# Carbon sequestration potential of two *Musa* cultivars from Mokokchung, Nagaland, North East India along an altitudinal gradient

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**The present study explores the carbon sequestration potential of two extensively cultivated banana cultivars, i.e. Atsu Mungo and Aot Mungo, from Nagaland, North East India. The *Musa* cultivars were planted on experimental plots along an altitudinal gradient. Plant traits such as suckers, number of leaves, height and diameter at breast height were recorded. The biomass and carbon sequestration potential were estimated using allometric equations. The cultivars had substantial carbon sequestration ability and higher values of sequestration were observed at lower altitudes for both cultivars.**

**Keywords:** Allometric equations, banana, biomass, bulk density, carbon sequestration.

INCREASED global emission of carbon has been widely linked to climate change. The atmospheric carbon dioxide ($CO_2$) concentration is reported to have increased by 650–700 μmol$^{-1}$ in the last century, thus resulting in increased temperature[1]. Moreover, anthropogenic factors such as industrial processes, destructive land use and over-combustion of fossil fuels have further increased $CO_2$ emissions. As such, there is a need for systems that capture and store carbon for a long duration. These include physical, chemical, membrane-based, ammonia and carbon-based systems[2]. Carbon sequestration by plants through photosynthesis that enables long-term storage of $CO_2$ is viable and aids in energy production due to their large biomass[3,4]. Although most carbon sequestration strategies have been focused on trees, banana plants have high biomass, they may also sequester relatively high $CO_2$. One limitation of carbon sequestration by woody ecosystems is their inability to simultaneously meet the food requirement[5]. With an increase in the requirement for food production, there is limited available land to enable woody systems to sequester carbon[6]. Owing to the perennial and crop-like nature of banana, it is important to the carbon cycle and food production. Allometric equations allow for the estimation of carbon sequestration without destroying the plant samples. These equations have acceptable levels of accuracy and are extensively utilized in ecological studies[7]. Bananas, belonging to the family Musaceae, are extensively cultivated in Nagaland, North East India. The present study explores their potential for carbon sequestration. Two *Musa* cultivars, i.e. Atsu Mungo (Ao Naga) and Aot Mungo (Ao Naga), were selected from Mokokchung district, Nagaland based on their utilization and cultivation by the indigenous inhabitants (Figures 1 and 2). The genomic group of the two cultivars was recorded as ABB, according to Simmonds and Shepherd[8]. Suckers were collected from the same mother plant for each cultivar to minimize variability and planted along an altitudinal gradient (Table 1) with a spacing of 5 m between suckers at each site (Table 1 and Figure 3). The plantation sites were then maintained with minimal disturbance without applying any chemical fertilizers. Plant traits such as suckers, number of leaves, height and diameter at breast height were estimated after 356 days. Composite soil samples were collected from each study site (0–15 cm) to estimate soil organic carbon (SOC)[9] and bulk density[10]. Statistical analysis was done utilizing SPSS 26 software. The widely accepted allometric method proposed by Kurniawan *et al.*[11] was utilized to estimate plant biomass (eq. (1)), carbon stock using the method of Hairiah *et al.*[12] (eq. (2)) and soil carbon storage was estimated using the method of Anderson and Ingram[13] (eq. (3)).

$$A = 0.0303 \times D^{2.1345} \quad (1)$$

$$B = A \times 0.46, \quad (2)$$

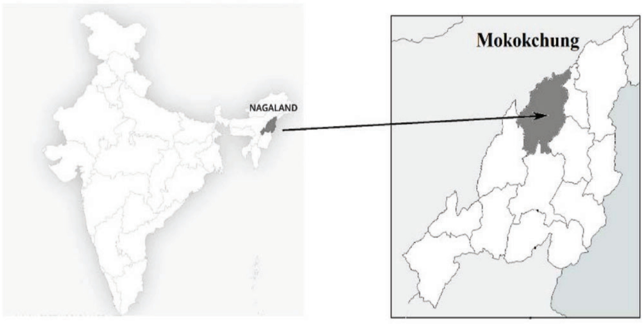


**Figure 1.** Study area map of Mokokchung, Nagaland.


**Figure 2.** ***a***, Atsu Mungo and ***b***, Aot Mungo.

**Table 1.** GPS coordinates of the study sites

| Site | GPS coordinates |
|---|---|
| I | 26°13′49″N, 94°32′22″E; 1036 m amsl |
| II | 26°14′32″N, 94°31′46″E; 808 m amsl |
| III | 26°14′33″N, 94°33′31″E; 638 m amsl |

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**Table 2.** Mean values of plant trait, bulk density, biomass, carbon stock and soil carbon storage of *Musa* cultivar Atsu Mungo along an altitudinal gradient

| Site | Sucker | Bulk density ($g\ cm^{-3}$) | Organic carbon (%) | Diameter at breast height, DBH (cm) | No. of functional leaves | Height (cm) | Biomass (kg) | Carbon stock (kg C/plant) | Soil carbon storage ($Mg\ ha^{-1}$) |
|---|---|---|---|---|---|---|---|---|---|
| I | 3.75 ± 1.47 | 1.39 ± 0.19 | 2.53 ± 0.43 | 43.75 ± 3.11 | 8.00 ± 1.22 | 292.00 ± 38.88 | 96.99 ± 14.34 | 44.61 ± 6.59 | 56.94 ± 4.73 |
| II | 2.75 ± 0.70 | 1.46 ± 0.14 | 3.43 ± 0.34 | 45.50 ± 4.84 | 5.50 ± 1.22 | 283.50 ± 35.08 | 106.45 ± 25.08 | 48.97 ± 11.54 | 56.62 ± 4.59 |
| III | 4.00 ± 1.08 | 1.30 ± 0.06 | 2.60 ± 1.23 | 61.00 ± 5.17 | 13.00 ± 0.86 | 328.50 ± 13.21 | 197.4 ± 32.73 | 90.84 ± 15.05 | 67.25 ± 16.10 |

