leads to loss of below-ground biomass.

In this project we have estimated species-wise and age-wise AGB, AGC, BGB (using empirical formula), sequestered carbon (based on AGC and age of the species), CO_2 – equivalent, soil organic carbon (SOC), soil pH and CO_2 level in the ambient air of the plantation sites.

4) Carbon dioxide absorption by the floral species depends on several components like edaphic factors, age, management of the planted species, water availability, weather / climate, pest attack *etc*. The absorption varies with age and hence the present project has assessed the age-wise stored carbon in the Above Ground Biomass (AGB) and Below Ground Biomass (BGB) of two Quick Growing Species (QGS) of South Bengal planted by the West Bengal Forest Department namely Akashmoni and Eucalyptus along with

Sal. The work was carried out in four major divisions of South Bengal namely Bankura North, Durgapur, Burdwan and Birbhum during March, 2022. The carbon stored in the root could not be estimated through direct field based survey as there was no provision for uprooting. We estimated the BGB of the selected species on the basis of AGB values as per the standard method (*https://www.climate-policy-watcher.org/carbon-stocks/grass-biomass-production-above-the-ground.html*).

5) Few relevant abiotic parameters like near surface atmospheric carbon dioxide, soil pH and soil organic carbon (SOC) were also estimated simultaneously to evaluate the role of floral species on the ambient abiotic parameters.

6) A total of 90 plots were monitored in the plantation sites of QGS and Sal in the above stated four divisions (Tables A – D).

Table A. Plots covered for the QGS and Sal in Bankura North division

Age of Plantation	Plantation	Range	Beat	Location	Area (ha)	No. of study plots
9 year	QGS - Akashmoni	Bankura (North)	Kanchanpur	Bahadurpur	20	8
9 year	Sal	Bankura (North)	Salboni	Gajrabari-28	1	1
5 year	QGS - Eucalyptus	Bankura (North)	Salboni	Gajrabari-28	15	6
5 year	QGS - Akashmoni	Bankura (North)	Kanchanpur	Ekchala-91	5	2
5 year	QGS - Akashmoni	Beliatore	Beliatore	Rajganj Madhabpur-124	10	4
1 year	QGS - Akashmoni	Bankura (North)	Kanchanpur	Kanchanpur-245	10	3
1 year	Sal	Beliatore	Beliatore	Ramchandrapur-129	9	3
Total						27

Table B. Plots covered for the QGS and Sal in Durgapur division

Age of Plantation	Plantation	Range	Beat	Location	Area (ha)	No. of study plots
9 year	QGS – Akashmoni	Ukhra	Fuljhore	Jemua, Paranganj	25	9
5 year	QGS – Akashmoni	Ukhra	Fuljhore	Jemua, Paranganj	25	9
Total						18

Table C. Plots covered for the QGS and Sal in Burdwan division

Age of Plantation	Plantation	Range	Beat	Location	Area (ha)	No. of study plots
9 year	Sal	Panagarh	Sonai	Bilaspur	10	3
9 year	Sal, QGS – Akashmoni & Eucalyptus	Panagarh	Sonai	Shyamsundarpur	5	2
9 year	Sal, QGS - Eucalyptus	Panagarh	Aduria	Fari Jungle	54	10
9 year	QGS- Akashmoni & Eucalyptus	Panagarh	Khandari	Khandari	10	2
5 year	QGS - Akashmoni	Panagarh	Aduria	Jalikandar-11	20	2
5 year	Sal, QGS - Akashmoni	Panagarh	Aduria	Chhora-6	20	4
5 year	QGS - Akashmoni	Panagarh	Khandari	Khandari	10	2
5 year	QGS	Panagarh	Sonai	Bilaspur	10	2
1 year	QGS - Akashmoni	Panagarh	Sonai	Paduma-69	7	2
1 year	QGS - Akashmoni	Panagarh	Sonai	jijira-68	11	4
1 year	QGS - Akashmoni	Panagarh	Khandari	Moukota-12	10	2
1 year	QGS - Akashmoni	Panagarh	Aduria	Bhuera 7	10	2
1 year	Sal	Panagarh	Aduria	Bhuera-7	10	2
Total						39

Table D. Plots covered for the QGS and Sal in Birbhum

Age of Plantation	Plantation	Range	Beat	Location	Area (ha)	No. of study plots
9 year	QGS	Bolpur	Bolpur	Faridpur (Nachansha)	10	3
9 year	QGS	Bolpur	Bolpur	Ballavpur	10	3
Total						6

7) The stored carbon in all the selected floral species exhibited significant spatial variation with highest value in Bankura (North) division followed by Birbhum division, Burdwan division and Durgapur division. This trend was observed in the floral species of all age groups of 1-year, 5-year and 9-year old plantations, irrespective of the species.

8) The soil is a potential reservoir of carbon and plays a major role in the carbon dynamics of the ecosystem. The litter and detritus contributed by the forest vegetation add organic carbon to the soil, while decomposers present in the soil compartment return the carbon to the atmosphere in the form of carbon dioxide. In the present study, the average soil organic carbon for **9-year old plantation** of **Akashmoni forest habitat** varied as per the order Bankura North (1.48 %) > Birbhum (1.39 %) > Burdwan (1.27 %) > Durgapur (1.15 %); the average soil organic carbon in **Eucalyptus forest habitat** varied as per the order Birbhum (1.28 %) > Burdwan (1.23 %) for the same age group and the average soil organic carbon in **Sal forest habitat** varied as per the order Bankura North (1.57 %) > Burdwan (1.32 %) for the same age group.

9) The average soil organic carbon for **5-year old plantation** of **Akashmoni forest habitat** varied as per the order Bankura North (1.37 %) > Burdwan (1.17 %) > Durgapur (1.08 %); the average soil organic carbon in **Eucalyptus forest habitat** under Bankura North was 1.13 % for the same age group and the average soil organic carbon in **Sal forest habitat** under Burdwan was 1.29 % for the same age group. It needs to be stated here that all the species were not available in the selected spots of the South Bengal forest divisions.

10) The average soil organic carbon for **1-year old plantation** of **Akashmoni forest habitat** varied as per the order Bankura North (0.96 %) > Burdwan (0.91 %) > and the average soil organic carbon in **Sal forest habitat** varied as per the order Bankura North (0.99 %) > Burdwan (0.96 %) for the same age group.

11) The SOC for the age group 9–year old plantations is maximum followed by 5-year and 1-year old plantations. It is crystal clear from the SOC data, that Sal contributes maximum to soil carbon data compared to other two species. Also it is interesting to note that SOC below eucalyptus vegetation exhibited the lowest value, which may be attributed to extremely slow rate of decomposition of the eucalyptus vegetative parts. Significant positive correlations are observed between AGB, BGB and SOC in plantations of all age groups, thus confirming the positive role/contribution of the plant biomass to SOC.

12) The soil pH plays a crucial role in the growth and survival of floral species. In the present study, the average soil pH for **9-year old plantation** of **Akashmoni forest habitat** varied as per the order Durgapur (6.30) > Burdwan (6.26) > Birbhum (6.20) > Bankura North (6.16); the average soil pH in **Eucalyptus forest habitat** Burdwan (6.34) > Birbhum (6.25) for the same age group and the average soil pH in **Sal forest habitat** varied as per the order Burdwan (6.24) > Bankura North (6.12) for the same age group.

13) The average soil pH for **5-year old plantation** of **Akashmoni forest habitat** varied as per the order Durgapur (6.74) > Burdwan (6.63) > Bankura North (6.50); the average soil pH in **Eucalyptus forest habitat** under Bankura North was 6.57 for the same age group and the average soil pH in **Sal forest habitat** under Burdwan was 6.60 for the same age group.

14) The average soil pH for **1-year old plantation** of **Akashmoni forest habitat** varied as per the order Burdwan (6.80) > Bankura North (6.70) and the average soil pH in **Sal forest habitat** varied as per the order Burdwan (6.76) > Bankura North (6.68) for the same age group.

15) The soil pH of the age group 1-year is maximum followed by 5-year and 9-year old plantation, irrespective of the species. Also significant negative correlations are observed between Soil pH and SOC in plantations of all age groups.

16) In the **9-year old plantation** of **Bankura North Division**, the **AGB of Akashmoni** in Bahadurpur under Kanchanpur Beat in Bankura North range (23°18′11.3″N; 87°06′39.0″E) was 204.937 tha^{-1}; in Gajrabari under Salboni Beat in Bankura North range (23°18′17.3″N; 87°01′24.0″E) the value of **AGB in Sal** was 233.945 tha^{-1}.

17) In the **9-year old plantation** of **Bankura North Division**, the **AGC of Akashmoni** in Bahadurpur under Kanchanpur Beat in Bankura North range (23°18′11.3″N; 87°06′39.0″E) was 90.324 tha^{-1}; in Gajrabari under Salboni Beat in Bankura North range (23°18′17.3″N; 87°01′24.0″E) the value of **AGC in Sal** was 109.041 tha^{-1}.

18) In the **9-year old plantation** of **Bankura North Division**, the **BGB of Akashmoni** in Bahadurpur under Kanchanpur Beat in Bankura North range (23°18′11.3″N;

87°06′39.0″E) was 53.284 tha^{-1}; in Gajrabari under Salboni Beat in Bankura North range (23°18′17.3″N; 87°01′24.0″E) the value of **BGB in Sal** was 60.826 tha^{-1}.

19) In the **9-year old plantation** of **Bankura North Division**, the **sequestered carbon in AGB of Akashmoni** in Bahadurpur under Kanchanpur Beat in Bankura North range (23°18′11.3″N; 87°06′39.0″E) was 10.036 $tha^{-1}y^{-1}$; in Gajrabari under Salboni Beat in Bankura North range (23°18′17.3″N; 87°01′24.0″E) the value of **sequestered carbon in** the **AGB of Sal** was 12.116 $tha^{-1}y^{-1}$.

20) In the **9-year old plantation** of **Bankura North Division**, the **CO_2-equivalent of Akashmoni** in Bahadurpur under Kanchanpur Beat in Bankura North range (23°18′11.3″N; 87°06′39.0″E) was 331.488 tha^{-1}; in Gajrabari under Salboni Beat in Bankura North range (23°18′17.3″N; 87°01′24.0″E) the value of **CO_2-equivalent of Sal** was 400.180 tha^{-1}.

21) In the **5-year old plantation** of **Bankura North Division**, the **AGB of Akashmoni** ranged from 85.695 tha^{-1} (Ekchala-91 under Kanchanpur Beat in Bankura North range; 23°21′41.7″N; 87°04′36.1″E) to 141.604 tha^{-1} (Raiganj Madhavpur under Beliatore Beat, Beliatore range; 23°19′33.5″N; 87°12′16.4″E); in Gajrabari under Salboni Beat in Bankura North range (23°18′20.3″N; 87°01′27.3″E), the value of **AGB in Eucalyptus** was 332.769 tha^{-1}.

22) In the **5-year old plantation** of **Bankura North Division**, the **AGC of Akashmoni** ranged from 37.624 tha^{-1} (Ekchala-91 under Kanchanpur Beat in Bankura North range; 23°21′41.7″N; 87°04′36.1″E) to 62.131 tha^{-1} (Raiganj Madhavpur under Beliatore Beat, Beliatore range; 23°19′33.5″N; 87°12′16.4″E); in Gajrabari under Salboni Beat in Bankura North range (23°18′20.3″N; 87°01′27.3″E), the value of **AGC in Eucalyptus** was 152.979 tha^{-1}.

23) In the **5-year old plantation** of **Bankura North Division**, the **BGB of Akashmoni** ranged from 22.281 tha^{-1} (Ekchala-91 under Kanchanpur Beat in Bankura North range; 23°21′41.7″N; 87°04′36.1″E) to 36.817 tha^{-1} (Raiganj Madhavpur under Beliatore Beat, Beliatore range; 23°19′33.5″N; 87°12′16.4″E); in Gajrabari under Salboni Beat in Bankura North range (23°18′20.3″N; 87°01′27.3″E), the value of **BGB in Eucalyptus** was 86.520 tha^{-1}.

24) In the **5-year old plantation** of **Bankura North Division**, the **sequestered carbon in AGB of Akashmoni** ranged from 7.525 tha^{-1}y^{-1} (Ekchala-91 under Kanchanpur Beat in Bankura North range; 23°21′41.7″N; 87°04′36.1″E) to 12.426 tha^{-1}y^{-1} (Raiganj Madhavpur under Beliatore Beat, Beliatore range; 23°19′33.5″N; 87°12′16.4″E); in Gajrabari under Salboni Beat in Bankura North range (23°18′20.3″N; 87°01′27.3″E) the value of **sequestered carbon in AGB in Eucalyptus** was 30.596 tha^{-1}y^{-1}.

25) In the **5-year old plantation** of **Bankura North Division**, the **CO_2-equivalent of Akashmoni** ranged from 138.079 tha^{-1} (Ekchala-91 under Kanchanpur Beat in Bankura North range; 23°21′41.7″N; 87°04′36.1″E) to 228.021 tha^{-1} (Raiganj Madhavpur under Beliatore Beat, Beliatore range; 23°19′33.5″N; 87°12′16.4″E); in Gajrabari under Salboni Beat in Bankura North range (23°18′20.3″N; 87°01′27.3″E) the value of **CO_2-equivalent in Eucalyptus** was 561.434 tha^{-1}.

26) In the **1-year old plantation** of **Bankura North Division**, the **AGB of Akashmoni** in Kanchanpur-245 under Kanchanpur Beat in Bankura North range (23°17′58.0″N; 87°05′55.2″E) was 3.439 tha^{-1}; in Ramchandrapur-129 under Beliatore Beat in Beliatore range (23°18′46.1″N; 87°12′05.5″E) the value of **AGB in Sal** was 4.043 tha^{-1}.

27) In the **1-year old plantation** of **Bankura North Division**, the **AGC of Akashmoni** in Kanchanpur-245 under Kanchanpur Beat in Bankura North range (23°17′58.0″N; 87°05′55.2″E) was 1.554 tha^{-1}; in Ramchandrapur-129 under Beliatore Beat in Beliatore range (23°18′46.1″N; 87°12′05.5″E) the value of **AGC in Sal** was 1.973 tha^{-1}.

28) In the **1-year old plantation** of **Bankura North Division**, the **BGB of Akashmoni** in Kanchanpur-245 under Kanchanpur Beat in Bankura North range (23°17′58.0″N; 87°05′55.2″E) was 0.791 tha^{-1}; in Ramchandrapur-129 under Beliatore Beat in Beliatore range (23°18′46.1″N; 87°12′05.5″E) the value of **BGB in Sal** was 0.930 tha^{-1}.

29) In the **1-year old plantation** of **Bankura North Division**, the **sequestered carbon in Akashmoni** in Kanchanpur-245 under Kanchanpur Beat in Bankura North range (23°17′58.0″N; 87°05′55.2″E) was 1.554 tha^{-1}y^{-1}; in Ramchandrapur-129 under Beliatore Beat in Beliatore range (23°18′46.1″N; 87°12′05.5″E) the value of **sequestered carbon in Sal** was 1.973 tha^{-1}y^{-1}.

30) In the **1-year plantation** of **Bankura North Division**, the **CO_2-equivalent of Akashmoni** in Kanchanpur-245 under Kanchanpur Beat in Bankura North range

(23°17′58.0″N; 87°05′55.2″E) was 5.704 tha^{-1}; in Ramchandrapur-129 under Beliatore Beat in Beliatore range (23°18′46.1″N; 87°12′05.5″E) the value of **CO_2-equivalent in Sal** was 7.242 tha^{-1}.

31) In the **9-year old plantation** of **Durgapur Division**, the **AGB of Akashmoni** in Jemua Paranganj under Fuljhore Beat in Ukhra range (23°33′32.1″N; 87°21′38.9″E) was 141.644 tha^{-1}.

32) In the **9-year old plantation** of **Durgapur Division**, the **AGC of Akashmoni** in Jemua Paranganj under Fuljhore Beat in Ukhra range (23°33′32.1″N; 87°21′38.9″E) was 65.843 tha^{-1}.

33) In the **9-year old plantation** of **Durgapur Division**, the **BGB of Akashmoni** in Jemua Paranganj under Fuljhore Beat in Ukhra range (23°33′32.1″N; 87°21′38.9″E) was 36.828 tha^{-1}.

34) In the **9-year old plantation** of **Durgapur Division**, the **sequestered carbon in AGB of Akashmoni** in Jemua Paranganj under Fuljhore Beat in Ukhra range (23°33′32.1″N; 87°21′38.9″E) was 7.316 tha^{-1}y^{-1}.

35) In the **9-year old plantation** of **Durgapur Division**, the **CO_2-equivalent of Akashmoni** in Jemua Paranganj under Fuljhore Beat in Ukhra range (23°33′32.1″N; 87°21′38.9″E) was 241.645 tha^{-1}.

36) In the **5-year old plantation** of **Durgapur Division**, the **AGB of Akashmoni** in Jemua Paranganj under Fuljhore Beat in Ukhra range (23°33′49.0″N; 87°20′23.3″E) was 48.454 tha^{-1}.

37) In the **5-year old plantation** of **Durgapur Division**, the **AGC of Akashmoni** in Jemua Paranganj under Fuljhore Beat in Ukhra range (23°33′49.0″N; 87°20′23.3″E) was 22.395 tha^{-1}.

38) In the **5-year old plantation** of **Durgapur Division**, the **BGB of Akashmoni** in Jemua Paranganj under Fuljhore Beat in Ukhra range (23°33′49.0″N; 87°20′23.3″E) was 12.598 tha^{-1}.

39) In the **5-year old plantation** of **Durgapur Division**, the **sequestered carbon in AGB of Akashmoni** in Jemua Paranganj under Fuljhore Beat in Ukhra range (23°33′49.0″N; 87°20′23.3″E) was 4.479 tha^{-1}y^{-1}.

40) In the **5-year old plantation** of **Durgapur Division**, the **CO_2-equivalent of Akashmoni** in Jemua Paranganj under Fuljhore Beat in Ukhra range (23°33′49.0″N; 87°20′23.3″E) was 82.188 tha^{-1}.

41) In the **9-year old plantation** of **Burdwan Division**, the **AGB of Akashmoni** ranged from 161.656 tha^{-1} (in Khandari under Khandari Beat in Panagarh range; 23°27′07.5″N; 87°31′53.1″E) to 220.532 tha^{-1} (in Shyamsundarpur under Sonai Beat in Panagarh range; 23°28′41.5″N; 87°30′09.4″E); in **Eucalyptus the AGB** ranged from 274.115 tha^{-1} (in Shyamsundarpur under Sonai beat in Panagarh range; 23°28′41.5″N; 87°30′09.4″E) to 379.952 tha^{-1} (in Khandari under Khandari beat in Panagarh range; 23°27′07.5″N; 87°31′53.1″E); in **Sal the AGB** value ranged from 187.696 tha^{-1} (in Bilaspur under Sonai beat in Panagarh range; 23°28′25.1″N; 87°29″E) to 285.177 tha^{-1} (in Fari jungle under Adhuria beat in Panagarh range; 23°33′09.8″N; 87°32′16.9″E).

42) In the **9-year old plantation** of **Burdwan Division**, the **AGC of Akashmoni** ranged from 74.820 tha^{-1} (in Khandari under Khandari Beat in Panagarh range; 23°27′07.5″N; 87°31′53.1″E) to 102.346 tha^{-1} (in Shyamsundarpur under Sonai Beat in Panagarh range; 23°28′41.5″N; 87°30′09.4″E); in **Eucalyptus the AGC** ranged from 125.715 tha^{-1} (in Shyamsundarpur under Sonai beat in Panagarh range; 23°28′41.5″N; 87°30′09.4″E) to 174.067 tha^{-1} (in Khandari under Khandari beat in Panagarh range; 23°27′07.5″N; 87°31′53.1″E); in **Sal the AGC** value ranged from 86.749 tha^{-1} (in Bilaspur under Sonai beat in Panagarh range; 23°28′25.1″N; 87°29″E) to 132.041 tha^{-1} (in Fari jungle under Adhuria beat in Panagarh range; 23°33′09.8″N; 87°32′16.9″E).

43) In the **9-year old plantation** of **Burdwan Division**, the **BGB of Akashmoni** ranged from 42.030 tha^{-1} (in Khandari under Khandari Beat in Panagarh range; 23°27′07.5″N; 87°31′53.1″E) to 57.338 tha^{-1} (in Shyamsundarpur under Sonai Beat in Panagarh range; 23°28′41.5″N; 87°30′09.4″E); in **Eucalyptus the BGB** ranged from 71.270 tha^{-1} (in Shyamsundarpur under Sonai beat in Panagarh range; 23°28′41.5″N; 87°30′09.4″E) to 98.788 tha^{-1} (in Khandari under Khandari beat in Panagarh range; 23°27′07.5″N; 87°31′53.1″E); in **Sal the BGB** value ranged from 48.801 tha^{-1} (in Bilaspur under Sonai beat in Panagarh range; 23°28′25.1″N; 87°29″E) to 74.146 tha^{-1} (in Fari jungle under Adhuria beat in Panagarh range; 23°33′09.8″N; 87°32′16.9″E).

44) In the **9-year old plantation** of **Burdwan Division**, the **sequestered carbon in AGB of Akashmoni** ranged from 8.313 $tha^{-1}y^{-1}$ (in Khandari under Khandari Beat in Panagarh range; 23°27′07.5″N; 87°31′53.1″E) to 11.372 $tha^{-1}y^{-1}$ (in Shyamsundarpur under Sonai Beat in Panagarh range; 23°28′41.5″N; 87°30′09.4″E); in **Eucalyptus the sequestered carbon in AGB** ranged from 13.968 $tha^{-1}y^{-1}$ (in Shyamsundarpur under Sonai beat in Panagarh range; 23°28′41.5″N; 87°30′09.4″E) to 19.341 $tha^{-1}y^{-1}$ (in Khandari under Khandari beat in Panagarh range; 23°27′07.5″N; 87°31′53.1″E); in **Sal the sequestered carbon in AGB** value ranged from 9.639 $tha^{-1}y^{-1}$ (in Bilaspur under Sonai beat in Panagarh range; 23°28′25.1″N; 87°29″E) to 14.671 $tha^{-1}y^{-1}$ (in Fari jungle under Adhuria beat in Panagarh range; 23°33′09.8″N; 87°32′16.9″E).

45) In the **9-year old plantation** of **Burdwan Division**, the **CO_2-equivalent of Akashmoni** ranged from 274.588 tha^{-1} (in Khandari under Khandari Beat in Panagarh range; 23°27′07.5″N; 87°31′53.1″E) to 375.610 tha^{-1} (in Shyamsundarpur under Sonai Beat in Panagarh range; 23°28′41.5″N; 87°30′09.4″E); in **Eucalyptus the CO_2-equivalent** ranged from 461.374 tha^{-1} (in Shyamsundarpur under Sonai beat in Panagarh range; 23°28′41.5″N; 87°30′09.4″E) to 638.824 tha^{-1} (in Khandari under Khandari beat in Panagarh range; 23°27′07.5″N; 87°31′53.1″E); in **Sal the CO_2-equivalent** value ranged from 318.370 tha^{-1} (in Bilaspur under Sonai beat in Panagarh range; 23°28′25.1″N; 87°29″E) to 484.589 tha^{-1} (in Fari jungle under Adhuria beat in Panagarh range; 23°33′09.8″N; 87°32′16.9″E).

46) In the **5-year old plantation** of **Burdwan Division**, the **AGB of Akashmoni** ranged from 66.171 tha^{-1} (in Chhora under Adhuria Beat in Panagarh range; 23°34′58.5″N; 87°34′27.6″E) to 88.169 tha^{-1} (in Khandari under Khandari Beat in Panagarh range; 23°27′17.1″N; 87°30′58.9″E); in Chhora under Adhuria beat in Panagarh range (23°34′58.5″N; 87°34′27.6″E), the value of **AGB in Sal** was 116.341 tha^{-1}.

47) In the **5-year old plantation** of **Burdwan Division**, the **AGC of Akashmoni** ranged from 30.323 tha^{-1} (in Chhora under Adhuria Beat in Panagarh range; 23°34′58.5″N; 87°34′27.6″E) to 40.572 tha^{-1} (in Khandari under Khandari Beat in Panagarh range; 23°27′17.1″N; 87°30′58.9″E); in Chhora under Adhuria beat in Panagarh range (23°34′58.5″N; 87°34′27.6″E), the value of **AGC in Sal** was 53.459 tha^{-1}.

48) In the **5-year old plantation** of **Burdwan Division**, the **BGB of Akashmoni** ranged from 17.204 tha^{-1} (in Chhora under Adhuria Beat in Panagarh range; 23°34′58.5″N; 87°34′27.6″E) to 22.924 tha^{-1} (in Khandari under Khandari Beat in Panagarh range; 23°27′17.1″N; 87°30′58.9″E); in Chhora under Adhuria beat in Panagarh range (23°34′58.5″N; 87°34′27.6″E), the value of **BGB in Sal** was 30.249 tha^{-1}.

49) In the **5-year old plantation** of **Burdwan Division**, the **sequestered carbon in AGB of Akashmoni** ranged from 6.065 $tha^{-1}y^{-1}$ (in Chhora under Adhuria Beat in Panagarh range; 23°34′58.5″N; 87°34′27.6″E) to 8.114 $tha^{-1}y^{-1}$ (in Khandari under Khandari Beat in Panagarh range; 23°27′17.1″N; 87°30′58.9″E); in Chhora under Adhuria beat in Panagarh range (23°34′58.5″N; 87°34′27.6″E), the value of **sequestered carbon in AGB in Sal** was 10.692 $tha^{-1}y^{-1}$.

50) In the **5-year old plantation** of **Burdwan Division**, the **CO_2-equivalent of Akashmoni** ranged from 111.286 tha^{-1} (in Chhora under Adhuria Beat in Panagarh range; 23°34′58.5″N; 87°34′27.6″E) to 148.898 tha^{-1} (in Khandari under Khandari Beat in Panagarh range; 23°27′17.1″N; 87°30′58.9″E); in Chhora under Adhuria beat in Panagarh range (23°34′58.5″N; 87°34′27.6″E), the value of **CO_2-equivalent in Sal** was 196.195 tha^{-1}.

51) In the **1-year old plantation** of **Burdwan Division**, the **AGB of Akashmoni** ranged from 2.255 tha^{-1} (in Jijira under Sonai Beat in Panagarh range; 23°30′35.2″N; 87°30′54.3″E) to 2.457 tha^{-1} (in Paduma under Sonai Beat in Panagarh range; 23°30′28.7″N; 87°30′19.5″E); in **Sal the AGB** value ranged from 2.387 tha^{-1} (in Paduma under Sonai Beat in Panagarh range; 23°30′28.7″N; 87°30′19.5″E) to 2.504 tha^{-1} (in Bhuera under Adhuria beat in Panagarh range; 23°33′17.0″N; 87°34′55.8″E).

52) In the **1-year old plantation** of **Burdwan Division**, the **AGC of Akashmoni** ranged from 1.087 tha^{-1} (in Jijira under Sonai Beat in Panagarh range; 23°30′35.2″N; 87°30′54.3″E) to 1.182 tha^{-1} (in Paduma under Sonai Beat in Panagarh range; 23°30′28.7″N; 87°30′19.5″E); in **Sal the AGC** value ranged from 1.170 tha^{-1} (in Paduma under Sonai Beat in Panagarh range; 23°30′28.7″N; 87°30′19.5″E) to 1.230 tha^{-1} (in Bhuera under Adhuria beat in Panagarh range; 23°33′17.0″N; 87°34′55.8″E).

53) In the **1-year old plantation** of **Burdwan Division**, the **BGB of Akashmoni** ranged from 0.496 tha^{-1} (in Jijira under Sonai Beat in Panagarh range; 23°30′35.2″N;

87°30′54.3″E) to 0.540 tha^{-1} (in Paduma under Sonai Beat in Panagarh range; 23°30′28.7″N; 87°30′19.5″E); in **Sal the BGB** value ranged from 0.525 tha^{-1} (in Paduma under Sonai Beat in Panagarh range; 23°30′28.7″N; 87°30′19.5″E) to 0.551 tha^{-1} (in Bhuera under Adhuria beat in Panagarh range; 23°33′17.0″N; 87°34′55.8″E).

54) In the **1-year old plantation** of **Burdwan Division**, the **sequestered carbon in AGB of Akashmoni** ranged from 1.087 $tha^{-1}y^{-1}$ (in Jijira under Sonai Beat in Panagarh range; 23°30′35.2″N; 87°30′54.3″E) to 1.182 $tha^{-1}y^{-1}$ (in Paduma under Sonai Beat in Panagarh range; 23°30′28.7″N; 87°30′19.5″E); in **Sal the sequestered carbon in AGB** value ranged from 1.170 $tha^{-1}y^{-1}$ (in Paduma under Sonai Beat in Panagarh range; 23°30′28.7″N; 87°30′19.5″E) to 1.230 $tha^{-1}y^{-1}$ (in Bhuera under Adhuria beat in Panagarh range; 23°33′17.0″N; 87°34′55.8″E).

55) In the **1-year old plantation** of **Burdwan Division**, the **CO_2-equivalent of AGB of Akashmoni** ranged from 3.990 tha^{-1} (in Jijira under Sonai Beat in Panagarh range; 23°30′35.2″N; 87°30′54.3″E) to 4.337 tha^{-1} (in Paduma under Sonai Beat in Panagarh range; 23°30′28.7″N; 87°30′19.5″E); in **Sal the CO_2-equivalent of AGB** value ranged from 4.293 tha^{-1} (in Paduma under Sonai Beat in Panagarh range; 23°30′28.7″N; 87°30′19.5″E) to 4.512 tha^{-1} (in Bhuera under Adhuria beat in Panagarh range; 23°33′17.0″N; 87°34′55.8″E).

56) In the **9-year old plantation** of **Birbhum Division**, the **AGB of Akashmoni** ranged from 174.455 tha^{-1} (in Ballavpur under Bolpur Beat in Bolpur range; 23°40′50.1″N; 87°39′08.1″E) to 213.589 tha^{-1} (in Faridpur under Bolpur Beat in Bolpur range; 23°41′44.1″N; 87°35′55.9″E).

57) In the **9-year old plantation** of **Birbhum Division**, the **AGC of Akashmoni** ranged from 80.379 tha^{-1} (in Ballavpur under Bolpur Beat in Bolpur range; 23°40′50.1″N; 87°39′08.1″E) to 98.434 tha^{-1} (in Faridpur under Bolpur Beat in Bolpur range; 23°41′44.1″N; 87°35′55.9″E).

58) In the **9-year old plantation** of **Birbhum Division**, the **BGB of Akashmoni** ranged from 45.358 tha^{-1} (in Ballavpur under Bolpur Beat in Bolpur range; 23°40′50.1″N; 87°39′08.1″E) to 55.533 tha^{-1} (in Faridpur under Bolpur Beat in Bolpur range; 23°41′44.1″N; 87°35′55.9″E).

59) In the **9-year old plantation** of **Birbhum Division**, the **sequestered carbon in AGB of Akashmoni** ranged from 8.931 $tha^{-1}y^{-1}$ (in Ballavpur under Bolpur Beat in Bolpur range; 23°40′50.1″N; 87°39′08.1″E) to 10.937 $tha^{-1}y^{-1}$ (in Faridpur under Bolpur Beat in Bolpur range; 23°41′44.1″N; 87°35′55.9″E).

60) In the **9-year old plantation** of **Birbhum Division**, the **CO_2-equivalent AGB of Akashmoni** ranged from 294.992 tha^{-1} (in Ballavpur under Bolpur Beat in Bolpur range; 23°40′50.1″N; 87°39′08.1″E) to 361.254 tha^{-1} (in Faridpur under Bolpur Beat in Bolpur range; 23°41′44.1″N; 87°35′55.9″E).

61) In the **9-year old plantation** of **Birbhum Division**, the **AGB of Eucalyptus** ranged from 216.371 tha^{-1} (in Ballavpur under Bolpur Beat in Bolpur range; 23°40′50.1″N; 87°39′08.1″E) to 467.922 tha^{-1} (in Faridpur under Bolpur Beat in Bolpur range; 23°41′44.1″N; 87°35′55.9″E).

62) In the **9-year old plantation** of **Birbhum Division**, the **AGC of Eucalyptus** ranged from 101.703 tha^{-1} (in Ballavpur under Bolpur Beat in Bolpur range; 23°40′50.1″N; 87°39′08.1″E) to 215.296 tha^{-1} (in Faridpur under Bolpur Beat in Bolpur range; 23°41′44.1″N; 87°35′55.9″E).

63) In the **9-year old plantation** of **Birbhum Division**, the **BGB of Eucalyptus** ranged from 56.256 tha^{-1} (in Ballavpur under Bolpur Beat in Bolpur range; 23°40′50.1″N; 87°39′08.1″E) to 121.660 tha^{-1} (in Faridpur under Bolpur Beat in Bolpur range; 23°41′44.1″N; 87°35′55.9″E).

64) In the **9-year old plantation** of **Birbhum Division**, the **sequestered carbon in AGB of Eucalyptus** ranged from 20.341 $tha^{-1}y^{-1}$ (in Ballavpur under Bolpur Beat in Bolpur range; 23°40′50.1″N; 87°39′08.1″E) to 43.059 $tha^{-1}y^{-1}$ (in Faridpur under Bolpur Beat in Bolpur range; 23°41′44.1″N; 87°35′55.9″E).

65) In the **9-year old plantation** of **Birbhum Division**, the **CO_2-equivalent AGB of Eucalyptus** ranged from 373.250 tha^{-1} (in Ballavpur under Bolpur Beat in Bolpur range; 23°40′50.1″N; 87°39′08.1″E) to 790.135 tha^{-1} (in Faridpur under Bolpur Beat in Bolpur range; 23°41′44.1″N; 87°35′55.9″E).

66) The data generated from 90 plots of South Bengal Forest Divisions in the state of West Bengal were analysed to evaluate the inter-relationships between sequestered carbon of each species, Soil Organic Carbon (SOC), soil pH and near surface atmospheric CO_2 level.

67) For all the species, **significant positive correlations were observed between sequestered carbon and the underlying SOC indicating considerable contribution of carbon of the trees to the soil compartment through litter and detritus**. The **significant negative relationships between sequestered carbon by the selected tree species and near surface atmospheric carbon dioxide confirm the potential of the trees as unique sink of carbon**. The sequestered carbon is taken from the CO_2 reservoir of the ambient atmosphere due which the negative correlations have been generated as the output.

68) ANOVA Computed for all the three species exhibited no significant differences ($p < 0.01$) between the divisions (Bankura North, Durgapur, Burdwan and Birbhum) and biotic parameters [age-wise AGB, AGC, BGB (using empirical formula), sequestered carbon (based on AGC and age of the species)] and CO_2 – equivalent. Total lack of plantation at some sites may be the cause for this anomalous result.

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B. Technical Contents

- ♣ **INTRODUCTION**
- ♣ **OBJECTIVES**
- ♣ **METHODOLOGY**
- ♣ **RESULTS**
- ♣ **DISCUSSION**
- ♣ **CONCLUSION**
- ♣ **PLATES**
- ♣ **REFERENCES**


Introduction

Climate change is one of the most important global environmental challenges, with adverse impacts on food production, water supply, biodiversity, health, energy, etc. Addressing climate change requires a good scientific understanding as well as coordinated action at national and global level. Historically, the responsibility for greenhouse gas emissions' increase lies largely with the industrialized world, though the developing countries are likely to be the source of an increasing proportion of future emissions. The projected climate change under various scenarios is likely to have serious implications on food production, water supply, biodiversity, forest ecosystems, health, energy security, etc. The adaptive capacity of communities likely to be impacted by climate change is low in developing countries. The efforts made by the UNFCCC and the Kyoto Protocol provisions are clearly inadequate to address the climate change challenge. The most effective way to address climate change is to adopt a sustainable development pathway by shifting to environmentally sustainable technologies and promotion of energy efficiency, renewable energy, forest conservation, reforestation, water conservation, etc. The issue of highest importance to developing countries is reducing the vulnerability of their natural and socio-economic systems to the projected climate change. India and other developing countries will face the challenge of promoting mitigation and adaptation strategies, bearing the cost of such an effort, and its implications for economic development. Hence it is utmost important to develop the most ecofiendly cost effective method to mitigate claimate change.

The planet Earth contains hundreds of billions of Giga tonnes of carbon. Only a fraction of this element is found in the atmosphere (as carbon dioxide) - most of it is held up in several compartments of this planet in various forms.

The most reliable method for measuring carbon dioxide concentrations in the atmosphere before the initiation of the direct sampling procedure is to measure bubbles of air (fluid or gas inclusions) trapped in the Antarctic or Greenland ice sheets. Thus, the most widely accepted result of such studies come from a variety of Antarctic cores and indicate that atmospheric carbon dioxide levels were about 260–280 ppmv immediately before industrial emissions started and did not change significantly from this level during the preceding 10,000 years (Fig. 1).

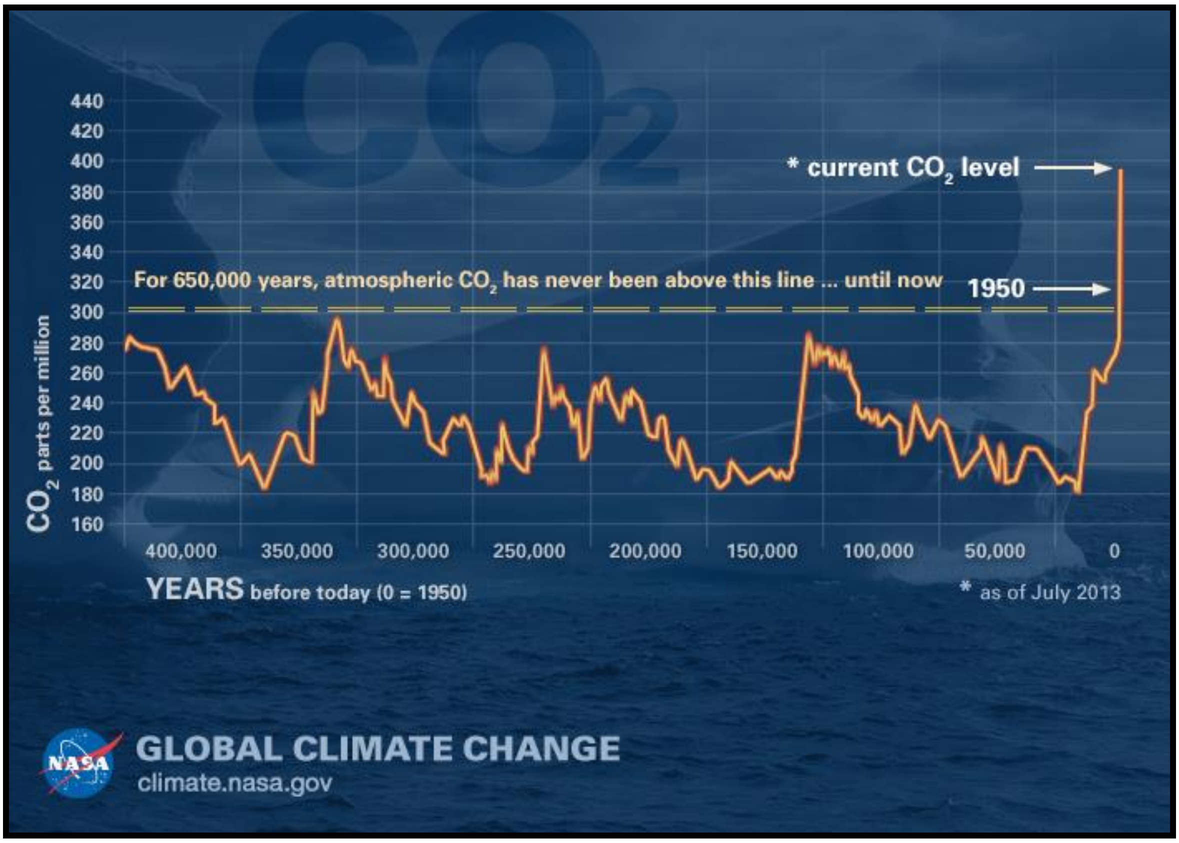


Fig. 1. Changes in carbon dioxide during the Phanerozoic (the last 542 million years)

The recent period is located on the right-hand side of the plot in Fig. 1.

One study disputed the claim of stable carbon dioxide levels during the present interglacial of the last 10 ka. Based on an analysis of fossil leaves, scientists argued that carbon dioxide levels during the period 7–10 ka were significantly higher (~300 ppm) and contained substantial variations that may be correlated to climate variations. Others have disputed such claims, suggesting they are more likely to reflect calibration problems than actual changes in carbon dioxide. Relevant to this dispute is the observation that Greenland ice cores often report higher and more variable carbon dioxide values than similar measurements in Antarctica. However, the groups responsible for such measurements believe the variations in Greenland cores result from *in situ* decomposition of calcium carbonate dust found in the ice. When dust levels in Greenland cores are low, as they nearly always are in Antarctic cores, the researchers report good agreement between Antarctic and Greenland carbon dioxide measurements.

The longest ice core record comes from East Antarctica, where ice has been sampled to an age of 800 ka. During this time, the atmospheric carbon dioxide concentration has varied between 180–210 ppm during ice ages, increasing to 280–300 ppm during warmer interglacial. The beginning of human agriculture during the current Holocene epoch may have been strongly connected to the atmospheric carbon dioxide increase after the last ice age ended, a fertilization effect boosting growth of plant biomass and reducing stomatal conductance requirements for carbon dioxide intake, consequently reducing transpiration water losses and increasing water usage efficiency.

On long timescales, atmospheric carbon dioxide content is determined by the balance among geochemical processes including organic carbon burial in sediments, silicate rock weathering, and volcanism. The net effect of slight imbalances in the carbon cycle over tens to hundreds of millions of years has been to reduce atmospheric carbon dioxide. On a timescale of billions of years, such downward trend appears bound to continue indefinitely as occasional massive historical releases of buried carbon due to volcanism will become less frequent (as earth mantle cooling and progressive exhaustion of internal radioactive heat proceeds further). The rates of these processes are extremely slow; hence they are of no relevance to the atmospheric carbon dioxide concentration over the next hundreds, thousands, or millions of years.

Various proxy measurements have been used to attempt to determine atmospheric carbon dioxide levels millions of years in the past. These include boron and carbon isotope ratios in certain types of marine sediments, and the number of stomatal observed on fossil plant leaves. While these measurements give much less precise estimates of carbon dioxide concentration than ice cores, there is evidence for very high carbon dioxide volume concentrations between 200 and 150 Ma of over 3,000 ppm and between 600 and 400 Ma of over 6,000 ppm. In more recent times, atmospheric carbon dioxide concentration continued to fall after about 60 Ma. About 34 Ma, the time of the Eocene–Oligocene extinction event and when the Antarctic ice sheet started to take its current form, carbon dioxide is found to have been about 760 ppm, and there is geochemical evidence that volume concentrations were less than 300 ppm by about 20 Ma. Carbon dioxide decrease, with a tipping point of 600 ppm, was the primary agent forcing Antarctic glaciation. Low carbon dioxide concentrations may have been the stimulus that favored the evolution of C4 plants, which increased greatly in abundance between 7 and 5 Ma.

Carbon can be stored in many forms - as mineral compounds in the ground, dissolved in water, as hydrates (like Methane Hydrates), and as organic compounds in live and dead matter (some as fossils–oil, gas and coal deposits that after hundreds of millions of years are now releasing their carbon back to the atmosphere as humans got a hold of them). There is a constant flow of carbon from one compartment to the other. This rotation is called the carbon cycle. Processes that release carbon to the atmosphere are called carbon sources. The mechanisms that take carbon out of the atmosphere and store it are called carbon sinks. Forests (grabbing carbon dioxide through photosynthesis) and oceans (dissolving carbon dioxide) are such sinks that store carbon coming from the atmosphere. Those sinks are very significant in determining the climatic condition of the globe. During the past 200 years, carbon stores have absorbed more than half of all man-made emissions of carbon dioxide, acting as a buffer. The rise in global average temperature is caused by the rest of the emissions that were not absorbed by the carbon stores.

Carbon dioxide atmospheric levels have increased from a pre-industrial concentration of 280 parts per million (ppm) to 383 ppm today, and they continue to increase with about 6-7 Gigatonnes more carbon being released annually. Around 3 Gigatonnes are stored by those sinks. There is a limit or critical level to how much more they can withhold. When the temperature rises above a certain degree the sinks will cross a critical tipping point and shift to become carbon sources, according to many scientists’ predictions.

Soil and vegetation act as potential carbon sinks. The photosynthetic process takes carbon away from the atmosphere and into the biomass (plants absorb carbon dioxide and incorporate carbon atoms into carbohydrates like sugar). Much of that carbon remains locked up in the plants' biomass for several hundreds of years and some is discharged back into the atmosphere as carbon dioxide by the plants’ breathing process. On the whole about 60 Gigatonnes of carbon, fluctuate back and forth from biomass to the atmosphere annually - as for today generally more is being taken in, than being released.

Over all, terrestrial vegetation contains today about 610 Gigatonnes of carbon, with tropical forests account for roughly 40% of this carbon store. Some of the carbon within the vegetation ends up in the soil (as the vegetation rots and piles up). Overall the amount of organic carbon stored in soils worldwide is 1580 Gigatonnes. Rainforests again stand out storing third or more of all the carbon in soils. Scientists consider the idea of forests (especially rainforests) turning to carbon dioxide sources as one of the more dramatic feedback scenarios. Vegetation biomass accumulates carbon over centuries building the potential to be a major and abrupt source of carbon dioxide.

Many researchers agree the entire Amazon is on its way to be a carbon source rather than sink, and documented that some regions are already acting as sources. Researches mainly focus on the rainforests since these are the most significant carbon stores of this planet – making them the most sensitive areas prone to sharp shifts.

Temperature rise reduces the growth of rainforests. Photosynthesis rates (which provide the raw materials necessary for growth) decline after a certain increase in temperature. At the same time carbon dioxide discharging respiration rates increase with the warming. This can completely alter the carbon balance of global vegetation. The feedback loop is the following – initial rise in temperature impedes growth (reducing carbon dioxide intake) and increases respiration (amplifying discharge), which boosts the greenhouse gas levels and causes further warming.

Both studies and recent records indicate reduced carbon intake with even small temperature increase. The forests soil is also expected to turn to a carbon source with the temperature rises. Warming accelerates the decay of organic matter by rising bacterial and fungal activities that perform respiration thus release additional carbon dioxide.

Rothman (2002) derived a 500-million-year history of the air's carbon dioxide content based on considerations related to the chemical weathering of rocks, volcanic and metamorphic degassing, and the burial of organic carbon, along with considerations related to the isotopic content of organic carbon and strontium in marine sedimentary rocks. The results of this analysis suggest that over the majority of the half-billion-year record, earth's atmospheric carbon dioxide concentration fluctuated between values that were two to four times greater than those of today at a dominant period on the order of 100 million years. Over the last 175 million years, however, the data depict a long-term decline in the air's carbon dioxide content.

Rothman reports that the carbon dioxide history 'exhibits no systematic correspondence with the geologic record of climatic variations at tectonic time scales.' A visual examination major cold and warm period indicates the three most striking peaks in the air's carbon dioxide concentration occur either totally or partially within periods of time when earth's climate was relatively cool.

A more detailed look at the most recent 50 million years of earth's thermal and carbon dioxide history was prepared by Pagani *et al*. (2005). They found about 43 million years ago, the atmosphere's carbon dioxide concentration was approximately 1400 ppm and the oxygen isotope ratio (a proxy for temperature) was about 1.0 per mil. Then, over the next ten million years, the air's carbon dioxide concentration experienced three huge oscillations on the order of 1000 ppm from peak to valley. In the first two oscillations, temperature did not appear to respond at all to the change in carbon dioxide, exhibiting an uninterrupted slow decline. Following to respond, but in the direction opposite to what the greenhouse theory of global warming predicts, as the rise in carbon dioxide was followed by the sharpest drop in temperature of the entire record.

Since 1958 the atmospheric carbon dioxide concentration has been measured continuously at Mauna Loa. It has been found that carbon dioxide has gradually increased from 280 ppm to 355 ppm in 1992 (Fig. 2). The cycle observed today reflects a superimposition of the natural situation and manmade activities. The recoverable fossil fuel resources are estimated about 4,000 Gt C, a huge amount compared to the atmospheric reservoir (600 Gt C) and to the live vegetation (550 Gt C). The burning of fossil fuel continuously is the primary cause behind the increment of atmospheric carbon dioxide several times. Deforestation is also another factor due to which the carbon dioxide concentrations in the atmosphere have increased. The atmospheric increase of carbon dioxide is due to emissions from combustion of fossil fuel which is 5.4 Gt C/yr for the period 1980-1989 (Rotty and Masters, 1985) and deforestation and land use the estimated emissions are 0.6-2.5 Gt C/yr (IPCC 1990; IPCC 1992). Table 1 summarizes best estimates for the average 1980-1989 budget of the anthropogenic carbon dioxide perturbations.

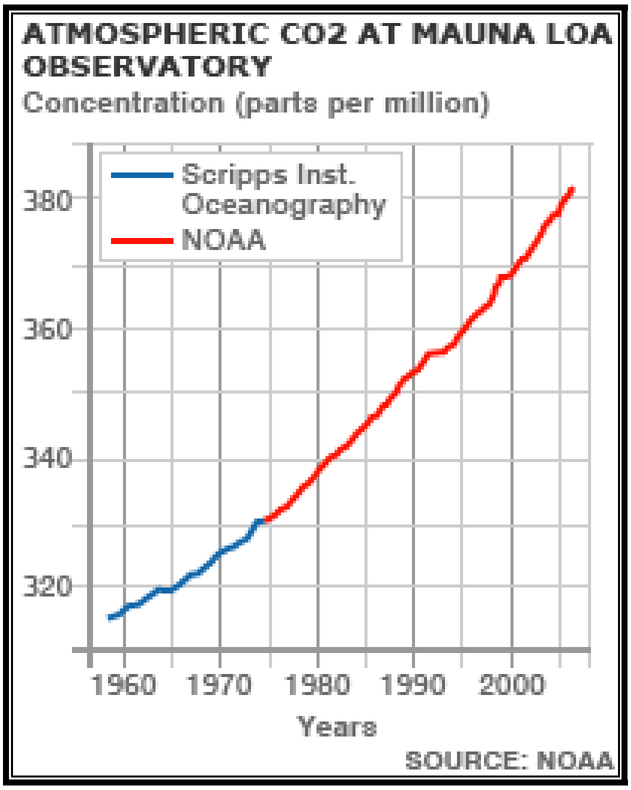


Fig. 2. The Keeling Curve: Atmospheric carbon dioxide concentrations as measured at Mauna Loa Observatory: Increase in atmospheric carbon dioxide concentration measured since 1958 at Mauna Loa.

Table 1. Budget of annual anthropogenic carbon dioxide perturbation

Emissions from fossil combustion	5.4 ± 0.5
Emissions from deforestation and landuse (IPCC 1990; IPCC 1992)	0.6 to 2.5
Atmospheric accumulation (Keeling, 1991)	3.2*
Uptake by the ocean	2.0 ± 0.6
Net imbalance	**1.8 ±1.3**

Average of Mauna Loa and South Pole.

These values are averages for the decade 1980-89. Emissions from deforestation and land use also include forest regrowth on abandoned land. For the deforestation flux, a range instead of an error is given, because estimates from different authors cannot just be averaged to get a best value. For estimating the net imbalance and its error (obtained by quadratic addition), however, 1.6 ±1.0 Gt C/yr is adopted for deforestation.

The increase of atmospheric carbon dioxide is unavoidable but sinks for this carbon are not well understood. During 2000-2009, combination of fossil fuel and land use change lead to an emission of 8.8±0.86 Gt C per year with coefficient of variance (C.V) 9.77%, whereas the atmospheric growth and uptake by land and ocean together could account 8.8±1.12 Gt C a^{-1} with C.V 12.75% (http://info@globalcarbomproject.org). Two large reservoirs: the terrestrial biosphere and the ocean uptake carbon dioxide are approximately in equal proposition. Greater coefficient of variance for the uptake by land and ocean indicates considerable annual variability in the estimation of carbon dioxide storage by the ocean and land. This could be due to the weakening of sink strength of the ocean and increasing capacity of forest uptake in response to atmospheric carbon dioxide increase. The carbon dioxide sinks are not stable; in fact, they are highly variable and respond to elevated atmospheric carbon dioxide levels and climatic change. Therefore, it is of interest to know the size of the land and ocean carbon dioxide sinks and their evolution with time.

Information on the spatial variation in carbon sequestration in different types of forest cover in the land could achieve further improvements of accuracy of global sinks. Sixty two percent (62%) to 78% of the global terrestrial carbon is sequestered in the forests, and about 70% of this carbon is stored in the soil (Schimel, 1995) with slow turnover rate. Tropical forests process about six times as much carbon as the anthropogenic emission. Changes in carbon dynamics in tropical forest with 50% contribution to global terrestrial gross primary production (GPP) (Grace *et al.*, 2001) could alter the pace of climate change. Regional studies of carbon exchange vary in showing disequilibrium state of Tropical Forest and in increasing stocks of tree carbon (Phillips *et al.*, 1998, Lewis *et al.*, 2009). Apart from resource availability and pollution stress, succession and global change could have varied importance at different region to produce different spatial and temporal pattern of carbon uptake by trees.

The carbon uptake by trees during the process of photosynthesis results in carbon sequestration. It is basically the pooling of the atmospheric carbon dioxide and its storage in the producer community of the ecosystems for a long period of time- many thousands of years. Forests offer considerable potential to act as a sink of carbon which is an important roadmap to promote net carbon sequestration. A stock or reservoir that takes up or absorbs carbon is referred to as 'sink', and one that releases or emits carbon is called a 'source'. Shifts or flows of carbon from one stock to another, for example, from the atmosphere to the forest vegetation (as happens during photosynthesis) or from industrial units/several anthropogenic sources to atmosphere (as occurs during emission) are referred to as carbon 'flux'. This process of shifting the carbon from one compartment to other constitutes the carbon cycle. In the carbon cycle, apart from emission from industrial and anthropogenic sources, carbon dioxide is also transferred to the atmosphere through respiration and microbial decomposition.

The basic constituent of all organic compounds and a major element involved in the fixation of energy by photosynthesis, carbon is so closely tied to energy flow that the two are inseparable. In fact, the measurement of productivity is commonly expressed in terms of grams of carbon fixed per square meter per year or tonnes of carbon per hectare per year. The source of all the fixed carbon in both living organisms and fossils deposits is carbon dioxide, found in the atmosphere and dissolved in the waters of the earth.

Once produced by the plant, the polysaccharides and fats synthesized from glucose and stored as tissue are utilized by plant-feeding animals that digest and synthesize the carbon compounds into others. Meat eating animals feed on the herbivores, and the carbon compounds are redigested and resynthesied into other forms. Some of the carbon is returned by these organisms directly because carbon dioxide is a by-product of the respiration of both plants and animals. Some is incorporated into the bones of land animals and the exoskeletons of invertebrates, especially such marine forms as Foraminifera.

The carbon contained in animal wastes and in the protoplasm of plants and animals is eventually released by assorted decomposer organisms. The rate of release depends on environmental conditions such as soil moisture, temperature, and precipitation. In tropical forests most of the carbon in plant remains is quickly recycled, for there is little accumulation in the soil. The turnover rate of atmospheric carbon over peat bogs is somewhere on the order of 3 to 5 years.

The cycling of carbon as carbon dioxide involves its assimilation and respiration by plants, its consumption in the form of plant and animal tissue by animals, its release through their respiration, the mineralization of litter and wood, soil respiration, accumulation of carbon in a standing crop, and withdrawal into longer-term reserves such as humus and peat fossil deposits.

At daylight, when photosynthesis begins, plants start to withdraw carbon dioxide from the air and the concentration declines sharply. By afternoon, when the temperature is increasing and the humidity is decreasing, the respiration rate of plants is increased, the assimilation rate of carbon dioxide declines, and the concentration of carbon dioxide in the atmosphere increases. By sunset the light phase of photosynthesis ceases, carbon dioxide is no longer being withdrawn from the atmosphere, and its concentration in the atmosphere increases sharply.

Over the years, forest ecologists have developed various methods to estimate the biomass of forests. Three important methods are usually adopted for estimating forest biomass: the harvest method, the mean-tree method, and the allometric method. In a mature forest, the total weight of an individual tree often reaches several tons (Komiyama *et al*., 2005). Therefore, the harvest method cannot be easily used in mature forests and in itself is not reproducible because all trees must be destructively harvested. The mean-tree method is utilized only in forests with a homogeneous tree size distribution, such as plantations. The allometric method estimates the whole or partial weight of a tree from measurable tree dimensions, including trunk diameter and height, using allometric equations. This is a non-destructive method and is thus useful for estimating temporal changes in forest biomass by means of subsequent measurements. However, the site- and species-specific dependencies of allometric equations pose a problem to researchers because tree weight measurement in forests is labour-intensive. Based on studies of forest biomass using the allometric method and other characters, Kira and Shidei (1967) summarized the so-called ‘‘summation method’’ for estimating the Net Primary Production (NPP) of forests. In this method, the rates of growth increment, death, and consumption by herbivores, are summed to obtain the NPP. The Gross Primary Production (GPP) of forests can then be calculated by adding the rate of metabolic respiration to the NPP. Recently, interest has grown in the study of carbon fluxes of an entire ecosystem, which includes carbon emissions from soil respiration. Net Ecosystem

Production (NEP) is a sophisticated criterion to judge carbon fixation from the NPP and the rate of soil respiration. One method for estimating the NEP is through the eddy covariance. Essentially, this consists of taking rapid measurements of the vertical component of air velocity and the concentration of carbon dioxide/water vapour in the air above forest canopies, and taking their covariance. However, this method requires large equipment in forests, high priced instruments, and complex computation (Monji *et al*., 2002).

Allometric equations for trees have been developed for several decades to estimate biomass and subsequent growth. Most studies have used allometric equations for single stemmed trees, but some species have multi-stemmed tree forms, as often seen in *Rhizophora*, *Avicennia*, and *Excoecaria* species (Clough *et al*., 1997; Dahdouh Guebas and Koedam, 2006). Clough *et al.* (1997) showed that the allometric relationship can be used for trunks in a multi-stemmed tree.

Moreover, for dwarf trees, allometric relationships have been used to estimate the biomass (Ross *et al*., 2001). For studies on single-stemmed trees published from 1984 to 2000, Saenger (2002) cited 43 allometric equations on AGB. His review and subsequent studies by Tam *et al.* (1995), Ong *et al.* (2004) and Soares and Schaeffer-Novelli (2005) provide a good overall survey of the relevant literature. They found that species-specific trait of allometry (*i.e.*, the allometric equation) is significantly different among forest tree species. Clough *et al.* (1997) found different relationships in different sites, although Ong *et al.* (2004) reported similar equations applied to two different sites for *Rhizophora apiculata*. This issue is important for practical uses of allometric equations. If the equations are segregated by species and site, then different expressions are established for each site.

On both the species and site-specific issues of allometry, Chave *et al.* (2005) and Komiyama *et al.* (2005) proposed the use of a common allometric equation for halophytic tree species. The common allometric equation that Komiyama *et al.* (2005) proposed is based on the pipe model (Shinozaki *et al*., 1964) and the static model of plant form (Oohata and Shinozaki, 1979). These models predict that the partial weight of the trunk at a certain height physically sustains the weight of the upper tree body, regardless of tree species and locality.

By using these two theories, Komiyama *et al.* (2005) derived equations with trunk diameter and wood density as parameters, and found good fits with 104 sample trees comprising 10 tree species from Thailand and Indonesia (the data, Tamai *et al*., 1986; Komiyama *et al*., 1988 are included in this common equation).

The common equation of Chave *et al.* (2005) was established based on statistical analysis but nevertheless consisted of the same two parameters used by Komiyama *et al.* (2005). These two common equations have the advantage of requiring only two parameters, even though Soares and Schaeffer-Novelli (2005) list a large number of parameters in their allometric equations for trees. The measurement of trunk diameter or girth is more practical than other parameters, especially for those working in closed and tall canopies where tree height is difficult to accurately measure. Wood density differs significantly in different tree species, but less for individuals within a species (Komiyama *et al*., 2005).

The issue of carbon sequestration and mitigation of GHG emission has cropped up from the exponential rise of GHG in the atmosphere.

There are two ways that Greenhouse Gas Emissions enters our atmosphere. One of them is through human activities. The main human sources of greenhouse gas emissions are: fossil fuel use, deforestation, intensive livestock farming, use of synthetic fertilizers and industrial processes. The other is through natural processes like animal and plant respiration.

There are four main types of forcing greenhouse gases: carbon dioxide, methane, nitrous oxide and fluorinated gases. The main feedback greenhouse gas is water vapor.

Greenhouse gas emissions trap heat in the Earth's atmosphere, just as the glass of a greenhouse keeps warm air inside. Human activity increases the amount of greenhouse gas emissions entering in the atmosphere, contributing to a warming of the Earth's surface.

Sources of greenhouse gas emissions

❖ **Carbon Dioxide**

There are both natural and human sources of carbon dioxide (CO_2) emissions. Natural sources include decomposition, ocean release, respiration and volcanoes (Fig. 3). Human sources come from activities like cement production, deforestation and the burning of fossil fuels (Fig. 4).

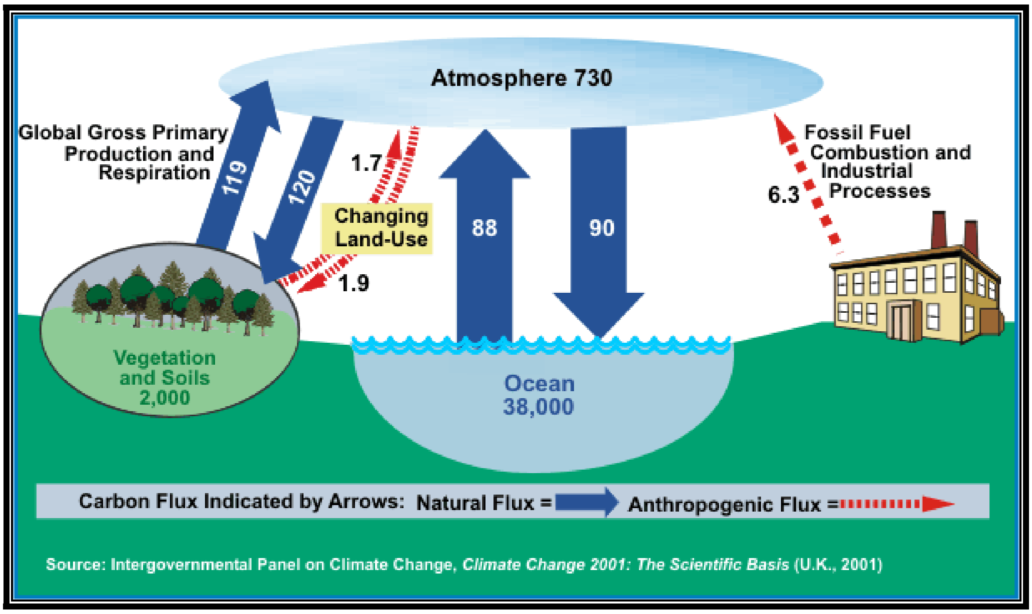


Fig. 3. Natural sources of carbon dioxide

42.8 percent of all naturally produced CO_2 emissions come from ocean-atmosphere exchange. Other important natural CO_2 sources include plant and animal respiration (28.56%) as well as soil respiration and decomposition (28.56%). A minor amount is also created by volcanic eruptions (0.03%).

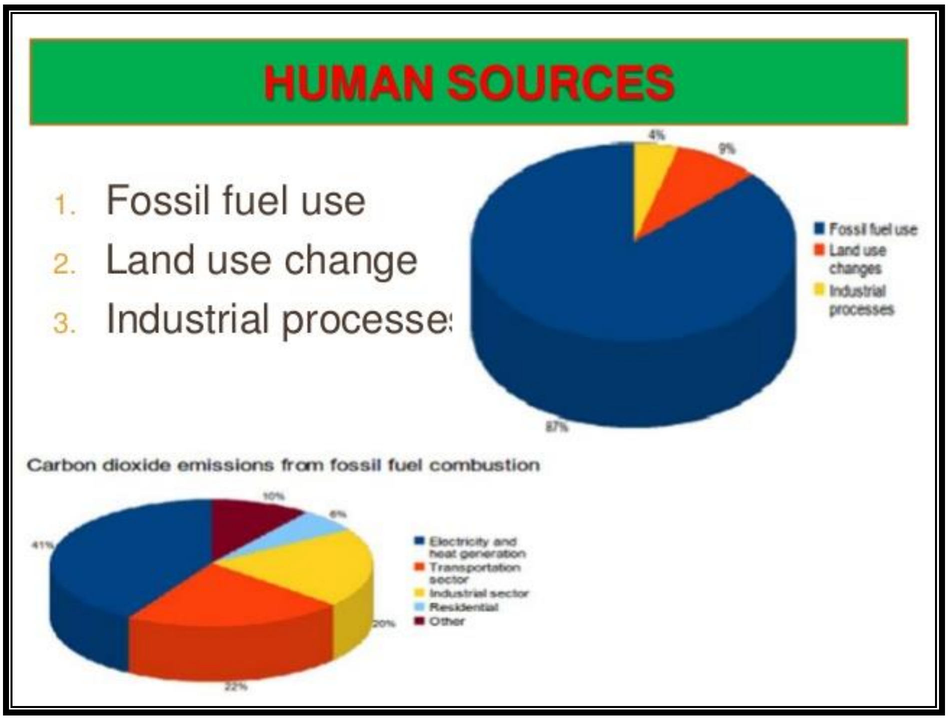


Fig. 4. Human sources of carbon dioxide

87 percent of all human CO_2 emissions come from the burning of fossil fuels like coal, natural gas and oil. Other sources include deforestation (9%), and industrial processes such as cement manufacturing (4%).

Human sources of CO_2 are much smaller than natural emissions but they upset the balance in the carbon cycle that existed before the Industrial Revolution. The amount of CO_2 produced by natural sources is completely offset by natural carbon sinks and has been for thousands of years.

Before the influence of humans, CO_2 levels were quite steady because of this natural balance. Since the Industrial Revolution, human sources of CO_2 emissions have been growing. Activities such as the burning of fossil fuels as well as deforestation are the primary cause of the increased CO_2 concentrations in the atmosphere.

- **Methane**

While there are both natural and human sources of methane (CH_4), humans create the majority of total emissions. The main natural sources include wetlands, termites and the oceans. Important human sources come from landfills, livestock farming, as well as the production, transportation and use of fossil fuels (Fig. 5).

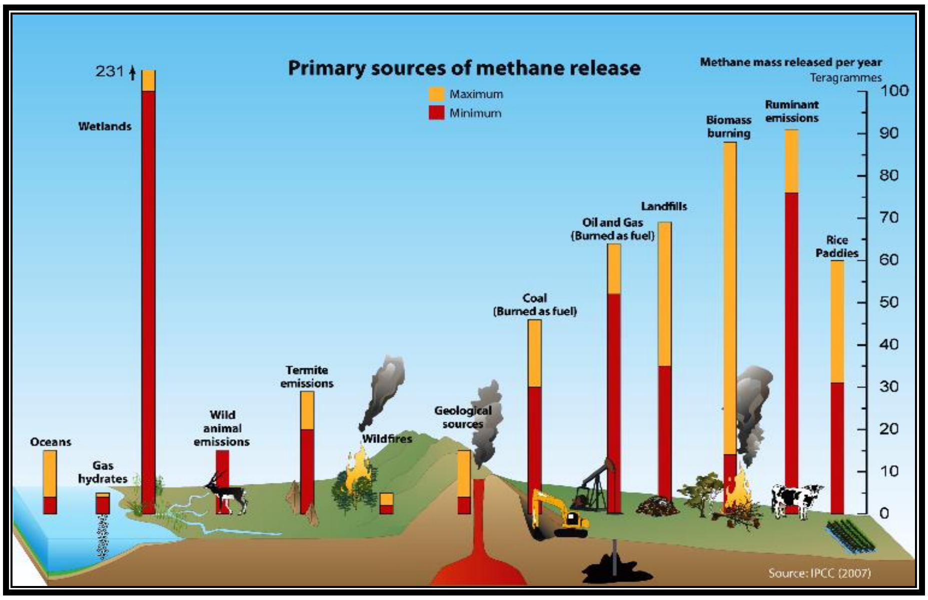


Fig. 5. Human sources of methane

Human-caused emissions have increased greatly since the Industrial Revolution. Activities such as fossil fuel production and intensive livestock farming are the primary cause of the increased CH_4 concentrations in the atmosphere. Together these two sources are responsible

for 60% of all human CH_4 emissions. Other sources include landfills and waste (16%), biomass burning (11%), rice agriculture (9%) as well as biofuels (4%).
78% of natural CH4 emissions are produced by wetlands. Other natural CH4 sources include termites (12%) and the oceans (10%) (Fig. 6).

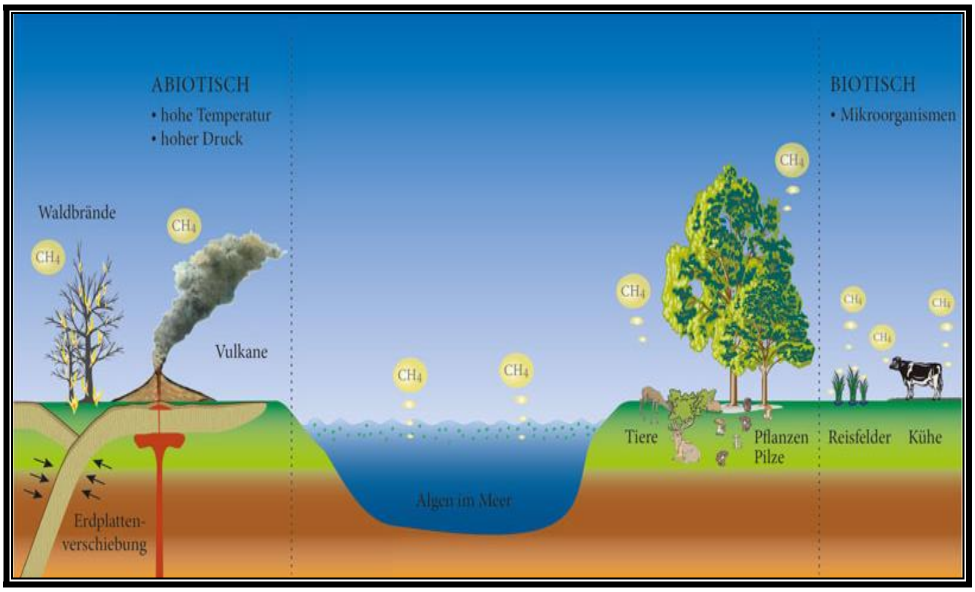


Fig. 6. Natural sources of methane

For thousands of years, natural CH_4 sources have been closely balanced by natural sinks. But today, human-related sources create the majority of total CH_4 emissions. This has upset the natural balance that existed before the Industrial Revolution and is increasing atmospheric levels.

❖ **Nitrous oxide**

Nitrous oxide (N_2O) emissions are also produced by both natural and human sources. The main natural sources are soils under natural vegetation and the oceans. Important human sources come from agriculture, fossil fuel combustion and industrial processes (Fig. 7).

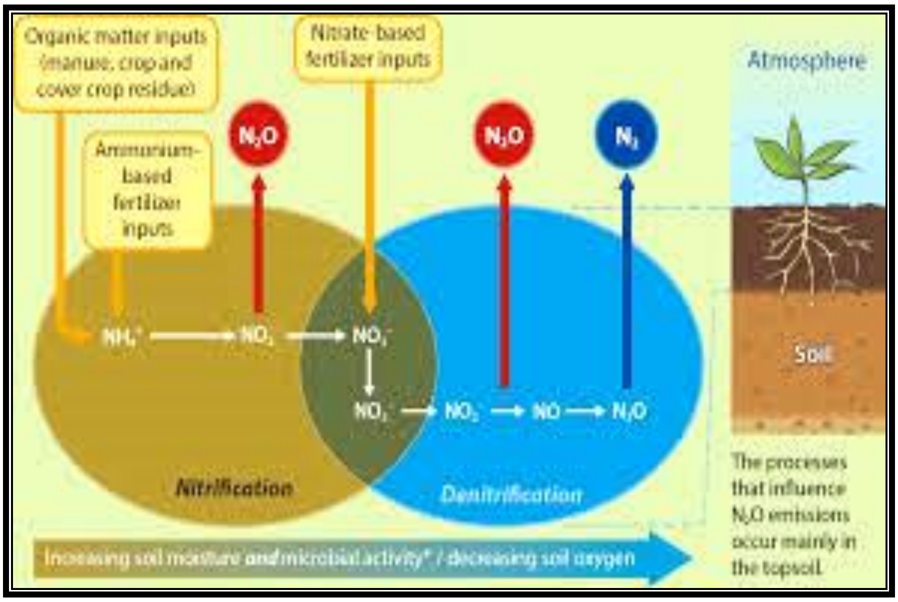


Fig. 7. Human sources of nitrous oxide

Human activities such as agriculture, fossil fuel use and industrial processes are the primary cause of the increased N_2O concentrations in the atmosphere. Together these sources are responsible for 77% of all human N_2O emissions. Other sources include biomass burning (10%), atmospheric deposition (9%) and human sewage (3%).

60% of natural N_2O emissions are produced by soils under natural vegetation. Other natural sources include the oceans (35%) and atmospheric chemical reactions (5%) (Fig. 8).

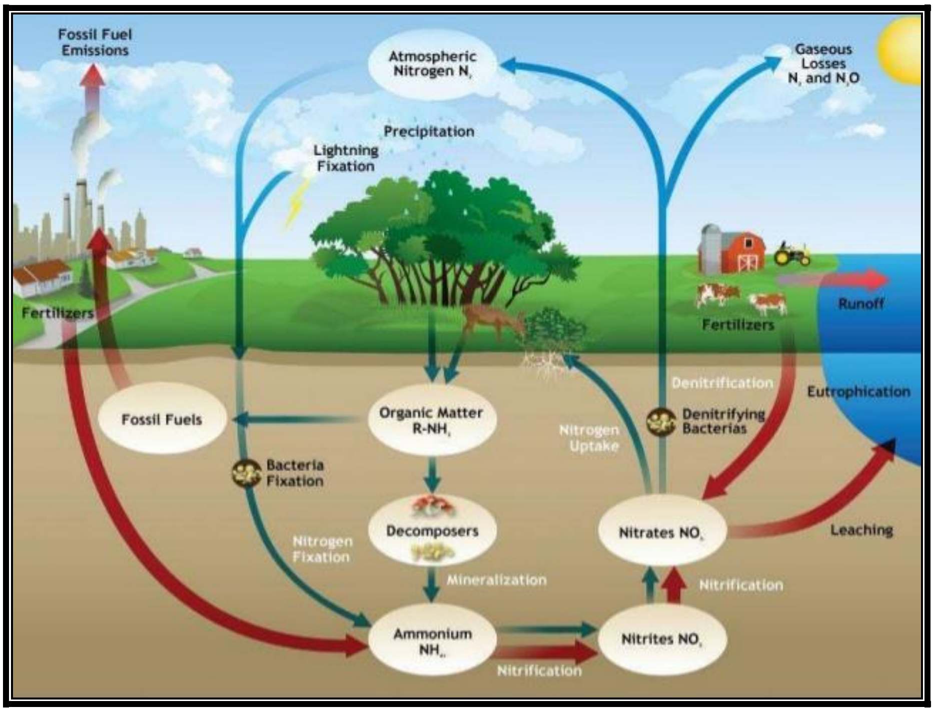


Fig. 8. Natural sources of nitrous oxide

Human N_2O sources are smaller than natural emissions. But increasing emissions from human sources have upset the balance in the nitrogen cycle that existed before the Industrial Revolution. For thousands of years, natural N_2O sources have been closely balanced by natural sinks. Before the influence of humans, N_2O levels were quite steady because of this natural balance.

❖ **Fluorinated gas**

Emissions of the three main fluorinated gases (hydrofluorocarbons (HFCs), perfluorocarbons (PFCs) and sulphur hexafluoride (SF_6)) are almost all created by humans and are used mainly in industrial processes. With the exception of PFC-14 (CF_4), fluorinated gases have no natural sources (Fig. 9).

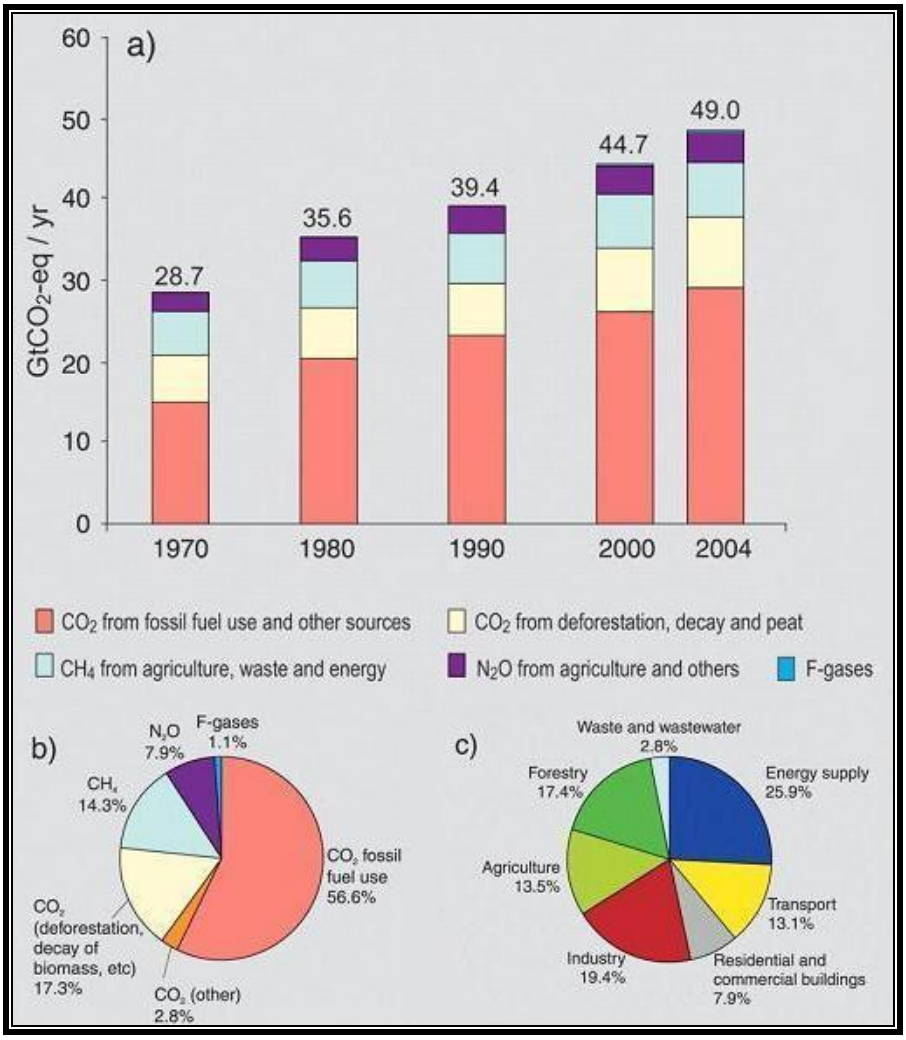


Fig. 9. Human sources of fluorinated gas

HFCs are the largest source of fluorinated gas emissions, accounting for 91%. HFCs are used inside of products like refrigerators, air-conditioners, foams and aerosol cans. Emissions from these products are caused by gas leakage during the manufacturing process as well as throughout the product's life. If disposal is not done properly, HFCs continue to leak out of the product until they are empty.

PFCs are responsible for 6% of fluorinated gas emissions. These gases are created during the production processes of aluminum and semiconductors. PFC-14 (CF_4) and PFC-116 (C_2F_6) account for the majority of PFC emissions. Less than 0.1% of PFC emissions are caused by natural sources. Small amounts of CF_4 are found in fluorite, granite and natural gas deposits. Geochemical reactions in the lithosphere cause these emissions.

SF_6 creates 3% of fluorinated gas emissions. This gas is mainly used by the electric power industry as an insulator and arc interrupter. The other important source of SF_6 emissions is from its use as a cover gas in magnesium production.

The increase in the atmospheric levels of fluorinated gases has been caused exclusively by human emissions. For a long time now human sources of fluorinated gases have been creating emissions much more rapidly than the Earth can remove them.

Water vapor is a highly active component of the climate system that responds rapidly to changes in conditions by either condensing into rain or snow, or evaporating to return to the atmosphere. The water content of the atmosphere is constantly being depleted by precipitation as well as being replenished by its main source, evaporation from seas, lakes, rivers, and moist earth. The atmospheric concentration of water vapor is highly variable and depends largely on temperature.

Human activity does not significantly affect water vapor concentrations except at local scales, such as near irrigated fields. Since its concentration is controlled by the climate itself, water vapor acts as fast feedback, reacting to, and amplifying the warming provided by the forcing greenhouse gases.

The warming effects have to be reduced and the concept of this retardation has been acceded globally by all nations. Increase of forest is a cost-effective road map to reduce global warming at local, regional and global scales.

Trees can potentially improve soils through numerous processes, including maintenance or increase of soil organic matter, biological nitrogen fixation, uptake of nutrients from below and reach of roots of under storey herbaceous vegetation, increase water infiltration and storage, reduce loss of nutrients by erosion and leaching, improve soil physical properties, reduce soil acidity and improve soil biological activity. Also, new self-sustaining top soils are created by trees. Plant litter and root exudates provide nutrient cycling to soil. In this context, a proposed litter decomposition unit of South Bengal can be an innovative roadmap to form biofertilizer from litter biomass (Fig. 10), with application of PGPR (Plant Growth Promoting Rhizobacteria).

Fig. 10. Abnormally high carbon dioxide level on the litter bed, which may be attributed to the gradual decomposition of the leaf litter by microbial action

The present project carried out during March, 2022 focussed on estimating the stored carbon in three major age groups of QGS (Eucalyptus and Akashmoni) and Sal to evaluate which particular age group stores maximum carbon in their vegetative parts.


Objectives

The present programme was undertaken in the plantation sites of West Bengal Forest Department in four major divisions of South Bengal namely Bankura North Division, Durgapur Division, Burdwan Division and Birbhum Division with the following objectives:

1. *Monitoring the variation of stored carbon in the Above Ground Biomass (AGB) of Akashmoni, Eucalyptus and Sal plantations of different ages.*
2. *Estimation of age-wise Below Ground Biomass (BGB) of the selected species*
3. *Assessment of age-wise carbon sequestration by the Above Ground Biomass (AGB) of the selected species and their respective CO_2 equivalents.*
4. *Monitoring of relevant environmental (abiotic variables) like near surface atmospheric CO_2 level, soil pH, soil organic carbon (SOC) etc. in the selected forest divisions.*


Methodology

PHASE A: SITE SELECTION AND SAMPLING

In the state of West Bengal four divisions were selected in the South Bengal region for carrying out the present study. These are:

(1) Bankura North Division

(2) Durgapur Division

(3) Burdwan Division

(4) Birbhum Division

Each of these divisions consists of some beats, which encompass locations. Few locations were selected in each division (Table 2) for studying the age-wise carbon pool in three major species namely Akashmoni, Eucalyptus and Sal, where former two are consider as Quick Growing Species (QGS).

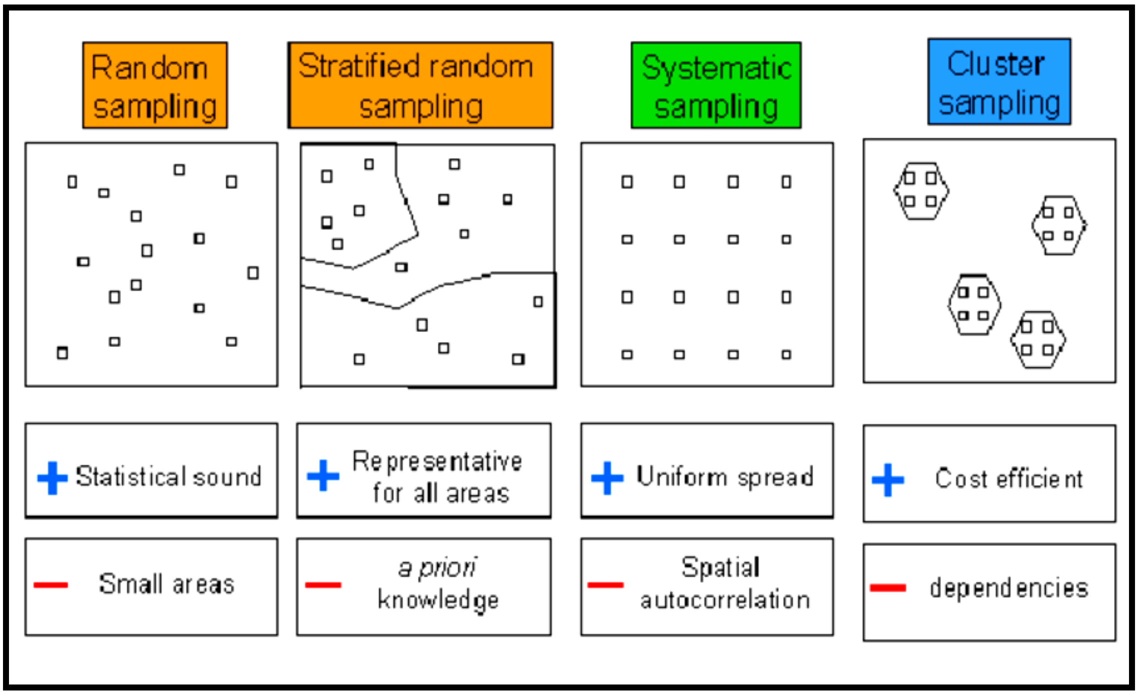
Table 2. Geographical locations of selected locations

Division	Age of Plantation	Range	Beat	Location	Coordinates
Bankura North	**9 year**	Bankura (North)	Kanchanpur	Bahadurpur	23°18′11.3″N 87°06′39.0″E
	9 year	Bankura (North)	Salboni	Gajrabari-28	23°18′17.3″N 87°01′24.0″E
	5 year	Bankura (North)	Salboni	Gazabari-28, Chottokatajhoria-29	23°18′20.3″N 87°01′27.3″E
	5 year	Bankura (North)	Kanchanpur	Ekchala-91	23°21′41.7″N 87°04′36.1″E
	5 year	Beliatore	Beliatore	Rajganj Madhabpur-124	23°19′33.5″N 87°12′16.4″E
	1 year	Bankura (North)	Kanchanpur	Kanchanpur-245	23°17′58.0″N 87°05′55.2″E
	1 year	Beliatore	Beliatore	Ramchandrapur-129	23°18′46.1″N 87°12′05.5″E
Durgapur	**9 year**	Ukhra	Fuljhore	Jemua Paranganj	23°33′32.1″N; 87°21′38.9″E
	5 year	Ukhra	Fuljhore	Jemua Paranganj	23°33′49.0″N; 87°20′23.3″E
Burdwan	**9 year**	Panagarh	Adhuria	Fari jungle	23°33′09.8″N; 87°32′16.9″E
	9 year	Panagarh	Khandari	Khandari	23°27′07.5″N; 87°31′53.1″E
	9 year	Panagarh	Sonai	Bilaspur	23°28′25.1″N; 87°29′45.5″E
	9 year	Panagarh	Sonai	Shyamsundarpur	23°28′41.5″N; 87°30′09.4″E
	5 year	Panagarh	Adhuria	Jalikandar	23°32′27.4″N; 87°33′43.0″E

	5 year	Panagarh	Khandari	Khandari	23°27′17.1″N; 87°30′58.9″E
	5 year	Panagarh	Adhuria	Chhora	23°34′58.5″N; 87°34′27.6″E
	1 year	Panagarh	Khandari	Moukota	23°30′54.7″N; 87°32′40.8″E
	1 year	Panagarh	Adhuria	Bhuera	23°33′17.0″N; 87°34′55.8″E
	1 year	Panagarh	Sonai	Paduma	23°30′28.7″N; 87°30′19.5″E
	1 year	Panagarh	Sonai	Jijira	23°30′35.2″N; 87°30′54.3″E
Birbhum	**9 year**	Bolpur	Bolpur	Faridpur	23°41′44.1″N; 87°35′55.9″E
	9 year	Bolpur	Bolpur	Ballavpur	23°40′50.1″N; 87°39′08.1″E

Plots were selected in each of these locations (GPS based coordinates specified), where stratified random sampling design was followed. The basic idea in stratified random sampling is to divide a heterogeneous population into sub-populations, usually known as strata, each of which is internally homogeneous in which case a precise estimate of any stratum mean can be obtained based on a small sample from that stratum and by combining such estimates, a precise estimate for the whole population can be obtained.

Stratified sampling provides a better cross section of the population than the procedure of simple random sampling. It may also simplify the organisation of the field work. Geographical proximity is sometimes taken as the basis of stratification. The assumption here is that geographically contiguous areas are often more alike than areas that are far apart. Administrative convenience may also dictate the basis on which the stratification is made. For example, the staff already available in each range of a forest division may have to supervise the survey in the area under their jurisdiction. Thus, compact geographical regions may form the strata. A fairly effective method of stratification is to conduct a quick reconnaissance survey of the area or pool the information already at hand and stratify the forest area according to forest types, stand density, site quality etc. (Scheme 1).



Scheme 1. Stratified Random sampling followed (amongst 4 categories) for Relative Abundance analysis of the selected floral community in South Bengal forest divisions under West Bengal Forest Department

If the characteristic under study is known to be correlated with a supplementary variable for which actual data or at least good estimates are available for the units in the population, the stratification may be done using the information on the supplementary variable. For instance, the volume estimates obtained at a previous inventory of the forest area may be used for stratification of the population. In stratified sampling, the variance of the estimator consists of only the 'within strata' variation. Thus the larger the number of strata into which a population is divided, the higher, in general, is the precision, since it is likely that, in this case, the units within a stratum will be more homogeneous.

Before sampling, it is assumed that the population is divided into k strata of N_1, N_2,…, N_k units respectively, and that a sample of n units is to be drawn from the population. The problem of allocation concerns the choice of the sample sizes in the respective strata, *i.e.*, how many units should be taken from each stratum such that the total sample is n. In this context 30 plots of each of three species were considered (n = 90 for all the three species).

Estimation of mean and variance

In this study, the population of N units is first divided into k strata of N_1, N_2,…,N_k units respectively. These strata are non-overlapping and together they comprise the whole population, so that

$N_1 + N_2 + \ldots\ldots + N_k = N$

When the strata have been determined, a sample is drawn from each stratum, the selection being made independently in each stratum. The sample sizes within the strata are denoted by $n_1, n_2, \ldots, n_k$ respectively, so that

$n_1 + n_2 + \ldots\ldots + n_3 = n$

Let y_{tj} ($j = 1, 2, \ldots, N_t$; $t = 1, 2, \ldots, k$) be the value of the characteristic under study for the j the unit in the tth stratum. In this case, the population mean in the stratum is given by the expression:

$$\overline{Y}_t = \frac{1}{N_t}\sum_{j=1}^{N_t} y_{tj}, \ (t = 1, 2, \ldots, k)$$

The overall population mean is given by

$$\overline{Y} = \frac{1}{N}\sum_{t=1}^{k} N_t \overline{Y}_t$$

The estimate of the population mean $\overline{Y}$, in this case was obtained by

$$\hat{\overline{Y}} = \frac{\sum_{t=1}^{k} N_t \overline{y}_t}{N}$$

Where, $$\overline{y}_t = \sum_{j=1}^{n_t} \frac{y_{tj}}{n_t}$$

Estimate of the variance of $\hat{\overline{Y}}$ is given by

$$\hat{V}(\hat{\overline{Y}}) = \frac{1}{N^2}\sum_{t=1}^{k} N_t (N_t - n_t) \frac{s^2_{t(y)}}{n_t}$$

Where, $$s^2_{t(y)} = \sum_{j=1}^{n_t} \frac{(y_{tj} - \overline{y}_t)^2}{n_t - 1}$$

Stratification, if properly done generates lower variance for the estimated population total or mean than a simple random sample of the same size. This leads to the assurance of quality data, which is followed in all the selected divisions to achieve the relative abundance of each species. This is the foundation of assessing plot/site - and species-wise biomass and stored carbon.

PHASE B: EXPERIMENTAL DESIGN

1. ABOVE GROUND BIOMASS (AGB) ESTIMATION

Above Ground Biomass (AGB) in tree species refers to the sum total of stem, branch and leaf biomass that are exposed above the soil.

i. STEM BIOMASS ESTIMATION

The stem volume of each species in each plots (10m × 10m) of all mouzas was estimated using the Newton's formula (Husch *et al.*, 1982).

$$V = h/6\ (A_b + 4A_m + A_t)$$

Where V is the volume (in m^3), h is the height measured with laser beam (BOSCH DLE 70 Professional model), and A_b, A_m, and A_t are the areas at base, middle and top respectively. Specific gravity (G) of the wood was estimated taking the stem cores by boring 4.5 cm deep. This was converted into stem biomass (B_S) as per the expression $B_S = GV$. The stem biomass of individual tree was finally multiplied by the number of trees of each species in all the selected mouzas and the mean values are expressed in t ha^{-1}.

In this study, aerial images were taken by a drone camera (Phantom-3 Professional, Djibouti) which has four propellers, a camera, a GPS (Global Positioning System) receiver, and a gimbal. Further, it has an exclusive remote controller. The camera used for the experiment can take 1.2M-pixel images and video with 4K (3840 × 2160) images. We used this parallel system to estimate the exact height of the trees in metres.

ii. BRANCH BIOMASS ESTIMATION

The total number of branches irrespective of size was counted on each of the sample trees. These branches were categorized on the basis of basal diameter into three groups, *viz*. < 6 cm, 6–10 cm and >10 cm. The leaves on the branches were removed by hand. The branches were oven-dried at 70^0C overnight in hot air oven in order to remove moisture content if any present in the branches. Dry weight of two branches from each size group was recorded separately using the equation of Chidumaya (1990).

$$B_{db} = n_1bw_1 + n_2bw_2 + n_3bw_3 = \Sigma\ n_ibw_i$$

Where B_{db} is the dry branch biomass per tree, n_i the number of branches in the ith branch group, b_{wi} the average weight of branches in the ith group and i = 1, 2, 3, …..n are the branch groups. The mean branch biomass of individual tree was finally multiplied with the number of trees of each species in all the plots for each site and expressed in t ha^{-1}.

iii. LEAF BIOMASS ESTIMATION

For leaf biomass estimation, one tree of each species per plot was randomly considered. All leaves from nine branches (three of each size group) of individual trees of each species were removed and oven dried at 70^0C and dry weight (species-wise) was estimated. The leaf biomass of each tree was then calculated by multiplying the average biomass of the leaves per branch with the number of branches in that tree. Finally, the dry leaf biomass of the selected species (for each plot) was recorded as per the expression:

$$L_{db} = n_1Lw_1N_1 + n_2Lw_2N_2 + \ldots\ldots\ldots n_iLw_iN_i$$

Where L_{db} is the dry leaf biomass of selected urban species per plot, $n_{1..}\ldots n_i$ are the number of branches of each tree of the species, Lw_1 …….Lw_i are the average dry weight of leaves removed from the branches and $N_{1\ldots\ldots\ldots}N_i$ are the number of trees per species in the plots. This exercise was performed for all the mouzas and the mean results were finally expressed in t ha^{-1}.

2. ABOVE GROUND CARBON (AGC) ESTIMATION

Direct estimation of percent carbon in the AGB (referred to as AGC) was done by CHN analyzer, after grinding and random mixing the oven-dried stem, branches and leaves separately for each species. For this, a portion of fresh sample of stem, branch and leaf from trees (of each species) was oven dried at 70^0C, randomly mixed and ground to pass through a 0.5 mm screen (1.0 mm screen for leaves). The carbon content (in %) was finally analyzed for each part of each species through a *Vario MACRO elementar CHN* analyzer.

The mean carbon values of these vegetative parts (expressed in %) were considered as the stored carbon in the AGB of each species separately for stems, branches and leaves.

In case of 1-year old samples, the root systems were dried at 70^0C, ground to dust and carbon percentage was directly estimated through CHN analyzer.

3. BELOW GROUND BIOMASS (BGB) ESTIMATION

The below ground biomass (BGB) includes all biomass of live roots excluding the fine roots. The BGB, in the present study was calculated by multiplying AGB × 0.26 factors considering the root: shoot ratio (Saral, A. Mary *et al.*, 2017). Thus BGB was calculated by following BGB (kg/tree) = AGB (kg/tree) × 0.26 (Fig. 11). This exercise was performed for all the selected species present in the sampling plots per site.

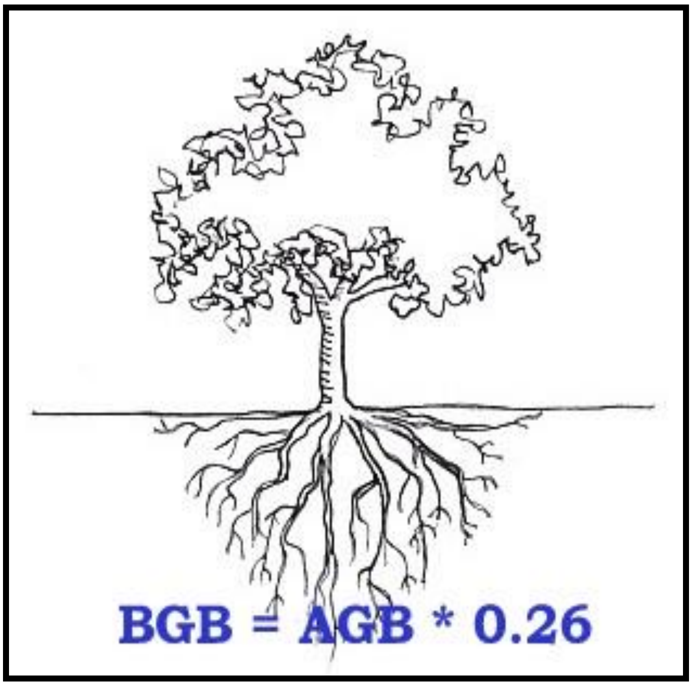


Fig. 11. AGB (Shoot): BGB (Root) ratio by non-destructive method

4. BIOMASS AND STORED CARBON OF 1-YEAR OLD PLANTATION

For the samples of 1-year old planations, Above Ground Biomass (AGB) is the sum total of leaves and stems and the Below Ground Biomass (BGB) comprises the roots of the seedlings. The 1-year old samples of the species after collection from each plot of 10m × 10m from different locations were thoroughly washed with ambient water and then with double distilled water to remove any sticking debris and dried at 70°C.

Along with the total biomass of the 1-year old plantation of each species, the biomass of leaf, stem and root of each species were estimated separately and the average values of all the selected plots from each location were documented (tonnes/ha) in the study area.

The carbon values of the vegetative parts (expressed in %) after analyzing through CHN analyzer were considered as the stored carbon in the AGB of each species separately for stems, branches and leaves.

In 1-year old samples, the root systems after uprooting were cleaned, processed and dried at 70^0C, ground to dust and carbon percentage was directly estimated through CHN analyzer.

5. CO_2 - EQUIVALENT ESTIMATION

The weight of CO_2 is C + 2 × O (Oxygen) = 43.99915. The ratio of CO_2 to C is calculated as: 43.99915/12.001118 = 3.6663. Therefore, in order to determine the weight of carbon dioxide sequestered in the plant body (CO_2-equivalent) of three different age groups, the weight of carbon in the vegetative parts of the tree (AGC) is multiplied by 3.6663.

6. SOIL ORGANIC CARBON (SOC) ESTIMATION

Soil samples from the upper 5 cm were collected from all the plots of all mouzas and dried at 60^0C for 48 hrs. For analysis, visible plant particles were handpicked and removed from the soil. After sieving the soil through a 2 mm sieve, the samples of the bulk soil (50 gm from each plot) were ground finely in a ball – mill. The fine dried sample was randomly mixed to get a representative picture of the study site. Modified version of Walkley and Black method (1934) was then followed to determine the organic carbon of the soil in %. The flow chart for determining of SOC is shown in Scheme 2.

1 gm of dried soil was taken in a conical flask

↓

1 ml of phosphoric acid (H_3PO_4) and 1 ml of distilled water were added

↓

The mixture was heated for 10 min at 100 to 110° C

↓

10 ml 1 N potassium dichromate ($K_2Cr_2O_7$) and 20 ml concentrated sulphuric acid (H_2SO_4) with silver sulphate (Ag_2SO_4) were added and mixed.

↓

Allowed the mixture to stand for 30 minutes

↓

The mixture was diluted to 200 ml with distilled water and 10 ml of phosphoric acid (H_3PO_4) and 1 ml of indicator (diphenyl amine) were added.

↓

The colour of the mixture changed to bluish purple

↓

The mixture was titrated with Mohr salt solution [$(NH_4)_2Fe(SO_4)_2.6H_2O$] until the colour of the solution changed to brilliant green

↓

The same titration was repeated without taking soil and the volume of the potassium dichromate required to oxidize organic carbon was calculated from the difference

Scheme 2. Estimation of Soil Organic Carbon by Walkley and Black method

CALCULATION

% of CARBON = 3.951/g × (1/ B/S)

Where, g = weight of sample in grams

B = Mohr salt solution for blank

S = Mohr salt solution for Sample

7. SOIL pH ESTIMATION

The measurement of soil pH was done in the field with a micro - pH meter (Systronics, Model No, 362) with glass – calomel electrode (sensitivity ± 0.01), standardized with buffer 7.0.

8. STATISTICAL ANALYSIS

To assess whether biomass, carbon content and CO_2-equivalent varied significantly among the forest divisions of South Bengal and age groups, analysis of variance (ANOVA) was performed. All statistical calculations were performed with SPSS 9.0 for Windows.


Results

For convenience, the results of the present study may be broadly divided into Biotic and Abiotic components.

1. Biotic Components

The biotic components encompass age-wise and species-wise AGB, AGC, BGB, sequestered carbon (based on age) and CO_2- equivalent (based on AGC). We present here our ground-zero observations for all the four divisions.

1.A] BANKURA NORTH DIVISION

1) In the **9-year old plantation** of **Bankura North Division**, the **AGB of Akashmoni** in Bahadurpur under Kanchanpur Beat in Bankura North range (23°18′11.3″N; 87°06′39.0″E) was 204.937 tha^{-1}; in Gajrabari under Salboni Beat in Bankura North range (23°18′17.3″N; 87°01′24.0″E) the value of **AGB in Sal** was 233.945 tha^{-1}.

2) In the **9-year old plantation** of **Bankura North Division**, the **AGC of Akashmoni** in Bahadurpur under Kanchanpur Beat in Bankura North range (23°18′11.3″N; 87°06′39.0″E) was 90.324 tha^{-1}; in Gajrabari under Salboni Beat in Bankura North range (23°18′17.3″N; 87°01′24.0″E) the value of **AGC in Sal** was 109.041 tha^{-1}.

3) In the **9-year old plantation** of **Bankura North Division**, the **BGB of Akashmoni** in Bahadurpur under Kanchanpur Beat in Bankura North range (23°18′11.3″N; 87°06′39.0″E) was 53.284 tha^{-1}; in Gajrabari under Salboni Beat in Bankura North range (23°18′17.3″N; 87°01′24.0″E) the value of **BGB in Sal** was 60.826 tha^{-1}.

4) In the **9-year old plantation** of **Bankura North Division**, the **sequestered carbon in AGB of Akashmoni** in Bahadurpur under Kanchanpur Beat in Bankura North range (23°18′11.3″N; 87°06′39.0″E) was 10.036 $tha^{-1}y^{-1}$; in Gajrabari under Salboni Beat in Bankura North range (23°18′17.3″N; 87°01′24.0″E) the value of **sequestered carbon in** the **AGB of Sal** was 12.116 $tha^{-1}y^{-1}$.

5) In the **9-year old plantation** of **Bankura North Division**, the **CO_2-equivalent of Akashmoni** in Bahadurpur under Kanchanpur Beat in Bankura North range (23°18′11.3″N; 87°06′39.0″E) was 331.488 tha^{-1}; in Gajrabari under Salboni Beat in Bankura North range (23°18′17.3″N; 87°01′24.0″E) the value of **CO_2-equivalent of Sal** was 400.180 tha^{-1}.

6) In the **5-year old plantation** of **Bankura North Division**, the **AGB of Akashmoni** ranged from 85.695 tha^{-1} (Ekchala-91 under Kanchanpur Beat in Bankura North range; 23°21′41.7″N; 87°04′36.1″E) to 141.604 tha^{-1} (Raiganj Madhavpur under Beliatore Beat, Beliatore range; 23°19′33.5″N; 87°12′16.4″E); in Gajrabari under Salboni Beat in Bankura North range (23°18′20.3″N; 87°01′27.3″E), the value of **AGB in Eucalyptus** was 332.769 tha^{-1}.

7) In the **5-year old plantation** of **Bankura North Division**, the **AGC of Akashmoni** ranged from 37.624 tha^{-1} (Ekchala-91 under Kanchanpur Beat in Bankura North range; 23°21′41.7″N; 87°04′36.1″E) to 62.131 tha^{-1} (Raiganj Madhavpur under Beliatore Beat, Beliatore range; 23°19′33.5″N; 87°12′16.4″E); in Gajrabari under Salboni Beat in Bankura North range (23°18′20.3″N; 87°01′27.3″E), the value of **AGC in Eucalyptus** was 152.979 tha^{-1}.

8) In the **5-year old plantation** of **Bankura North Division**, the **BGB of Akashmoni** ranged from 22.281 tha^{-1} (Ekchala-91 under Kanchanpur Beat in Bankura North range; 23°21′41.7″N; 87°04′36.1″E) to 36.817 tha^{-1} (Raiganj Madhavpur under Beliatore Beat, Beliatore range; 23°19′33.5″N; 87°12′16.4″E); in Gajrabari under Salboni Beat in Bankura North range (23°18′20.3″N; 87°01′27.3″E), the value of **BGB in Eucalyptus** was 86.520 tha^{-1}.

9) In the **5-year old plantation** of **Bankura North Division**, the **sequestered carbon in AGB of Akashmoni** ranged from 7.525 $tha^{-1}y^{-1}$ (Ekchala-91 under Kanchanpur Beat in Bankura North range; 23°21′41.7″N; 87°04′36.1″E) to 12.426 $tha^{-1}y^{-1}$ (Raiganj Madhavpur under Beliatore Beat, Beliatore range; 23°19′33.5″N; 87°12′16.4″E); in Gajrabari under Salboni Beat in Bankura North range (23°18′20.3″N; 87°01′27.3″E) the value of **sequestered carbon in AGB in Eucalyptus** was 30.596 $tha^{-1}y^{-1}$.

10) In the **5-year old plantation** of **Bankura North Division**, the **CO_2-equivalent of Akashmoni** ranged from 138.079 tha^{-1} (Ekchala-91 under Kanchanpur Beat in Bankura North range; 23°21′41.7″N; 87°04′36.1″E) to 228.021 tha^{-1} (Raiganj Madhavpur under Beliatore Beat, Beliatore range; 23°19′33.5″N; 87°12′16.4″E); in Gajrabari under Salboni Beat in Bankura North range (23°18′20.3″N; 87°01′27.3″E) the value of **CO_2-equivalent in Eucalyptus** was 561.434 tha^{-1}.

11) In the **1-year old plantation** of **Bankura North Division**, the **AGB of Akashmoni** in Kanchanpur-245 under Kanchanpur Beat in Bankura North range (23°17′58.0″N; 87°05′55.2″E) was 3.439 tha^{-1}; in Ramchandrapur-129 under Beliatore Beat in Beliatore range (23°18′46.1″N; 87°12′05.5″E) the value of **AGB in Sal** was 4.043 tha^{-1}.

12) In the **1-year old plantation** of **Bankura North Division**, the **AGC of Akashmoni** in Kanchanpur-245 under Kanchanpur Beat in Bankura North range (23°17′58.0″N; 87°05′55.2″E) was 1.554 tha^{-1}; in Ramchandrapur-129 under Beliatore Beat in Beliatore range (23°18′46.1″N; 87°12′05.5″E) the value of **AGC in Sal** was 1.973 tha^{-1}.

13) In the **1-year old plantation** of **Bankura North Division**, the **BGB of Akashmoni** in Kanchanpur-245 under Kanchanpur Beat in Bankura North range (23°17′58.0″N; 87°05′55.2″E) was 0.791 tha^{-1}; in Ramchandrapur-129 under Beliatore Beat in Beliatore range (23°18′46.1″N; 87°12′05.5″E) the value of **BGB in Sal** was 0.930 tha^{-1}.

14) In the **1-year old plantation** of **Bankura North Division**, the **sequestered carbon in Akashmoni** in Kanchanpur-245 under Kanchanpur Beat in Bankura North range (23°17′58.0″N; 87°05′55.2″E) was 1.554 $tha^{-1}y^{-1}$; in Ramchandrapur-129 under Beliatore Beat in Beliatore range (23°18′46.1″N; 87°12′05.5″E) the value of **sequestered carbon in Sal** was 1.973 $tha^{-1}y^{-1}$.

15) In the **1-year plantation** of **Bankura North Division**, the **CO_2-equivalent of Akashmoni** in Kanchanpur-245 under Kanchanpur Beat in Bankura North range (23°17′58.0″N; 87°05′55.2″E) was 5.704 tha^{-1}; in Ramchandrapur-129 under Beliatore Beat in Beliatore range (23°18′46.1″N; 87°12′05.5″E) the value of **CO_2-equivalent in Sal** was 7.242 tha^{-1}.

1.B] DURGAPUR DIVISION

16) In the **9-year old plantation** of **Durgapur Division**, the **AGB of Akashmoni** in Jemua Paranganj under Fuljhore Beat in Ukhra range (23°33′32.1″N; 87°21′38.9″E) was 141.644 tha^{-1}.

17) In the **9-year old plantation** of **Durgapur Division**, the **AGC of Akashmoni** in Jemua Paranganj under Fuljhore Beat in Ukhra range (23°33′32.1″N; 87°21′38.9″E) was 65.843 tha^{-1}.

18) In the **9-year old plantation** of **Durgapur Division**, the **BGB of Akashmoni** in Jemua Paranganj under Fuljhore Beat in Ukhra range (23°33′32.1″N; 87°21′38.9″E) was 36.828 tha^{-1}.

19) In the **9-year old plantation** of **Durgapur Division**, the **sequestered carbon in AGB of Akashmoni** in Jemua Paranganj under Fuljhore Beat in Ukhra range (23°33′32.1″N; 87°21′38.9″E) was 7.316 $tha^{-1}y^{-1}$.

20) In the **9-year old plantation** of **Durgapur Division**, the **CO_2-equivalent of Akashmoni** in Jemua Paranganj under Fuljhore Beat in Ukhra range (23°33′32.1″N; 87°21′38.9″E) was 241.645 tha^{-1}.

21) In the **5-year old plantation** of **Durgapur Division**, the **AGB of Akashmoni** in Jemua Paranganj under Fuljhore Beat in Ukhra range (23°33′49.0″N; 87°20′23.3″E) was 48.454 tha^{-1}.

22) In the **5-year old plantation** of **Durgapur Division**, the **AGC of Akashmoni** in Jemua Paranganj under Fuljhore Beat in Ukhra range (23°33′49.0″N; 87°20′23.3″E) was 22.395 tha^{-1}.

23) In the **5-year old plantation** of **Durgapur Division**, the **BGB of Akashmoni** in Jemua Paranganj under Fuljhore Beat in Ukhra range (23°33′49.0″N; 87°20′23.3″E) was 12.598 tha^{-1}.

24) In the **5-year old plantation** of **Durgapur Division**, the **sequestered carbon in AGB of Akashmoni** in Jemua Paranganj under Fuljhore Beat in Ukhra range (23°33′49.0″N; 87°20′23.3″E) was 4.479 $tha^{-1}y^{-1}$.

25) In the **5-year old plantation** of **Durgapur Division**, the **CO_2-equivalent of Akashmoni** in Jemua Paranganj under Fuljhore Beat in Ukhra range (23°33′49.0″N; 87°20′23.3″E) was 82.188 tha^{-1}.

1.C] BURDWAN DIVISION

26) In the **9-year old plantation** of **Burdwan Division**, the **AGB of Akashmoni** ranged from 161.656 tha^{-1} (in Khandari under Khandari Beat in Panagarh range; 23°27′07.5″N; 87°31′53.1″E) to 220.532 tha^{-1} (in Shyamsundarpur under Sonai Beat in Panagarh range; 23°28′41.5″N; 87°30′09.4″E); in **Eucalyptus the AGB** ranged from 274.115 tha^{-1} (in

Shyamsundarpur under Sonai beat in Panagarh range; 23°28′41.5″N; 87°30′09.4″E) to 379.952 tha^{-1} (in Khandari under Khandari beat in Panagarh range; 23°27′07.5″N; 87°31′53.1″E); in **Sal the AGB** value ranged from 187.696 tha^{-1} (in Bilaspur under Sonai beat in Panagarh range; 23°28′25.1″N; 87°29″E) to 285.177 tha^{-1} (in Fari jungle under Adhuria beat in Panagarh range; 23°33′09.8″N; 87°32′16.9″E).

27) In the **9-year old plantation** of **Burdwan Division**, the **AGC of Akashmoni** ranged from 74.820 tha^{-1} (in Khandari under Khandari Beat in Panagarh range; 23°27′07.5″N; 87°31′53.1″E) to 102.346 tha^{-1} (in Shyamsundarpur under Sonai Beat in Panagarh range; 23°28′41.5″N; 87°30′09.4″E); in **Eucalyptus the AGC** ranged from 125.715 tha^{-1} (in Shyamsundarpur under Sonai beat in Panagarh range; 23°28′41.5″N; 87°30′09.4″E) to 174.067 tha^{-1} (in Khandari under Khandari beat in Panagarh range; 23°27′07.5″N; 87°31′53.1″E); in **Sal the AGC** value ranged from 86.749 tha^{-1} (in Bilaspur under Sonai beat in Panagarh range; 23°28′25.1″N; 87°29″E) to 132.041 tha^{-1} (in Fari jungle under Adhuria beat in Panagarh range; 23°33′09.8″N; 87°32′16.9″E).

28) In the **9-year old plantation** of **Burdwan Division**, the **BGB of Akashmoni** ranged from 42.030 tha^{-1} (in Khandari under Khandari Beat in Panagarh range; 23°27′07.5″N; 87°31′53.1″E) to 57.338 tha^{-1} (in Shyamsundarpur under Sonai Beat in Panagarh range; 23°28′41.5″N; 87°30′09.4″E); in **Eucalyptus the BGB** ranged from 71.270 tha^{-1} (in Shyamsundarpur under Sonai beat in Panagarh range; 23°28′41.5″N; 87°30′09.4″E) to 98.788 tha^{-1} (in Khandari under Khandari beat in Panagarh range; 23°27′07.5″N; 87°31′53.1″E); in **Sal the BGB** value ranged from 48.801 tha^{-1} (in Bilaspur under Sonai beat in Panagarh range; 23°28′25.1″N; 87°29″E) to 74.146 tha^{-1} (in Fari jungle under Adhuria beat in Panagarh range; 23°33′09.8″N; 87°32′16.9″E).

29) In the **9-year old plantation** of **Burdwan Division**, the **sequestered carbon in AGB of Akashmoni** ranged from 8.313 $tha^{-1}y^{-1}$ (in Khandari under Khandari Beat in Panagarh range; 23°27′07.5″N; 87°31′53.1″E) to 11.372 $tha^{-1}y^{-1}$ (in Shyamsundarpur under Sonai Beat in Panagarh range; 23°28′41.5″N; 87°30′09.4″E); in **Eucalyptus the sequestered carbon in AGB** ranged from 13.968 $tha^{-1}y^{-1}$ (in Shyamsundarpur under Sonai beat in Panagarh range; 23°28′41.5″N; 87°30′09.4″E) to 19.341 $tha^{-1}y^{-1}$ (in Khandari under Khandari beat in Panagarh range; 23°27′07.5″N; 87°31′53.1″E); in **Sal the sequestered carbon in AGB** value ranged from 9.639 $tha^{-1}y^{-1}$ (in Bilaspur under Sonai beat in

Panagarh range; 23°28′25.1″N; 87°29″E) to 14.671 $tha^{-1}y^{-1}$ (in Fari jungle under Adhuria beat in Panagarh range; 23°33′09.8″N; 87°32′16.9″E).

30) In the **9-year old plantation** of **Burdwan Division**, the **CO_2-equivalent of Akashmoni** ranged from 274.588 tha^{-1} (in Khandari under Khandari Beat in Panagarh range; 23°27′07.5″N; 87°31′53.1″E) to 375.610 tha^{-1} (in Shyamsundarpur under Sonai Beat in Panagarh range; 23°28′41.5″N; 87°30′09.4″E); in **Eucalyptus the CO_2-equivalent** ranged from 461.374 tha^{-1} (in Shyamsundarpur under Sonai beat in Panagarh range; 23°28′41.5″N; 87°30′09.4″E) to 638.824 tha^{-1} (in Khandari under Khandari beat in Panagarh range; 23°27′07.5″N; 87°31′53.1″E); in **Sal the CO_2-equivalent** value ranged from 318.370 tha^{-1} (in Bilaspur under Sonai beat in Panagarh range; 23°28′25.1″N; 87°29″E) to 484.589 tha^{-1} (in Fari jungle under Adhuria beat in Panagarh range; 23°33′09.8″N; 87°32′16.9″E).

31) In the **5-year old plantation** of **Burdwan Division**, the **AGB of Akashmoni** ranged from 66.171 tha^{-1} (in Chhora under Adhuria Beat in Panagarh range; 23°34′58.5″N; 87°34′27.6″E) to 88.169 tha^{-1} (in Khandari under Khandari Beat in Panagarh range; 23°27′17.1″N; 87°30′58.9″E); in Chhora under Adhuria beat in Panagarh range (23°34′58.5″N; 87°34′27.6″E), the value of **AGB in Sal** was 116.341 tha^{-1}.

32) In the **5-year old plantation** of **Burdwan Division**, the **AGC of Akashmoni** ranged from 30.323 tha^{-1} (in Chhora under Adhuria Beat in Panagarh range; 23°34′58.5″N; 87°34′27.6″E) to 40.572 tha^{-1} (in Khandari under Khandari Beat in Panagarh range; 23°27′17.1″N; 87°30′58.9″E); in Chhora under Adhuria beat in Panagarh range (23°34′58.5″N; 87°34′27.6″E), the value of **AGC in Sal** was 53.459 tha^{-1}.

33) In the **5-year old plantation** of **Burdwan Division**, the **BGB of Akashmoni** ranged from 17.204 tha^{-1} (in Chhora under Adhuria Beat in Panagarh range; 23°34′58.5″N; 87°34′27.6″E) to 22.924 tha^{-1} (in Khandari under Khandari Beat in Panagarh range; 23°27′17.1″N; 87°30′58.9″E); in Chhora under Adhuria beat in Panagarh range (23°34′58.5″N; 87°34′27.6″E), the value of **BGB in Sal** was 30.249 tha^{-1}.

34) In the **5-year old plantation** of **Burdwan Division**, the **sequestered carbon in AGB of Akashmoni** ranged from 6.065 $tha^{-1}y^{-1}$ (in Chhora under Adhuria Beat in Panagarh range; 23°34′58.5″N; 87°34′27.6″E) to 8.114 $tha^{-1}y^{-1}$ (in Khandari under Khandari Beat in Panagarh range; 23°27′17.1″N; 87°30′58.9″E); in Chhora under Adhuria beat in Panagarh range (23°34′58.5″N; 87°34′27.6″E), the value of **sequestered carbon in AGB in Sal** was 10.692 $tha^{-1}y^{-1}$.

35) In the **5-year old plantation** of **Burdwan Division**, the **CO_2-equivalent of Akashmoni** ranged from 111.286 tha^{-1} (in Chhora under Adhuria Beat in Panagarh range; 23°34′58.5″N; 87°34′27.6″E) to 148.898 tha^{-1} (in Khandari under Khandari Beat in Panagarh range; 23°27′17.1″N; 87°30′58.9″E); in Chhora under Adhuria beat in Panagarh range (23°34′58.5″N; 87°34′27.6″E), the value of **CO_2-equivalent in Sal** was 196.195 tha^{-1}.

36) In the **1-year old plantation** of **Burdwan Division**, the **AGB of Akashmoni** ranged from 2.255 tha^{-1} (in Jijira under Sonai Beat in Panagarh range; 23°30′35.2″N; 87°30′54.3″E) to 2.457 tha^{-1} (in Paduma under Sonai Beat in Panagarh range; 23°30′28.7″N; 87°30′19.5″E); in **Sal the AGB** value ranged from 2.387 tha^{-1} (in Paduma under Sonai Beat in Panagarh range; 23°30′28.7″N; 87°30′19.5″E) to 2.504 tha^{-1} (in Bhuera under Adhuria beat in Panagarh range; 23°33′17.0″N; 87°34′55.8″E).

37) In the **1-year old plantation** of **Burdwan Division**, the **AGC of Akashmoni** ranged from 1.087 tha^{-1} (in Jijira under Sonai Beat in Panagarh range; 23°30′35.2″N; 87°30′54.3″E) to 1.182 tha^{-1} (in Paduma under Sonai Beat in Panagarh range; 23°30′28.7″N; 87°30′19.5″E); in **Sal the AGC** value ranged from 1.170 tha^{-1} (in Paduma under Sonai Beat in Panagarh range; 23°30′28.7″N; 87°30′19.5″E) to 1.230 tha^{-1} (in Bhuera under Adhuria beat in Panagarh range; 23°33′17.0″N; 87°34′55.8″E).

38) In the **1-year old plantation** of **Burdwan Division**, the **BGB of Akashmoni** ranged from 0.496 tha^{-1} (in Jijira under Sonai Beat in Panagarh range; 23°30′35.2″N; 87°30′54.3″E) to 0.540 tha^{-1} (in Paduma under Sonai Beat in Panagarh range; 23°30′28.7″N; 87°30′19.5″E); in **Sal the BGB** value ranged from 0.525 tha^{-1} (in Paduma under Sonai Beat in Panagarh range; 23°30′28.7″N; 87°30′19.5″E) to 0.551 tha^{-1} (in Bhuera under Adhuria beat in Panagarh range; 23°33′17.0″N; 87°34′55.8″E).

39) In the **1-year old plantation** of **Burdwan Division**, the **sequestered carbon in AGB of Akashmoni** ranged from 1.087 $tha^{-1}y^{-1}$ (in Jijira under Sonai Beat in Panagarh range; 23°30′35.2″N; 87°30′54.3″E) to 1.182 $tha^{-1}y^{-1}$ (in Paduma under Sonai Beat in Panagarh range; 23°30′28.7″N; 87°30′19.5″E); in **Sal the sequestered carbon in AGB** value ranged from 1.170 $tha^{-1}y^{-1}$ (in Paduma under Sonai Beat in Panagarh range;

23°30′28.7″N; 87°30′19.5″E) to 1.230 $tha^{-1}y^{-1}$ (in Bhuera under Adhuria beat in Panagarh range; 23°33′17.0″N; 87°34′55.8″E).

40) In the **1-year old plantation** of **Burdwan Division**, the **CO_2-equivalent of AGB of Akashmoni** ranged from 3.990 tha^{-1} (in Jijira under Sonai Beat in Panagarh range; 23°30′35.2″N; 87°30′54.3″E) to 4.337 tha^{-1} (in Paduma under Sonai Beat in Panagarh range; 23°30′28.7″N; 87°30′19.5″E); in **Sal the CO_2-equivalent of AGB** value ranged from 4.293 tha^{-1} (in Paduma under Sonai Beat in Panagarh range; 23°30′28.7″N; 87°30′19.5″E) to 4.512 tha^{-1} (in Bhuera under Adhuria beat in Panagarh range; 23°33′17.0″N; 87°34′55.8″E).

1.D] BIRBHUM DIVISION

41) In the **9-year old plantation** of **Birbhum Division**, the **AGB of Akashmoni** ranged from 174.455 tha^{-1} (in Ballavpur under Bolpur Beat in Bolpur range; 23°40′50.1″N; 87°39′08.1″E) to 213.589 tha^{-1} (in Faridpur under Bolpur Beat in Bolpur range; 23°41′44.1″N; 87°35′55.9″E).

42) In the **9-year old plantation** of **Birbhum Division**, the **AGC of Akashmoni** ranged from 80.379 tha^{-1} (in Ballavpur under Bolpur Beat in Bolpur range; 23°40′50.1″N; 87°39′08.1″E) to 98.434 tha^{-1} (in Faridpur under Bolpur Beat in Bolpur range; 23°41′44.1″N; 87°35′55.9″E).

43) In the **9-year old plantation** of **Birbhum Division**, the **BGB of Akashmoni** ranged from 45.358 tha^{-1} (in Ballavpur under Bolpur Beat in Bolpur range; 23°40′50.1″N; 87°39′08.1″E) to 55.533 tha^{-1} (in Faridpur under Bolpur Beat in Bolpur range; 23°41′44.1″N; 87°35′55.9″E).

44) In the **9-year old plantation** of **Birbhum Division**, the **sequestered carbon in AGB of Akashmoni** ranged from 8.931 $tha^{-1}y^{-1}$ (in Ballavpur under Bolpur Beat in Bolpur range; 23°40′50.1″N; 87°39′08.1″E) to 10.937 $tha^{-1}y^{-1}$ (in Faridpur under Bolpur Beat in Bolpur range; 23°41′44.1″N; 87°35′55.9″E).

45) In the **9-year old plantation** of **Birbhum Division**, the **CO_2-equivalent AGB of Akashmoni** ranged from 294.992 tha^{-1} (in Ballavpur under Bolpur Beat in Bolpur range; 23°40′50.1″N; 87°39′08.1″E) to 361.254 tha^{-1} (in Faridpur under Bolpur Beat in Bolpur range; 23°41′44.1″N; 87°35′55.9″E).

46) In the **9-year old plantation** of **Birbhum Division**, the **AGB of Eucalyptus** ranged from 216.371 tha^{-1} (in Ballavpur under Bolpur Beat in Bolpur range; 23°40′50.1″N; 87°39′08.1″E) to 467.922 tha^{-1} (in Faridpur under Bolpur Beat in Bolpur range; 23°41′44.1″N; 87°35′55.9″E).

47) In the **9-year old plantation** of **Birbhum Division**, the **AGC of Eucalyptus** ranged from 101.703 tha^{-1} (in Ballavpur under Bolpur Beat in Bolpur range; 23°40′50.1″N; 87°39′08.1″E) to 215.296 tha^{-1} (in Faridpur under Bolpur Beat in Bolpur range; 23°41′44.1″N; 87°35′55.9″E).

48) In the **9-year old plantation** of **Birbhum Division**, the **BGB of Eucalyptus** ranged from 56.256 tha^{-1} (in Ballavpur under Bolpur Beat in Bolpur range; 23°40′50.1″N; 87°39′08.1″E) to 121.660 tha^{-1} (in Faridpur under Bolpur Beat in Bolpur range; 23°41′44.1″N; 87°35′55.9″E).

49) In the **9-year old plantation** of **Birbhum Division**, the **sequestered carbon in AGB of Eucalyptus** ranged from 20.341 $tha^{-1}y^{-1}$ (in Ballavpur under Bolpur Beat in Bolpur range; 23°40′50.1″N; 87°39′08.1″E) to 43.059 $tha^{-1}y^{-1}$ (in Faridpur under Bolpur Beat in Bolpur range; 23°41′44.1″N; 87°35′55.9″E).

50) In the **9-year old plantation** of **Birbhum Division**, the **CO_2-equivalent AGB of Eucalyptus** ranged from 373.250 tha^{-1} (in Ballavpur under Bolpur Beat in Bolpur range; 23°40′50.1″N; 87°39′08.1″E) to 790.135 tha^{-1} (in Faridpur under Bolpur Beat in Bolpur range; 23°41′44.1″N; 87°35′55.9″E).

For convenience, division – wise comparative accounts for the three candidate species are highlighted in Tables 3, 4 and 5 and Figs. 12 - 26.

Table 3. Biotic Report Card in the selected forest divisions for Akashmoni tree of three different ages

Divisions	**Years**	**AGB (tha^{-1})**	**AGC (tha^{-1})**	**BGB (tha^{-1})**	**Sequestered Carbon (tha^{-1} yr^{-1})**	**CO_2-equivalent (tha^{-1})**
Bankura North	**1 year**	3.439	1.554	0.791	1.554	5.704
	5 year	113.649	49.877	29.549	9.975	183.050
	9 year	204.937	90.324	53.284	10.036	331.488
Durgapur	**1 year**	NA	NA	NA	NA	NA
	5 year	48.454	22.395	12.598	4.479	82.188
	9 year	141.644	65.843	36.828	7.316	241.645
Burdwan	**1 year**	2.392	1.151	0.526	1.151	4.224

	5 year	75.147	34.521	19.538	6.904	126.691
	9 year	191.094	88.583	49.684	9.843	325.099
Birbhum	**1 year**	NA	NA	NA	NA	NA
	5 year	NA	NA	NA	NA	NA
	9 year	194.022	89.407	50.446	9.934	328.123

'NA' – means non-availability of the species in the sites

Table 4. Biotic Report Card in the selected forest divisions of Eucalyptus tree of three different ages

Divisions	**Years**	**AGB (tha^{-1})**	**AGC (tha^{-1})**	**BGB (tha^{-1})**	**Sequestered Carbon ($tha^{-1}\ yr^{-1}$)**	**CO_2-equivalent (tha^{-1})**
Bankura North	**1 year**	NA	NA	NA	NA	NA
	5 year	332.769	152.979	86.520	30.596	561.434
	9 year	NA	NA	NA	NA	NA
Durgapur	**1 year**	NA	NA	NA	NA	NA
	5 year	NA	NA	NA	NA	NA
	9 year	NA	NA	NA	NA	NA
Burdwan	**1 year**	NA	NA	NA	NA	NA
	5 year	NA	NA	NA	NA	NA
	9 year	327.271	150.076	85.090	16.675	550.777
Birbhum	**1 year**	NA	NA	NA	NA	NA
	5 year	NA	NA	NA	NA	NA
	9 year	342.147	158.499	88.958	31.700	581.692

'NA' – means non-availability of the species in the sites

Table 5. Biotic Report Card in five selected forest divisions of Sal tree of three different ages

Divisions	**Years**	**AGB (tha^{-1})**	**AGC (tha^{-1})**	**BGB (tha^{-1})**	**Sequestered Carbon ($tha^{-1}\ yr^{-1}$)**	**CO_2-equivalent (tha^{-1})**
Bankura North	**1 year**	4.043	1.973	0.930	1.973	7.242
	5 year	NA	NA	NA	NA	NA
	9 year	233.945	109.041	60.826	12.116	400.180
Durgapur	**1 year**	NA	NA	NA	NA	NA
	5 year	NA	NA	NA	NA	NA
	9 year	NA	NA	NA	NA	NA
Burdwan	**1 year**	2.446	1.200	0.538	1.200	4.403
	5 year	116.341	53.459	30.249	10.692	196.195
	9 year	226.964	105.001	59.011	11.667	385.353
Birbhum	**1 year**	NA	NA	NA	NA	NA
	5 year	NA	NA	NA	NA	NA
	9 year	NA	NA	NA	NA	NA

'NA' – means non-availability of the species in the sites

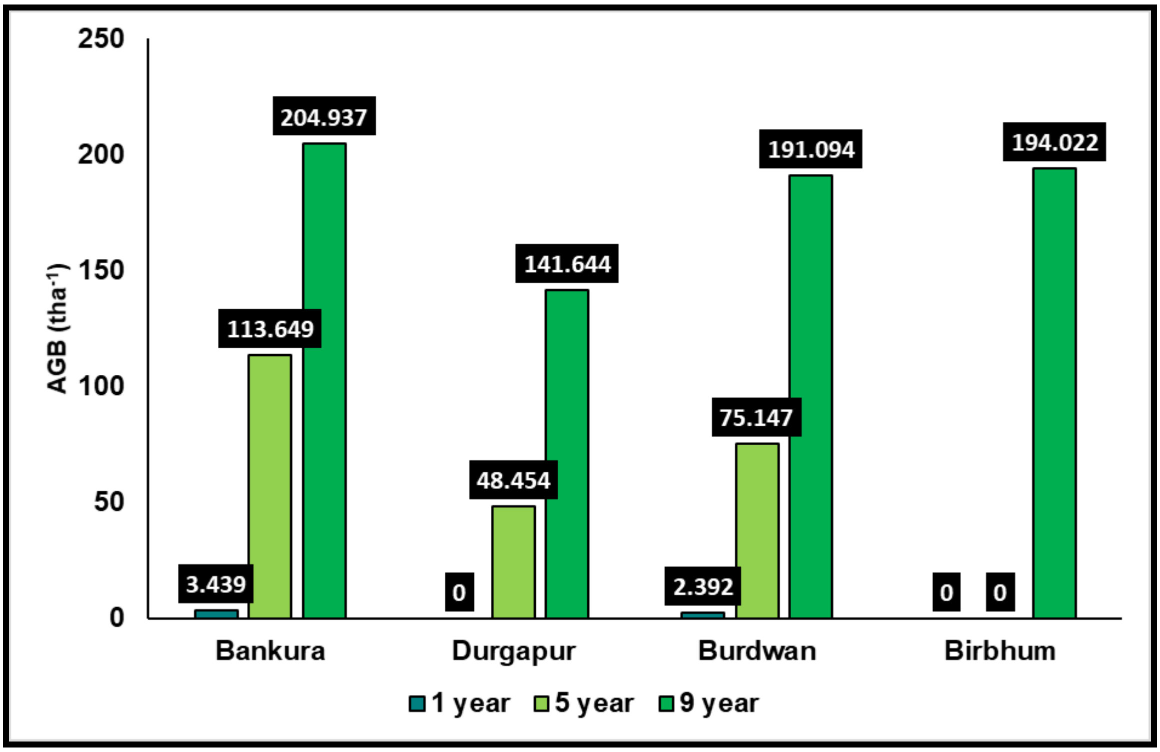


Fig. 12. Age-wise AGB (in tha^{-1}) of Akashmoni tree in four selected forest divisions of three different ages; '0' means non-availability of the species

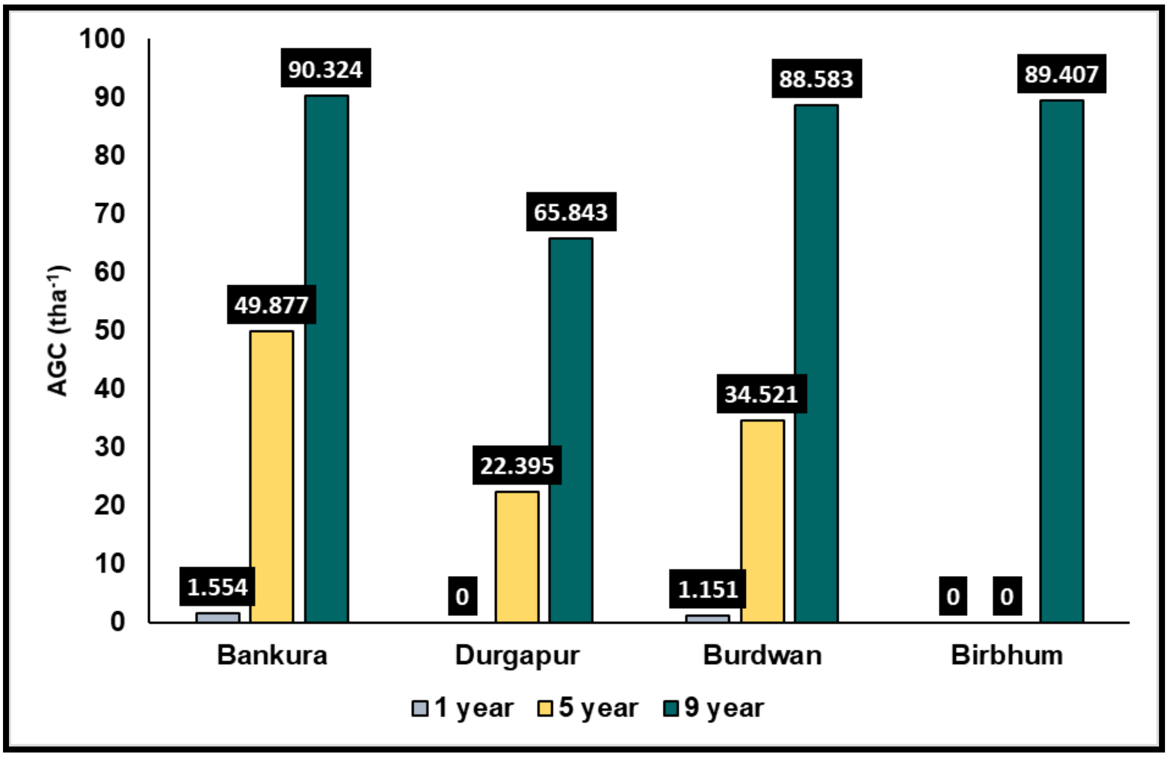


Fig. 13. Age-wise AGC (in tha^{-1}) of Akashmoni tree in four selected forest divisions of three different ages; '0' means non-availability of the species

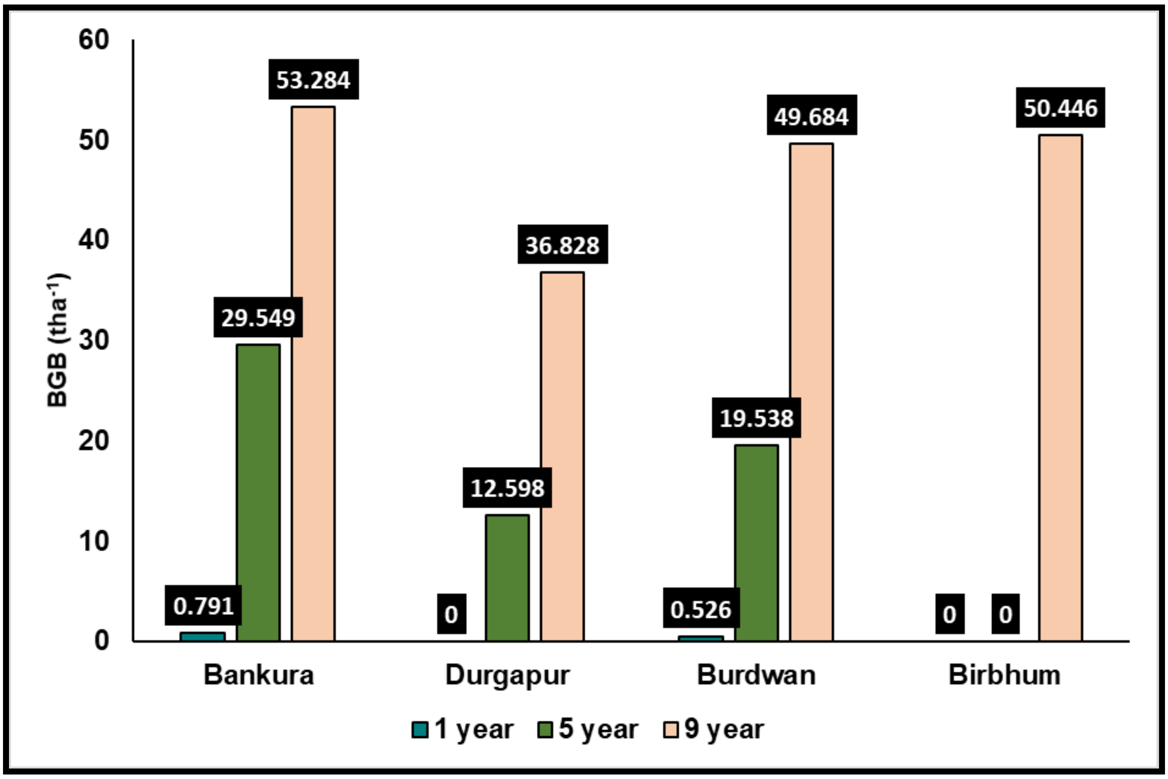


Fig. 14. Age-wise BGB (in tha^{-1}) of Akashmoni tree in four selected forest divisions of three different ages; '0' means non-availability of the species

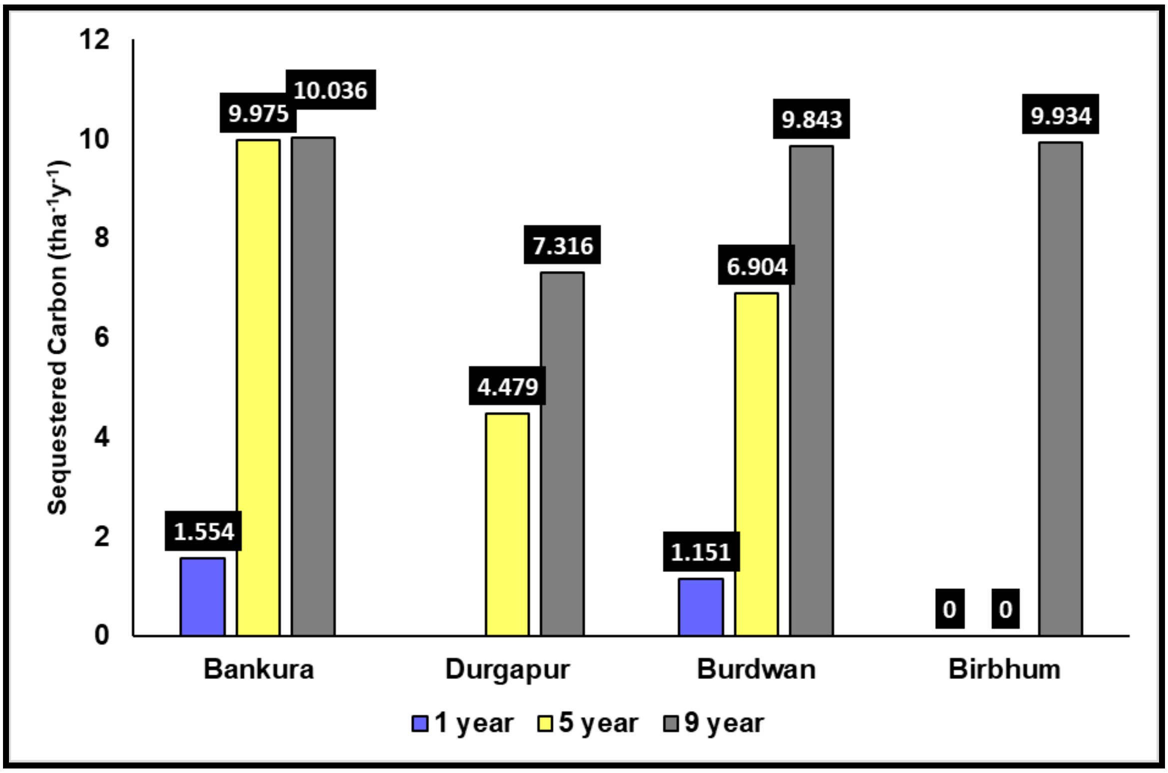


Fig. 15. Age-wise sequestered carbon of AGB (in tha^{-1}y^{-1}) of Akashmoni tree in four selected forest divisions of three different ages; '0' means non-availability of the species

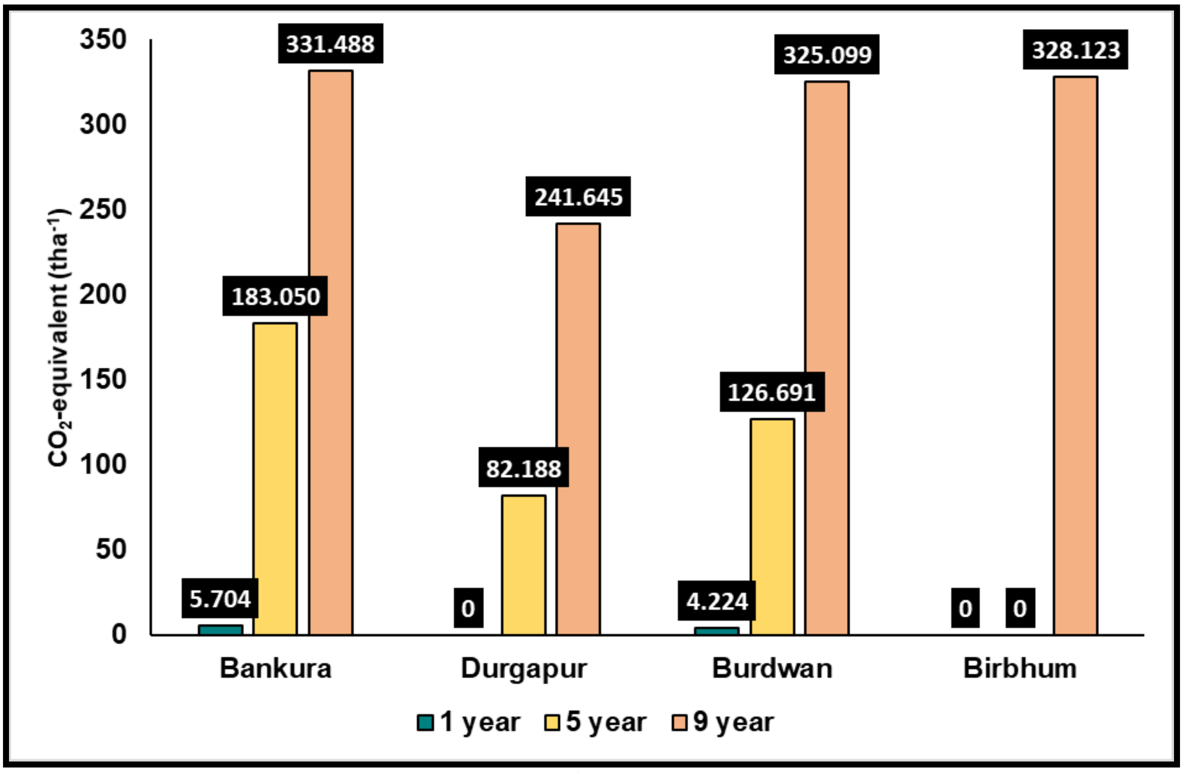


Fig. 16. Age-wise CO_2-equivalent (in tha^{-1}) of Akashmoni tree in four selected forest divisions of three different ages; '0' means non-availability of the species

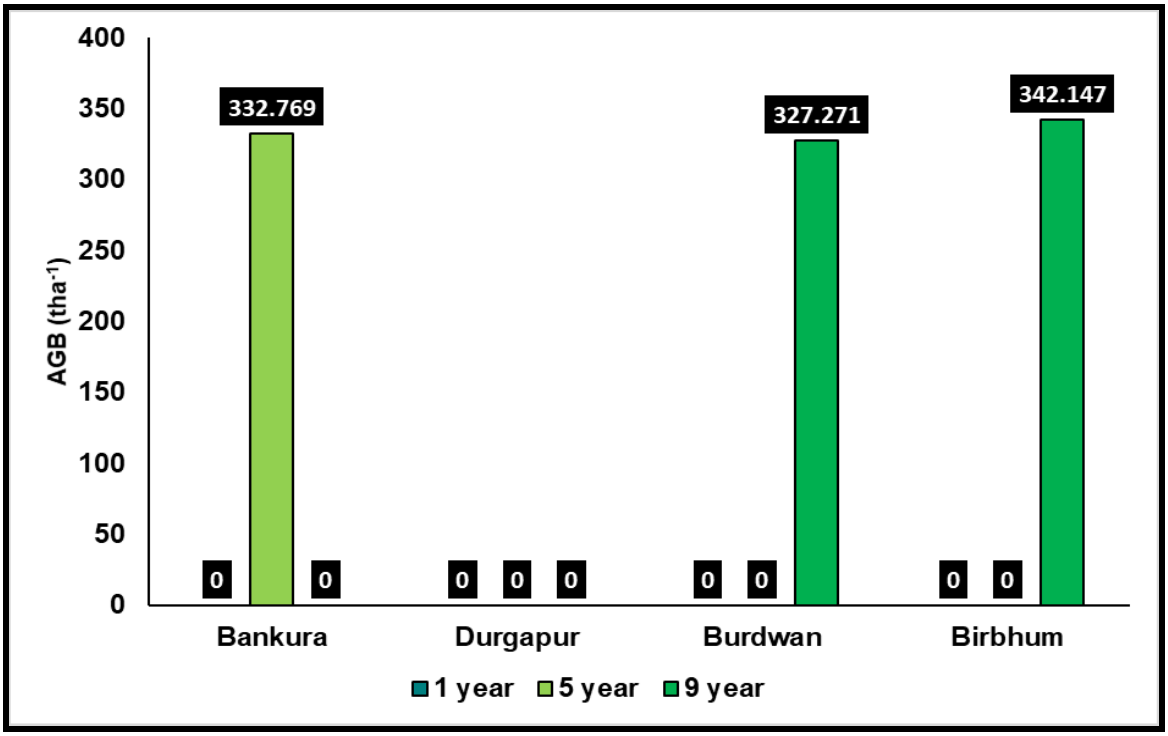


Fig. 17. Age-wise AGB (in tha^{-1}) of Eucalyptus tree in four selected forest divisions of three different ages; '0' means non-availability of the species

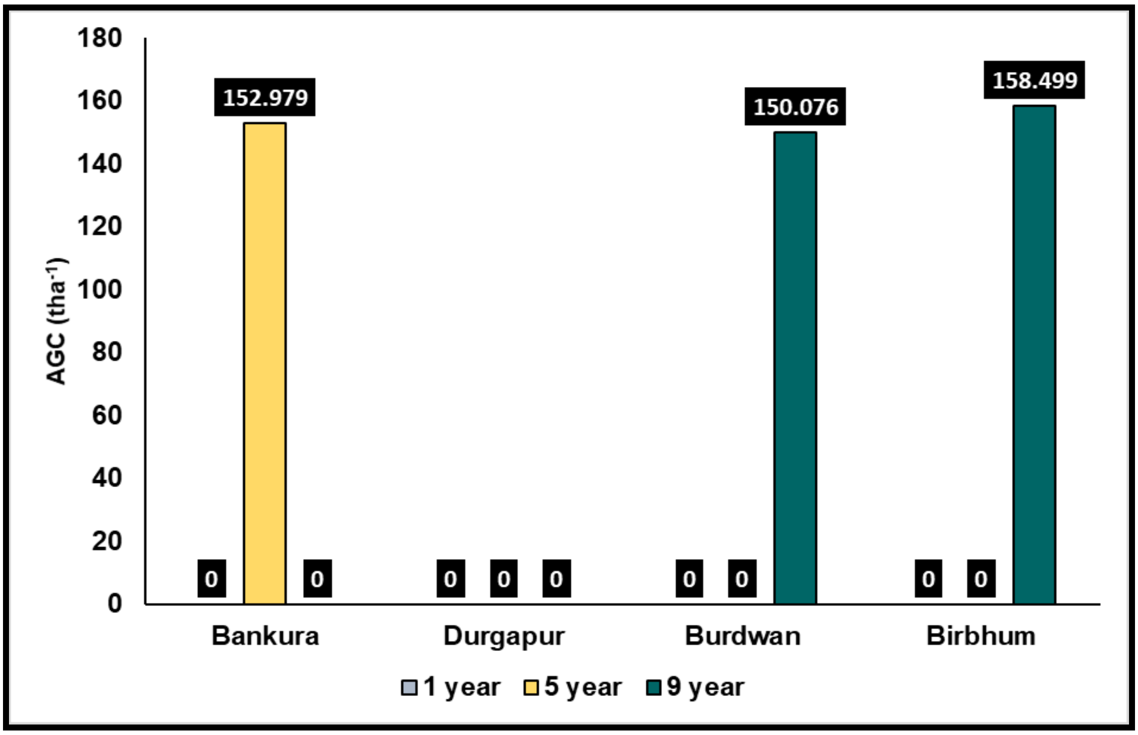


Fig. 18. Age-wise AGC (in tha^{-1}) of Eucalyptus tree in four selected forest divisions of three different ages; ‘0’ means non-availability of the species

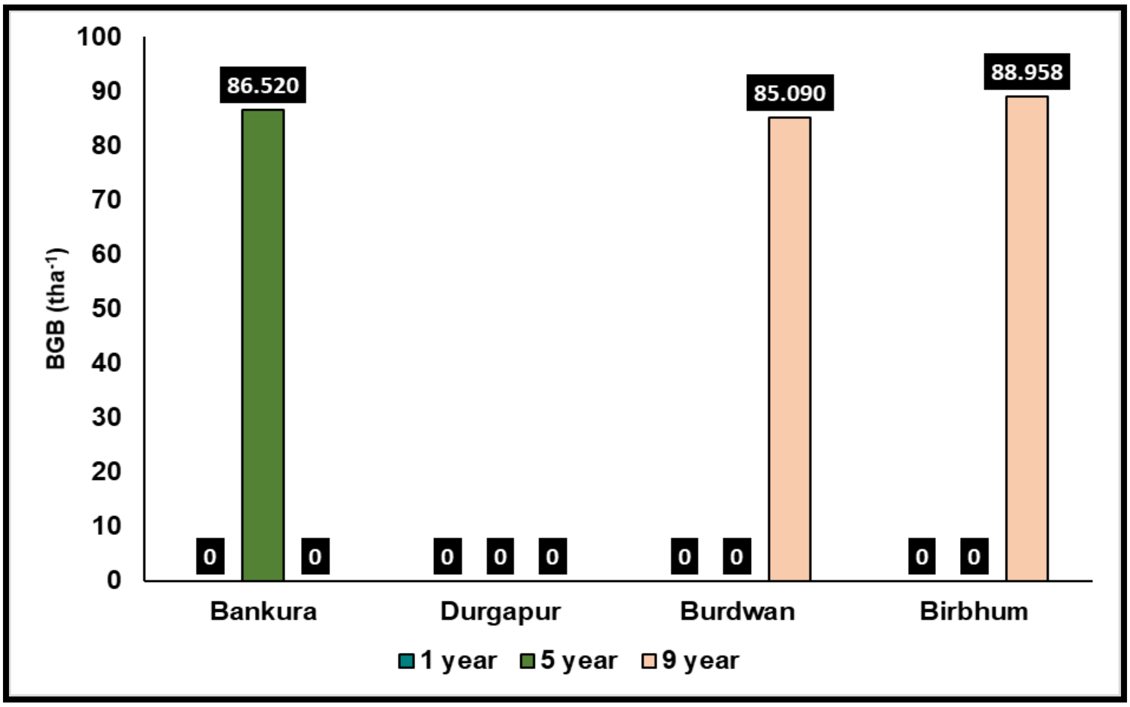


Fig. 19. Age-wise BGB (in tha^{-1}) of Eucalyptus tree in four selected forest divisions of three different ages; ‘0’ means non-availability of the species

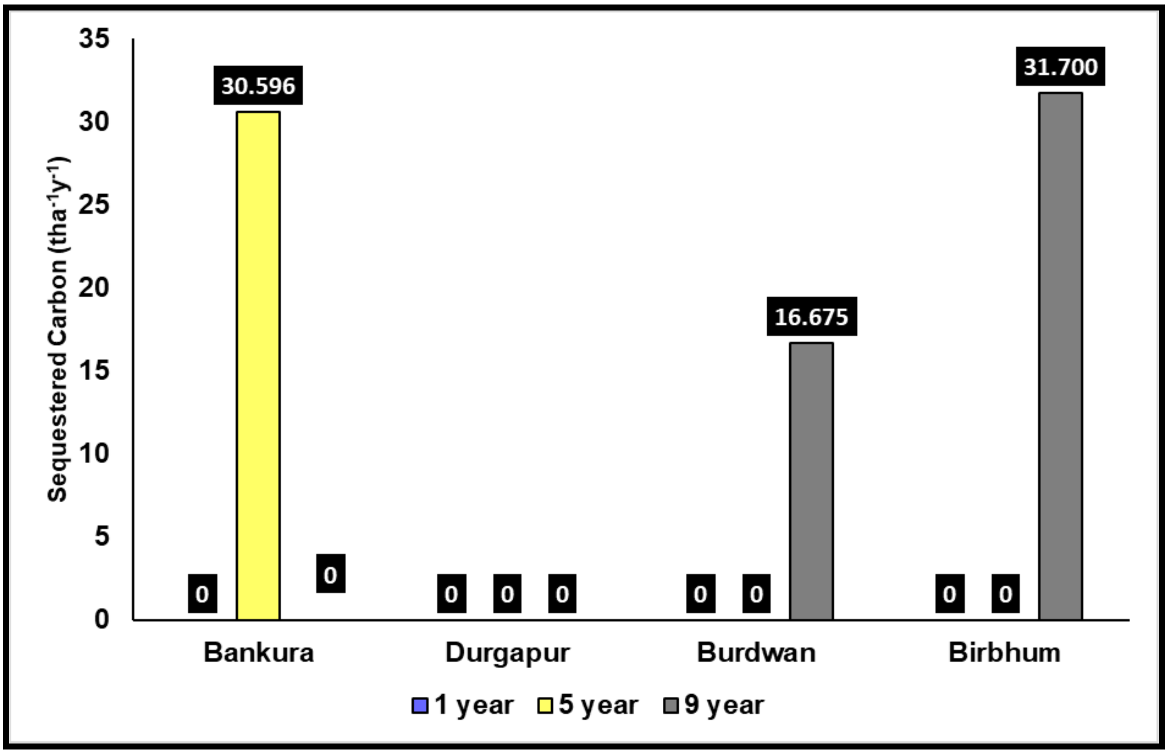


Fig. 20. Age-wise sequestered carbon of AGB (in $tha^{-1}y^{-1}$) of Eucalyptus tree in four selected forest divisions of three different ages; '0' means non-availability of the species

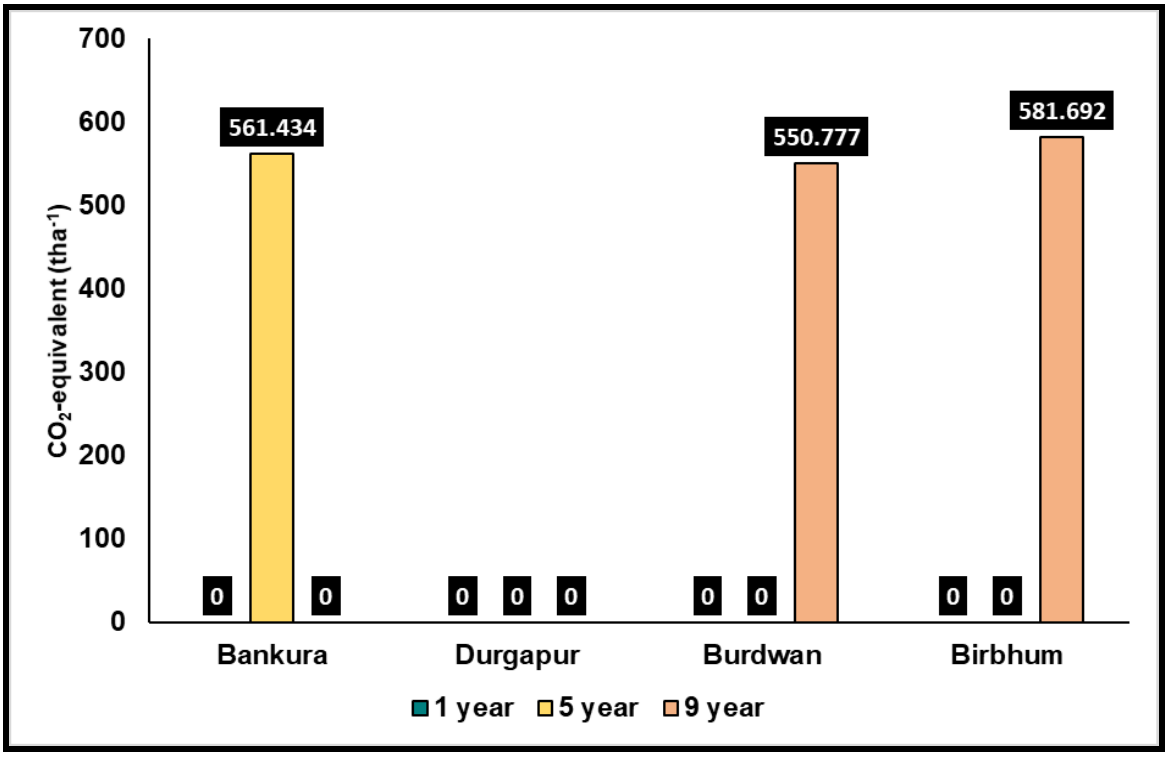


Fig. 21. Age-wise CO_2-equivalent (in tha^{-1}) of Eucalyptus tree in four selected forest divisions of three different ages; '0' means non-availability of the species

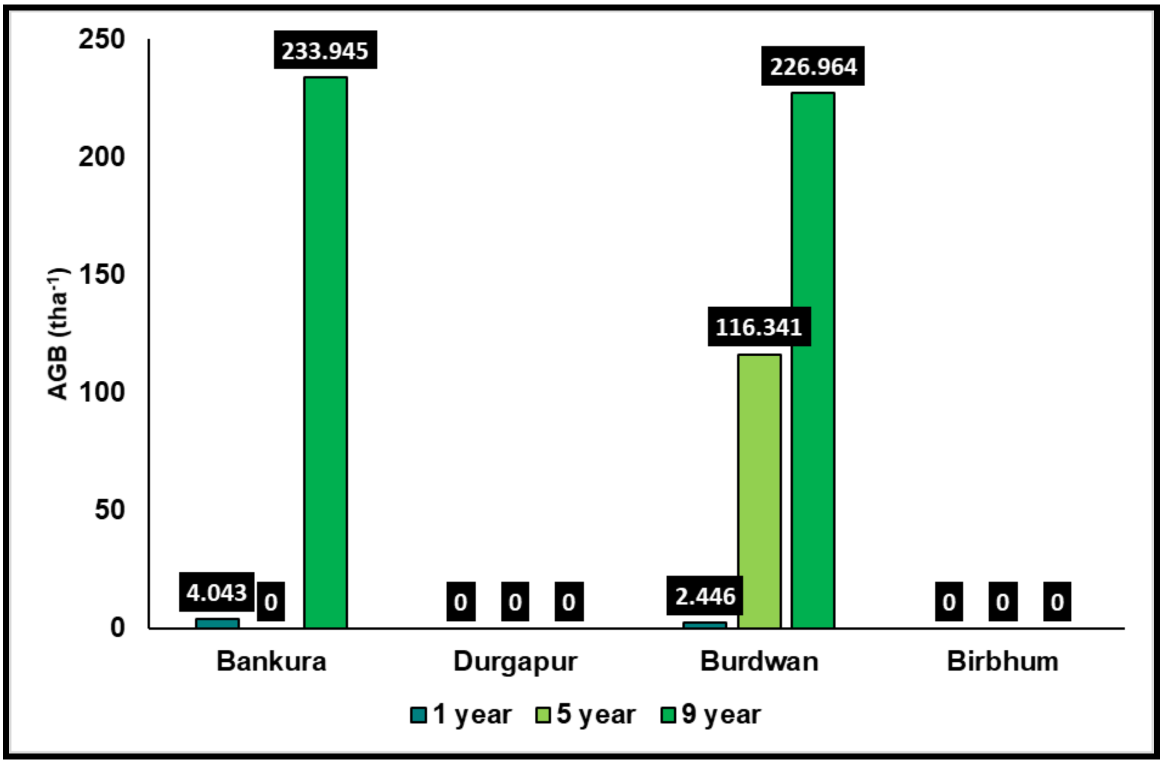


Fig. 22. Age-wise AGB (in tha^{-1}) of Sal tree in four selected forest divisions of three different ages; '0' means non-availability of the species

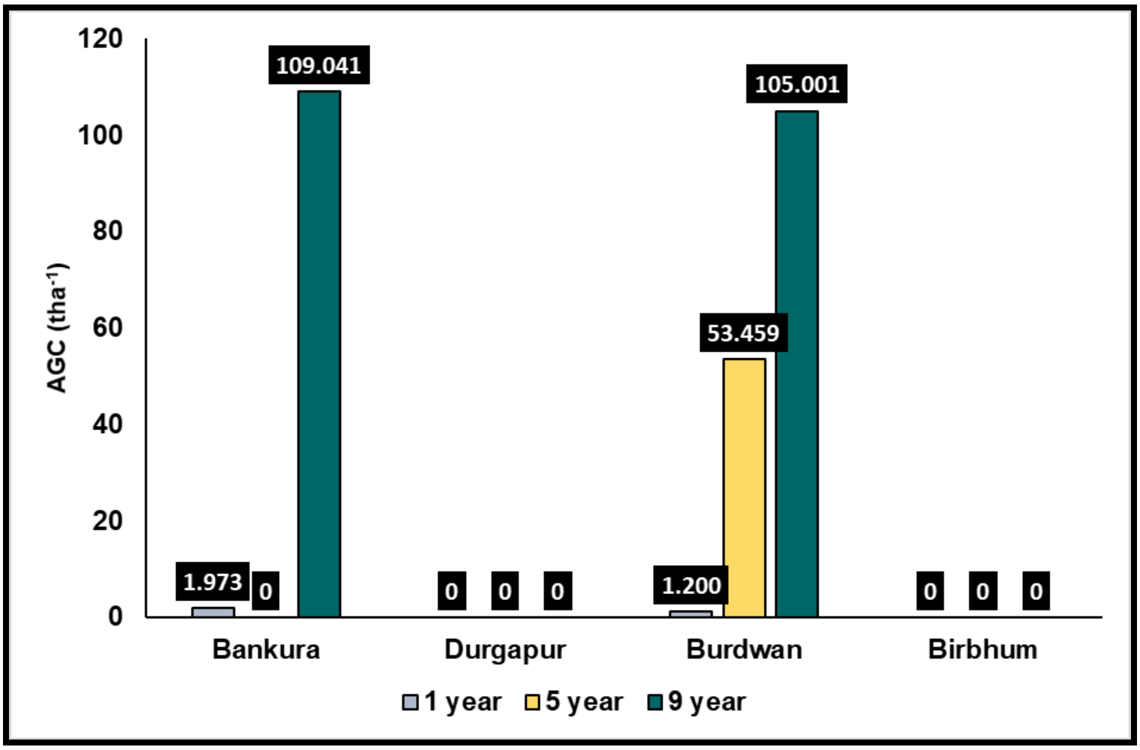


Fig. 23. Age-wise AGC (in tha^{-1}) of Sal tree in four selected forest divisions of three different ages; '0' means non-availability of the species

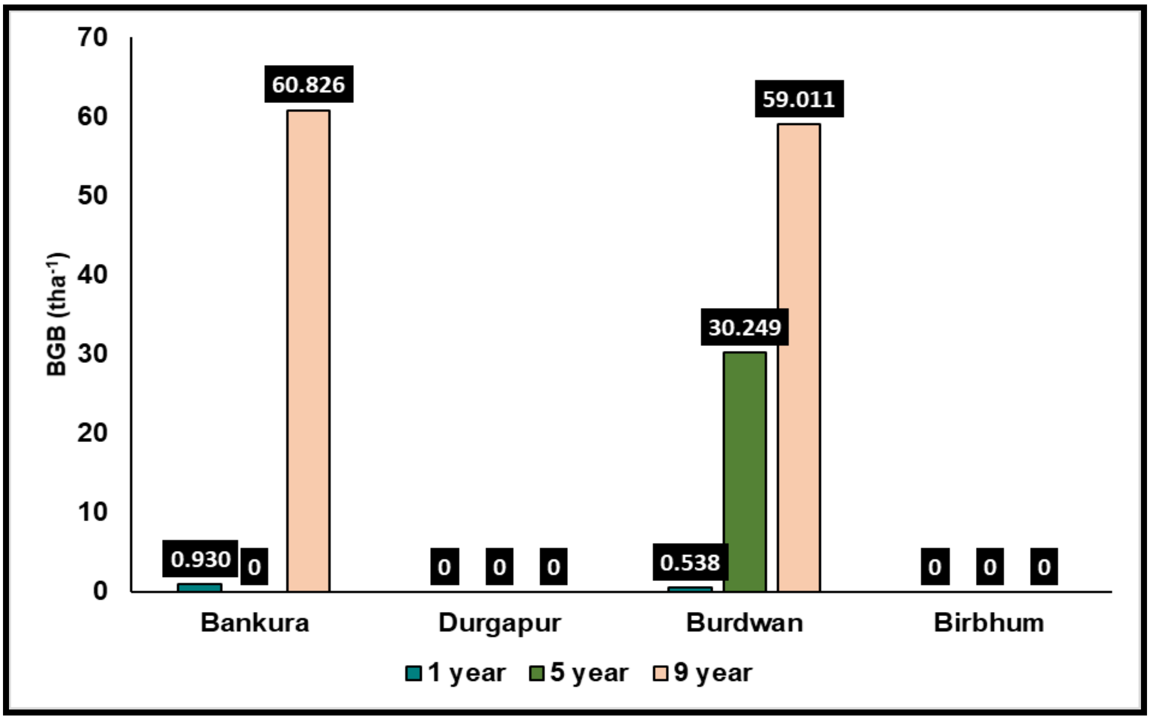


Fig. 24. Age-wise BGB (in tha^{-1}) of Sal tree in four selected forest divisions of three different ages; '0' means non-availability of the species

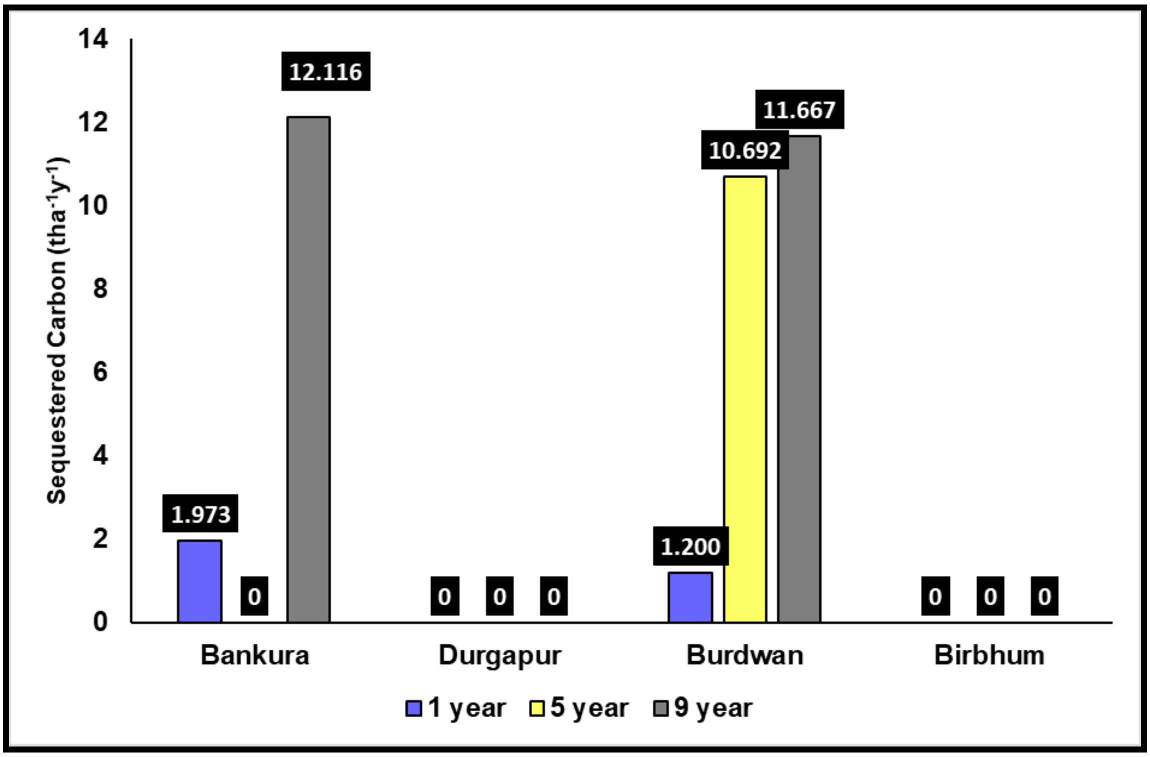


Fig. 25. Age-wise sequestered carbon of AGB (in tha^{-1}y^{-1}) of Sal tree in four selected forest divisions of three different ages; '0' means non-availability of the species

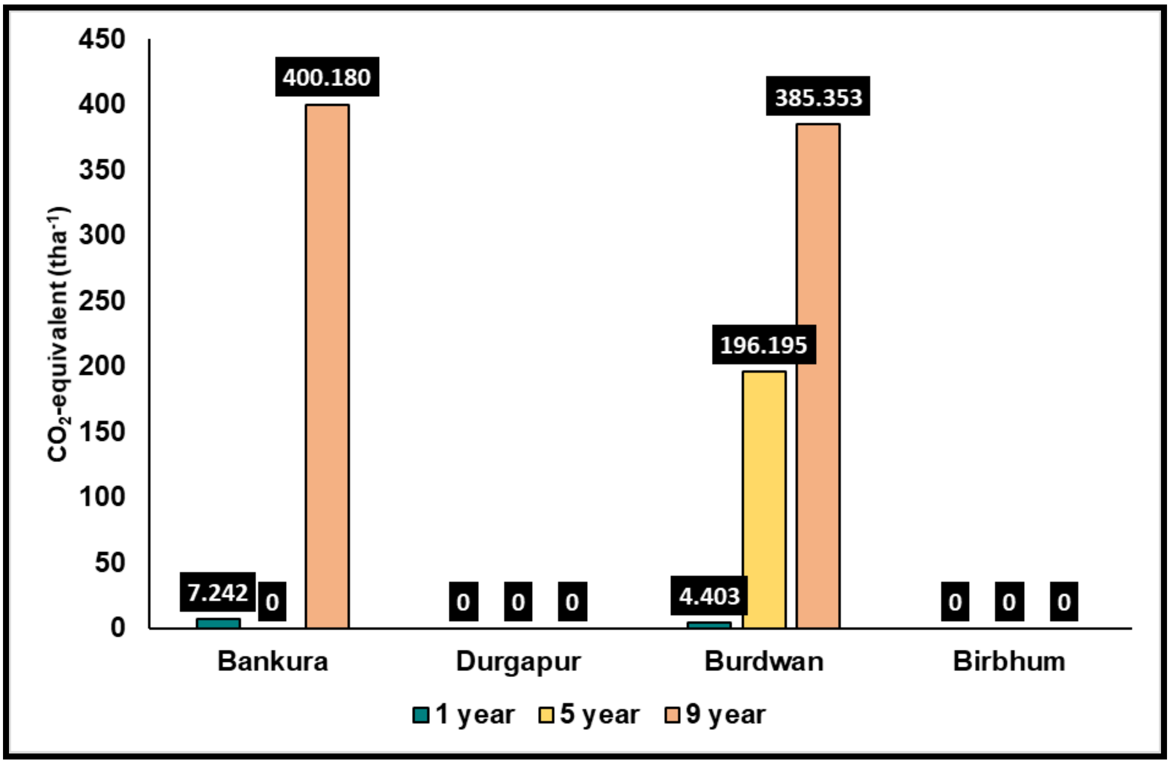


Fig. 26. Age-wise CO_2-equivalent (in tha^{-1}) of Sal tree in four selected forest divisions of three different ages; '0' means non-availability of the species

2. Abiotic Components

The abiotic components have great influence on the forest floral community *e.g.*, the edaphic factors like SOC, pH etc. regulate the survival and growth of the plants, which in turn pose a considerable impact on the ambient carbon dioxide level. Based on our ground-zero monitoring of abiotic components like near surface atmospheric carbon dioxide, SOC and soil pH, we furnish here the abiotic report cards in and around the habitats of the three floral candidate species separately for four forest divisions of South Bengal in Tables 6, 7 and 8.

2.1 Average Near Surface Atmospheric CO_2 (ppm)

In the present study, the average near surface atmospheric CO_2 level in **Akashmoni forest habitat** varied as per the order Durgapur (393 ppm) > Burdwan (388 ppm) > Birbhum (375 ppm) > Bankura North (352 ppm); the average near surface atmospheric CO_2 level in **Eucalyptus forest habitat** varied as per the order Burdwan (395 ppm) > Birbhum (378 ppm) > Bankura North (354 ppm) and the average near surface atmospheric CO_2 level in **Sal forest habitat** varied as per the order Burdwan (367 ppm) > Bankura North (336 ppm) (*Vide* Tables 6, 7 and 8; Figs. 27 - 29).

Table 6. Average Near Surface atmospheric CO_2 level of Akashmoni tree habitat in four selected forest divisions

Divisions	Average Near Surface Atmospheric CO_2 (ppm)
Bankura North	352
Durgapur	393
Burdwan	388
Birbhum	375

Table 7. Average Near Surface atmospheric CO_2 level of Eucalyptus tree habitat in four selected forest divisions

Divisions	Average Near Surface Atmospheric CO_2 (ppm)
Bankura North	354
Durgapur	NA
Burdwan	395
Birbhum	378

'NA' – means non-availability of the species in the sites

Table 8. Average Near Surface atmospheric CO_2 level of Sal tree habitat in four selected forest divisions

Divisions	Average Near Surface Atmospheric CO_2 (ppm)
Bankura North	336
Durgapur	NA
Burdwan	367
Birbhum	NA

'NA' – means non-availability of the species in the sites

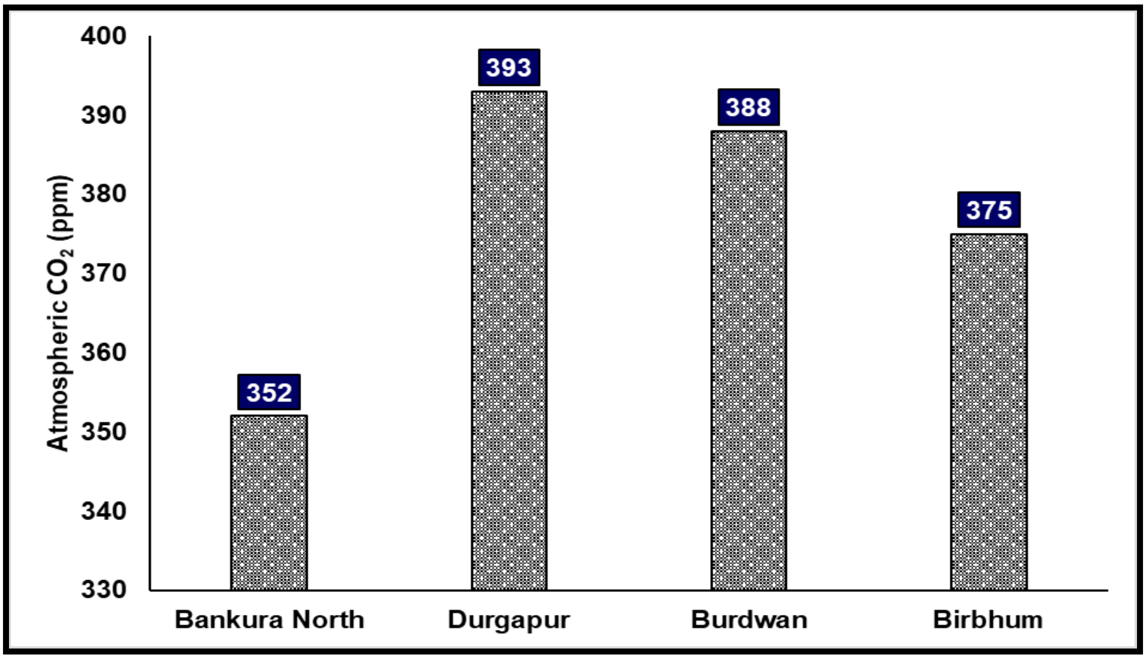


Fig. 27. Near surface atmospheric CO_2 (in ppm) in the Akashmoni forest habitat in the four selected forest divisions in South Bengal; '0' means non-availability of the species

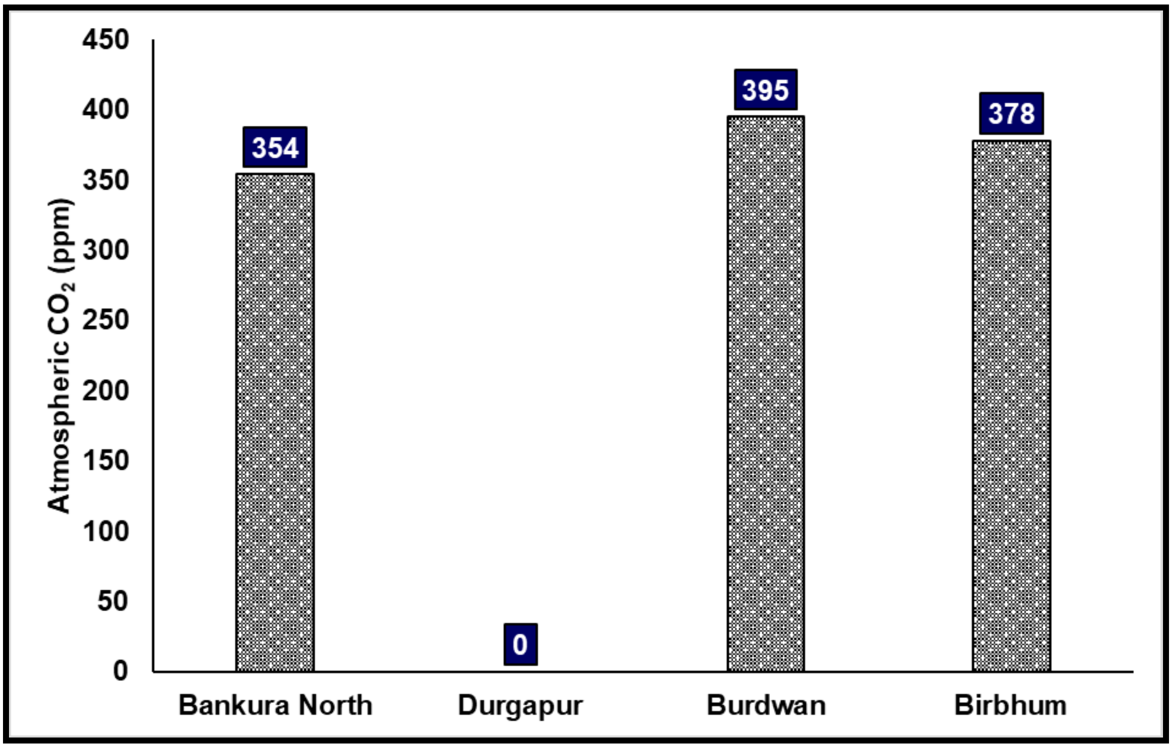


Fig. 28. Near surface atmospheric CO_2 (in ppm) in the Eucalyptus forest habitat in the four selected forest divisions in South Bengal; '0' means non-availability of the species

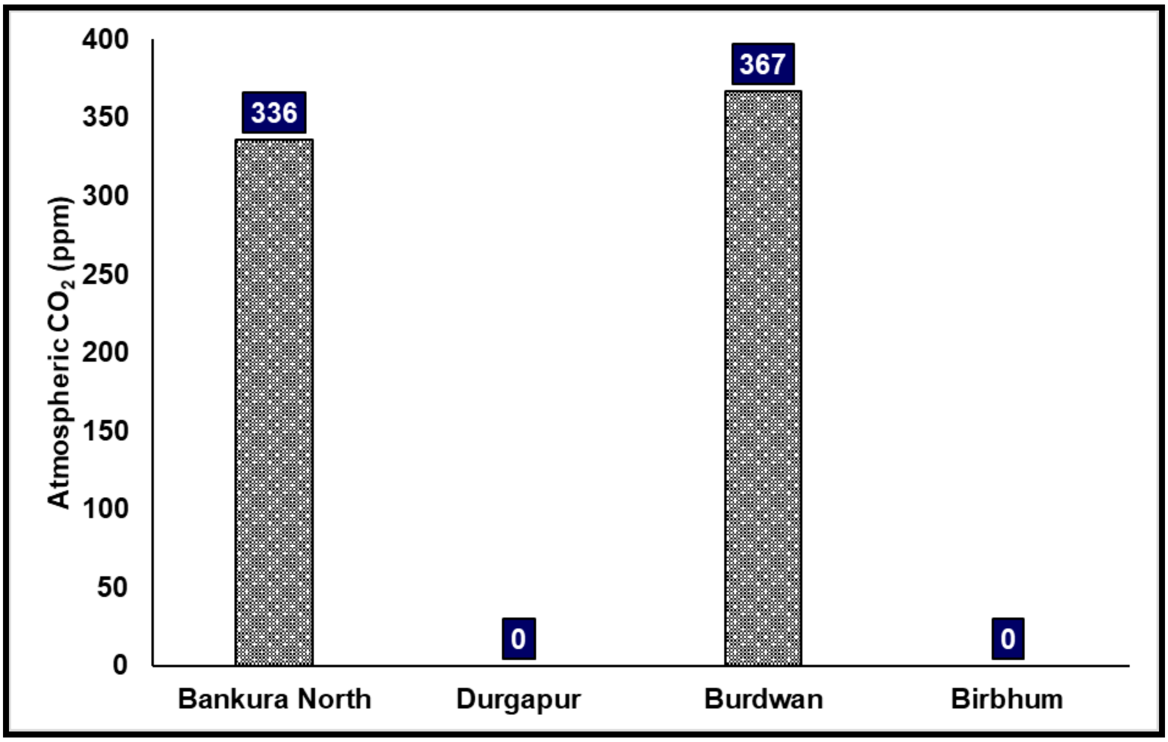


Fig. 29. Near surface atmospheric CO_2 (in ppm) in the Sal forest habitat in the four selected forest divisions in South Bengal; '0' means non-availability of the species

2.2 Soil Organic Carbon (SOC)

The average SOC in **Akashmoni forest habitat** varied as per the order Bankura North (0.96 %) > Burdwan (0.91 %) for 1-year plantation; Bankura North (1.37 %) > Burdwan (1.17%) > Durgapur (1.08 %) for 5-year old plantation; Bankura North (1.48 %) > Birbhum (1.39 %) > Burdwan (1.27 %) > Durgapur (1.15 %) for 9-year old plantation; the average SOC in **Eucalyptus forest habitat** was 1.13 (Bankura North) in 5-year old plantation; but in 9-year old plantation varied as per the order Birbhum (1.28 %) > Burdwan (1.23 %) and the average SOC in **Sal forest habitat** varied as per the order Bankura North (0.99) > Burdwan (0.96 %) in 1-year old plantation; the SOC value was 1.29 (Burdwan) in 5-year old plantation and in 9-year old plantation the value was varied as per the order Bankura North (1.57 %) > Burdwan (1.32 %) (*Vide* Tables 9, 10 and 11; Figs. 30 - 32).

Table 9. Soil Organic Carbon (in %) of 1-year, 5-year and 9-year old Akashmoni forest habitat in the selected four forest divisioins

Divisions	Soil Organic Carbon (%)		
	1-year	5-year	9-year
Bankura North	0.96	1.37	1.48
Durgapur	NA	1.08	1.15
Burdwan	0.91	1.17	1.27
Birbhum	NA	NA	1.39

'NA' – means non-availability of the species in the sites

Table 10. Soil Organic Carbon (in %) of 1-year, 5-year and 9-year old Eucalyptus forest habitat in the selected four forest divisioins

Divisions	Soil Organic Carbon (%)		
	1-year	5-year	9-year
Bankura North	NA	1.13	NA
Durgapur	NA	NA	NA
Burdwan	NA	NA	1.23
Birbhum	NA	NA	1.28

'NA' – means non-availability of the species in the sites

Table 11. Soil Organic Carbon (in %) of 1-year, 5-year and 9-year old Sal forest habitat in the selected four forest divisioins

Divisions	Soil Organic Carbon (%)		
	1-year	5-year	9-year
Bankura North	0.99	NA	1.57
Durgapur	NA	NA	NA
Burdwan	0.96	1.29	1.32
Birbhum	NA	NA	NA

'NA' – means non-availability of the species in the sites

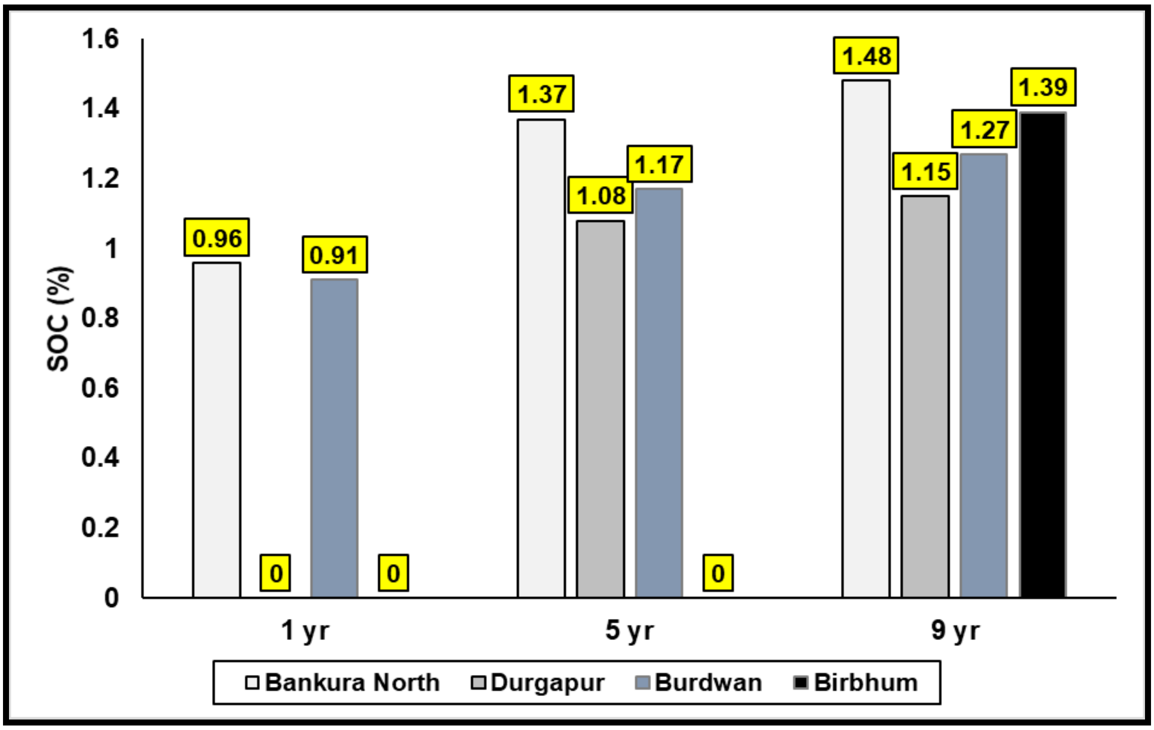


Fig. 30. Soil Organic Carbon (in %) in the Age-wise Akashmoni forest habitat of four selected forest divisions in South Bengal; '0' means non-availability of the species

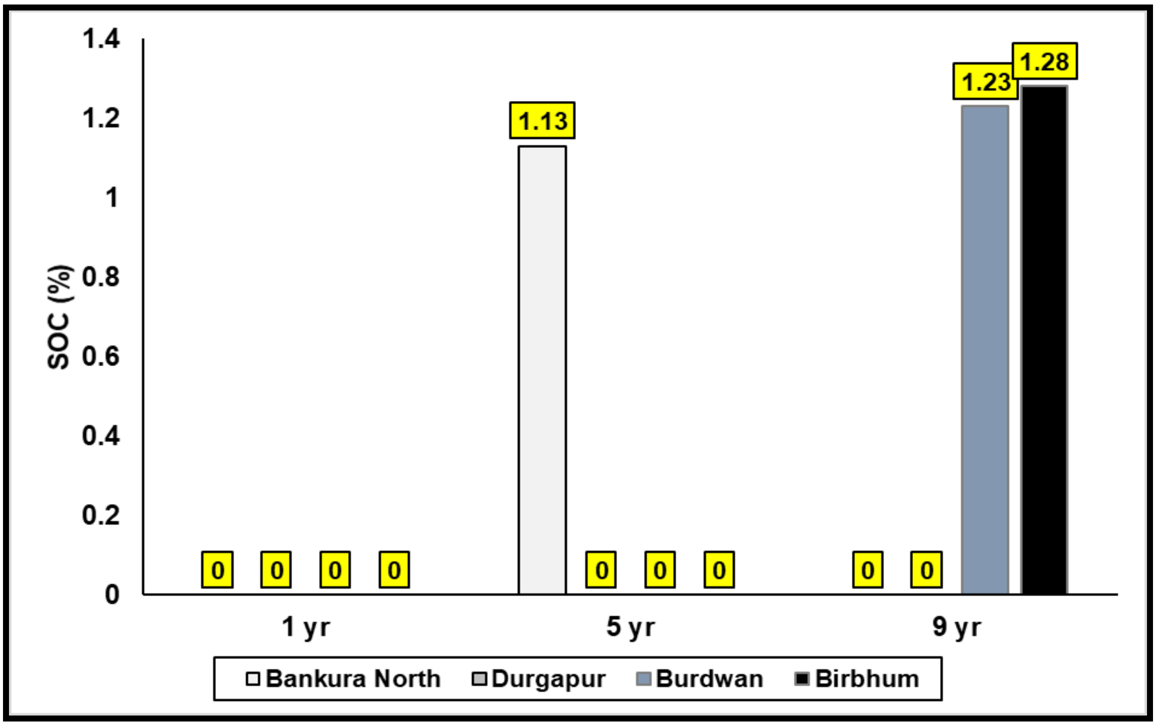


Fig. 31. Soil Organic Carbon (in %) in the Age-wise Eucalyptus forest habitat of four selected forest divisions in South Bengal; '0' means non-availability of the species

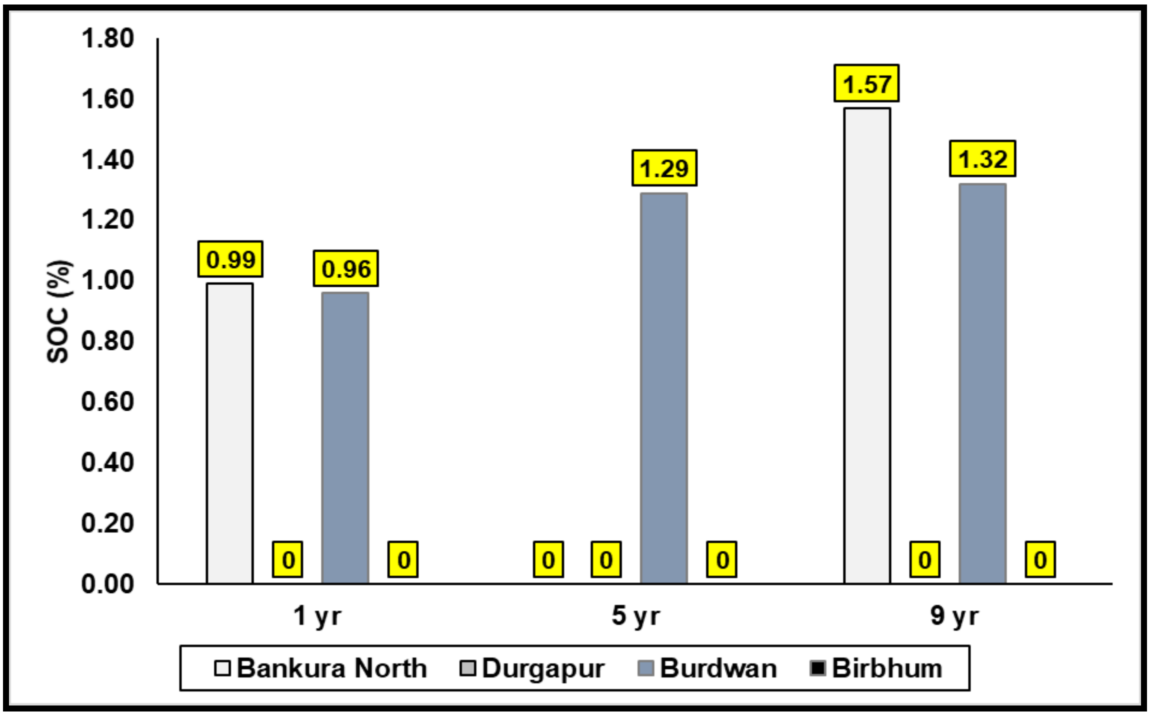


Fig. 32. Soil Organic Carbon (in %) in the Age-wise Sal forest habitat of four selected forest divisions in South Bengal; '0' means non-availability of the species

2.3 Soil pH

The average pH in **Akashmoni forest habitat** varied as per the order Burdwan (6.80) > Bankura North (6.70) for 1-year plantation; Durgapur (6.74) > Burdwan (6.63) > Bankura North (6.50) for 5-year old plantation; Durgapur (6.30) > Burdwan (6.26) > Birbhum (6.20) > Bankura North (6.16) for 9-year old plantation; the average pH in **Eucalyptus forest habitat** was 6.57 (Bankura North) in 5-year old plantation; for 9-year old plantation the order followed Burdwan (6.34) > Birbhum (6.25) and the average pH in **Sal forest habitat** varied as per the order Burdwan (6.76) > Bankura North (6.68) in 1-year old plantation; the value was 6.60 (Burdwan) in 5-year old plantation and for 9-year old plantation the value was varied as per the order Burdwan (6.24) > Bankura North (6.12) (*Vide* Tables 12, 13 and 14; Figs. 33 - 35).

Table 12. Soil pH in 1-year, 5-year and 9-year planted Akashmoni forest in the selected four forest divisions

Divisions	**pH**		
	1-year	**5-year**	**9-year**
Bankura North	6.70	6.50	6.16
Durgapur	NA	6.74	6.30
Burdwan	6.80	6.63	6.26
Birbhum	NA	6.58	6.20

'NA' – means non-availability of the species in the sites

Table 13. Soil pH in 1 year, 5 years and 9 years planted Eucalyptus forest in the selected four forest divisions

Divisions	pH		
	1-year	5-year	9-year
Bankura North	NA	6.57	NA
Durgapur	NA	NA	NA
Burdwan	NA	NA	6.34
Birbhum	NA	NA	6.25

'NA' – means non-availability of the species in the sites

Table 14. Soil pH in 1 year, 5 years and 9 years planted Sal forest in the selected four forest divisions

Divisions	pH		
	1-year	5-year	9-year
Bankura North	6.68	NA	6.12
Durgapur	NA	NA	NA
Burdwan	6.76	6.60	6.24
Birbhum	NA	NA	NA

'NA' – means non-availability of the species in the sites

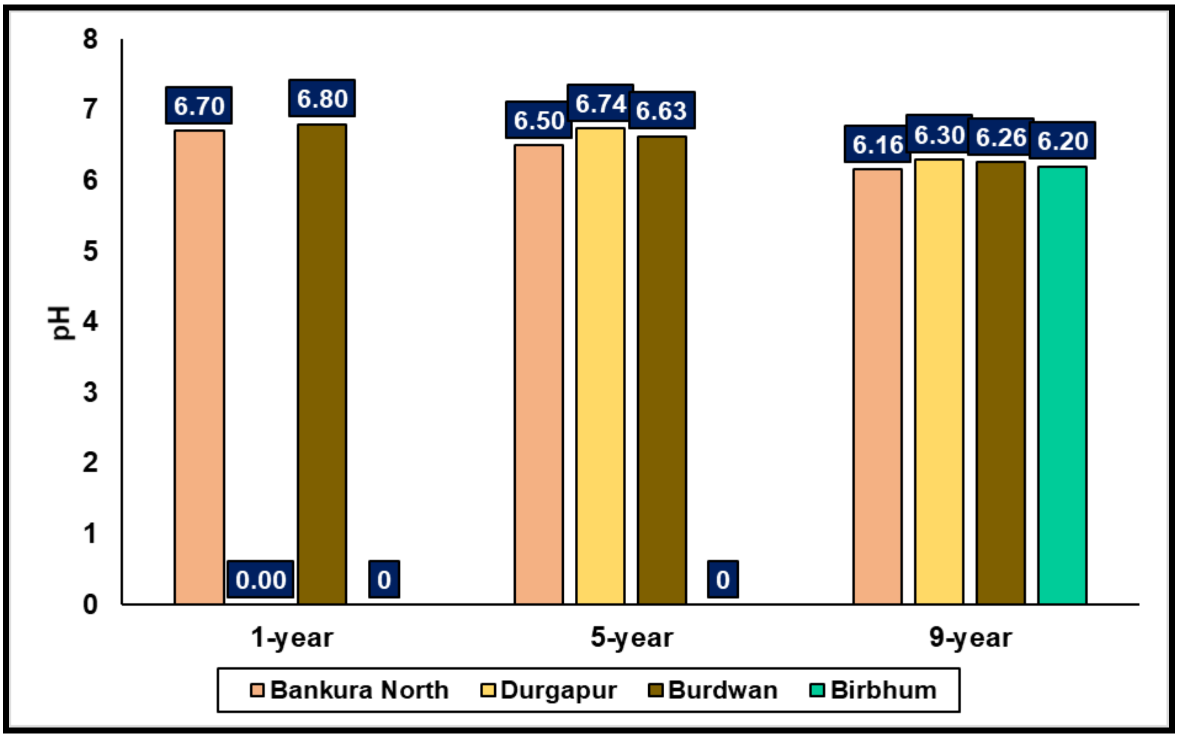


Fig. 33. Soil pH in the Akashmoni forest habitat of four selected forest divisions in South Bengal; '0' means non-availability of the species

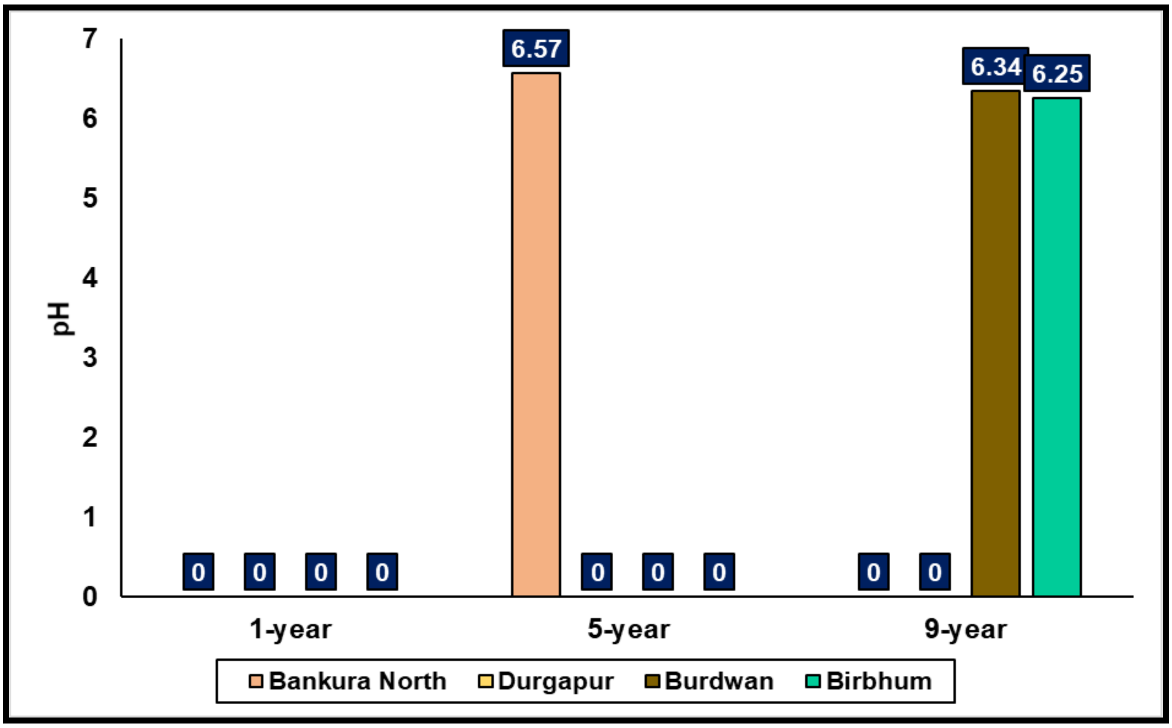


Fig. 34. Soil pH in the Eucalyptus forest habitat of four selected forest divisions in South Bengal; '0' means non-availability of the species

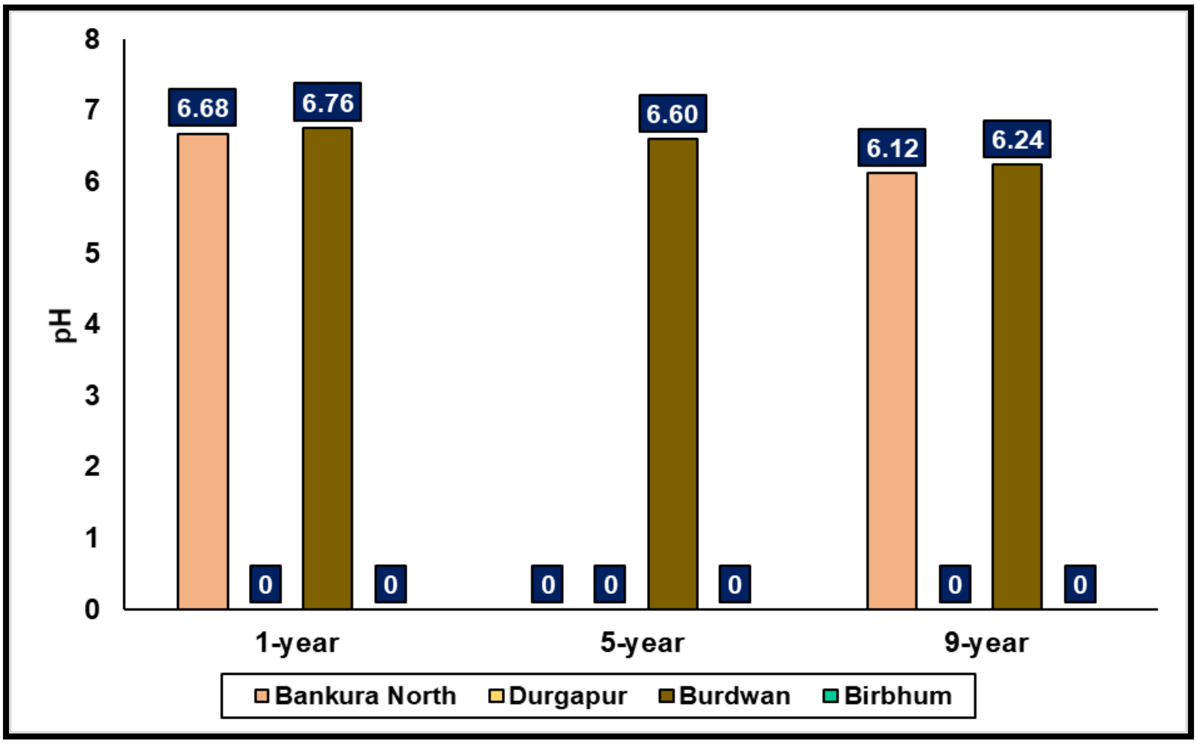


Fig. 35. Soil pH in the Sal forest habitat of four selected forest divisions in South Bengal; '0' means non-availability of the species


Discussion

The forest ecosystem and the underlying soil compartment serve as the major terrestrial carbon pools with the potential to absorb and store carbon dioxide from the air. The dynamics of the source and sink of carbon dioxide depend on the age of the tree, disturbance on the forest ecosystem and forest management. The role of forest ecosystem in mitigating climate change induced carbon dioxide rise has led almost all countries of the World to study their forest carbon budgets and initiate the assessment of enhancing and maintaining carbon sequestration of the forest vegetation. According to IPCC Report, 2000 the total global potential for afforestation and reforestation activities for the period 1995 – 2050 is estimated to be between 1.1 and 1.6 Peta gram Carbon per year, of which 70% could occur in the tropics. Afforestation and reforestation are seen as potentially attractive mitigation strategies, as wood production and carbon (C) storage can be combined. Several carbon budget models of different complexity have been developed and used to account for forest carbon dynamics (e.g. Parton *et al.*, 1987; Kurz *et al.*, 1992; Kimmins *et al.*, 1999; Price *et al.*, 1999; Karjalainen *et al.*, 2002; Peng *et al.*, 2002; Seely *et al.*, 2002; Masera *et al.*, 2003). Some of these studies not only account for the carbon in the forest ecosystem but also for the carbon contained in the harvested wood products (Burshel *et al.*, 1993; Karjalainen *et al.*, 1994, 2002, 2003; Harmon *et al.*, 1996; Pingoud *et al.*, 2001; Skog and Nicholson, 1998; Winjum *et al.*, 1998; Masera *et al.*, 2003). In the present progrmme, a survey was carried out during March, 2022, in the South Bengal Forests Region of West Bengal on age- wise stored carbon and subsequent carbon sequestration of three species namely Akashmoni, Eucalyptus and Sal. Four major divisions were focused namely Bankura North, Durgapur, Burdwan and Birbhum to monitor the slected species of one year, five year and nine year plantations.

The main findings that emerge from the entire results of age-wise carbon sequestration are highlighted below in points:

1) In all the four divisions of South Bengal region namely Bankura North, Durgapur, Burdwan and Birbhum the sequence of AGB, AGC, BGB and sequestered carbon are Bankura North > Birbhum > Burdwan > Durgapur. This sequence was observed for all the three age group, irrespective of the species.

2) The spatial variation of soil organic carbon is Bankura North > Birbhum > Burdwan > Durgapur.

3) For all the species the soil organic carbon was highest in the nine year old plantation followed by five year old and 1 year old plantations.

4) It is noted that striking variations was observed in the soil organic carbon profile of different species. The soil under the Sal plantation exhibited maximum organic cabon followed by Akashmoni and Eucalyptus. This variation may be attributed to extremely low rate of decomposition of Eucalyptus leaves compared to Akashmoni and Sal. The soil pH was lowest in the Sal plantation and highest in Eucalyptus plantation, irrespective of age and divisions.

5) The pH of the soil is primarily regulated by soil organic carbon and it has been documented that a negative correlation exists between soil pH and organic carbon thus confirming the role of decomposition of litter and detritus in lowering the pH.

6) To assess whether biomass, carbon content and CO_2-equivalent varied significantly among the forest divisions of South Bengal and age groups, analysis of variance (ANOVA) was performed and it is observed that for all the three species no significant differences ($p < 0.01$) were observed between the divisions (Bankura North, Durgapur, Burdwan and Birbhum) and biotic parameters [age-wise AGB, AGC, BGB (using empirical formula), sequestered carbon (based on AGC and age of the species] and CO_2 – equivalent. Total lack of plantation at some sites may be the cause for this anomalous result (Tables 15-29).

Table 15. ANOVA of AGB of Akashmoni between years and divisions

Source of Variation	**SS**	**df**	**MS**	**F**	**P-value**	**F crit**
Between Years	68742.840	2	34371.420	39.7042	0.000347	5.1432
Between Divisions	4032.513	3	1344.171	1.5537	0.295397	4.7571
Error	5194.127	6	865.688			
Total	77969.480	11				

Table 16. ANOVA of AGC of Akashmoni between years and divisions

Source of Variation	**SS**	**df**	**MS**	**F**	**P-value**	**F crit**
Between Years	14365.760	2	7182.880	41.0933	0.000315	5.1433
Between Divisions	701.967	3	233.989	1.3387	0.347144	4.7571
Error	1048.768	6	174.795			
Total	16116.500	11				

Table 17. ANOVA of BGB of Akashmoni between years and divisions

Source of Variation	**SS**	**df**	**MS**	**F**	**P-value**	**F crit**
Between Years	4655.321	2	2327.661	39.5871	0.000350	5.1433
Between Divisions	270.785	3	90.262	1.5351	0.299268	4.7571
Error	352.791	6	58.799			
Total	5278.897	11				

Table 18. ANOVA of sequestered carbon of Akashmoni between years and divisions

Source of Variation	SS	df	MS	F	P-value	F crit
Between Years	148.473	2	74.2363	14.2561	0.005255	5.1433
Between Divisions	29.026	3	9.6754	1.8580	0.237484	4.7571
Error	31.244	6	5.2073			
Total	208.743	11				

Table 19. ANOVA of CO_2-equivalent of Akashmoni between years and divisions

Source of Variation	SS	df	MS	F	P-value	F crit
Between Years	193490.500	2	96745.260	41.0935	0.000315	5.1433
Between Divisions	9454.814	3	3151.605	1.3387	0.347138	4.7571
Error	14125.630	6	2354.272			
Total	217071.000	11				

Table 20. ANOVA of AGB of Eucalyptus between years and divisions

Source of Variation	SS	df	MS	F	P-value	F crit
Between Years	56015.680	2	28007.840	1.0047	0.420380	5.1433
Between Divisions	27937.130	3	9312.377	0.3341	0.801712	4.7571
Error	167255.000	6	27875.840			
Total	251207.900	11				

Table 21. ANOVA of AGC of Eucalyptus between years and divisions

Source of Variation	SS	df	MS	F	P-value	F crit
Between Years	11902.600	2	5951.301	1.0069	0.419692	5.1433
Between Divisions	5929.763	3	1976.588	0.3344	0.801471	4.7571
Error	35462.270	6	5910.379			
Total	53294.640	11				

Table 22. ANOVA of BGB of Eucalyptus between years and divisions

Source of Variation	SS	df	MS	F	P-value	F crit
Between Years	3786.631	2	1893.315	1.0047	0.420382	5.1433
Between Divisions	1888.541	3	629.514	0.3341	0.801712	4.7571
Error	11306.400	6	1884.400			
Total	16981.570	11				

Table 23. ANOVA of sequestered carbon of Eucalyptus between years and divisions

Source of Variation	SS	df	MS	F	P-value	F crit
Between years	299.362	2	149.681	0.7611	0.5075	5.1433
Between divisions	219.986	3	73.329	0.3729	0.7760	4.7571
Error	1180.012	6	196.669			
Total	1699.359	11				

Table 24. ANOVA of CO_2-equivalent of Eucalyptus between years and divisions

Source of Variation	SS	df	MS	F	P-value	F crit
Between Years	160314.600	2	80157.300	1.0069	0.4197	5.1433
Between Division	79867.390	3	26622.460	0.3344	0.8015	4.7571
Error	477638.100	6	79606.350			
Total	717820.100	11				

Table 25. ANOVA of AGB of Sal between years and divisions

Source of Variation	SS	df	MS	F	P-value	F crit
Between Years	28107.680	2	14053.840	2.5579	0.1572	5.1433
Between Divisions	30331.410	3	10110.470	1.8402	0.2404	4.7571
Error	32965.450	6	5494.242			
Total	91404.540	11				

Table 26. ANOVA of AGC of Sal between years and divisions

Source of Variation	SS	df	MS	F	P-value	F crit
Between Years	6065.110	2	3032.555	2.5598	0.1571	5.1433
Between Divisions	6499.773	3	2166.591	1.8288	0.2424	4.7571
Error	7108.096	6	1184.683			
Total	19672.980	11				

Table 27. ANOVA of BGB of Sal between years and divisions

Source of Variation	SS	df	MS	F	P-value	F crit
Between Years	1905.465	2	952.732	2.5592	0.1572	5.1433
Between Divisions	2045.110	3	681.703	1.8312	0.2420	4.7571
Error	2233.631	6	372.272			
Total	6184.205	11				

Table 28. ANOVA of sequestered carbon of Sal between years and divisions

Source of Variation	SS	df	MS	F	P-value	F crit
Between Years	54.390	2	27.195	1.6821	0.2631	5.1433
Between Divisions	133.061	3	44.354	2.7435	0.1353	4.7571
Error	97.002	6	16.168			
Total	284.454	11				

Table 29. ANOVA of CO_2-equivalent of Eucalyptus between years and divisions

Source of Variation	SS	df	MS	F	P-value	F crit
Between Years	81690.050	2	40845.030	2.5598	0.1571	5.1433
Between Divisions	87544.590	3	29181.530	1.8288	0.2424	4.7571
Error	95738.140	6	15956.360			
Total	264972.800	11				


Conclusion

The conclusions that can be drawn from this study are highlighted in points:

1) For all species selected in the present study namely Akashmoni, Eucalyptus and Sal, the AGB, AGC, BGB and sequestered carbon values are highest in 9-year old plantation followed by 5-year and 1-year old plantations. This sequence is observed in all the four divisions of South Bengal region.

2) The stored carbon is highest in Eucalyptus followed by Sal and Akashmoni. This may be attributed to high biomass of Eucalyptus compared to other two species. The broad leaf surface (lamina) of Sal is the primry cause behind high AGC of the species.

3) The soil organic carbon which is an indicator of soil fertility/soil health was highest in Sal plantation sites followed by Akashmoni and Eucalyptus plantation sites. This point indicates the low decomposition rate of the vegetative parts of Eucalyptus compared to Akashmoni and Sal. This probably impacted the soil pH in the Eucalyptus plantations making them relatively high compared to the plantation of Akashmoni and Sal. The low decomposition rate of the vegetative parts of trees is never congenial to the environment in terms of soil fertility.

4) The overall results confirm maximum weightage towards Sal plantation due to considerable high biomass, stored carbon, carbon sequestration potential, resistance to fire, coppicing ability and adaptability to various edaphic factors. The ecosystem services of Sal (considering the commercial aspect) is also better compared to Eucalyptus and Akashmoni because it is a unique timber yielding species, which is known for its hard, heavy and tough wood and thus has wide demand in the furniture industries.

Plates

Plate 1

Fig. A. Drone view (~ 89 m) of plantations by West Bengal Forest Department in South Bengal

Fig. B. Akashmoni plantation of 5- years in South Bengal

Plate 2

Fig. C. Quadrate study of the Akashmoni tree in the forest of South Bengal Division

Fig. D. Measurement of ambient Carbon dioxide level in the Sal forest habitat

Plate 3

Fig. E. Measurement of the DBH for the estimation of biomass of the tree

Fig. F. Measurement of Soil pH to evaluate the soil health

Plate 4

Fig. G. Collection of the soil sample for the estimation of soil organic carbon

Fig. H. Weighing the leaves for the estimation of leaf biomass, a component of AGB

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