**Table 3.** Mean values of plant trait, bulk density, biomass, carbon stock and soil carbon storage of *Musa* cultivar Aot Mungo along an altitudinal gradient

| Site | Sucker | Bulk density ($g\ cm^{-3}$) | Organic carbon (%) | DBH (cm) | No. of functional leaves | Height (cm) | Biomass (kg) | Carbon stock (kg C/plant) | Soil carbon storage ($Mg\ ha^{-1}$) |
|---|---|---|---|---|---|---|---|---|---|
| I | 4.50 ± 0.77 | 1.33 ± 0.26 | 3.23 ± 0.53 | 42.25 ± 3.89 | 8.25 ± 1.29 | 262.75 ± 35.95 | 90.40 ± 25.29 | 41.58 ± 7.80 | 63.34 ± 11.23 |
| II | 4.25 ± 0.82 | 1.34 ± 0.23 | 2.37 ± 0.53 | 52.75 ± 4.43 | 7.87 ± 1.47 | 339.75 ± 28.12 | 144.94 ± 26.36 | 66.67 ± 11.63 | 51.97 ± 0.90 |
| III | 5.00 ± 1.73 | 1.39 ± .0.13 | 3.25 ± 0.56 | 58.50 ± 4.03 | 12.66 ± 0.50 | 340.00 ± 25.49 | 180.26 ± 26.36 | 82.81 ± 12.00 | 72.78 ± 1.21 |

**Table 4.** Carbon sequestration potential of *Musa* cultivar Atsu Mungo along an altitudinal gradient

| Site | Sucker | Bulk density ($g\ cm^{-3}$) | Organic carbon (%) | DBH (cm) | No. of functional leaves | Height (cm) | Biomass (kg) | Carbon stock (kg C/plant) | Soil carbon storage ($Mg\ ha^{-1}$) |
|---|---|---|---|---|---|---|---|---|---|
| I | $3.75^a$ | $1.39^a$ | $2.53^a$ | $43.75^a$ | $8.00^b$ | $292.00^a$ | $96.99^a$ | $44.61^a$ | $56.94^a$ |
| II | $2.75^a$ | $1.46^a$ | $3.43^a$ | $45.50^a$ | $5.50^a$ | $283.50^a$ | $106.45^a$ | $48.97^a$ | $56.62^a$ |
| III | $4.00^a$ | $1.30^a$ | $2.60^a$ | $61.00^b$ | $13.00^c$ | $328.50^a$ | $197.48^b$ | $90.84^b$ | $67.25^a$ |

*Values in the same column with different superscripts are significantly different at 5% level by Duncan's multiple range test.

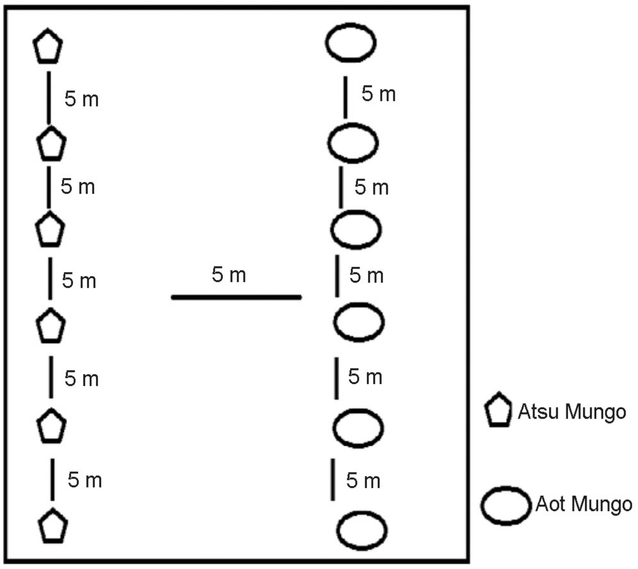


**Figure 3.** Schematic diagram of sucker plantation at sites I–III.

where *A* is the plant biomass (kg), *D* the diameter at breast height (cm) and *B* is the carbon stock (kg C/plant).

$$\text{Carbon storage in the soil} = \%\ \text{Carbon concentration} \times \text{bulk density} \times \text{soil depth}. \quad (3)$$

Tables 2 and 3 display the findings of the present study. Higher plant traits and SOC were observed for both cultivars at lower altitudes. The highest carbon stock for Atsu Mungo was observed at site III (90.84 kg C/plant) and similarly for Aot Mungo at site III (82.81 kg C/plant). Although edible cultivars have lower carbon sequestration than wild *Musa*, the presence of type-B genome (*Musa balbisiana*) in certain cultivars leads to higher biomass[3]. Both cultivars had the type-B genome, which may result in higher carbon sequestration ability. Tables 4 and 5 show the effect of altitude on plant traits and carbon sequestration potential of the two cultivars respectively. We observed higher values of biomass, carbon stock and soil carbon storage at a lower altitude for both *Musa* cultivars. There existed a negative correlation between altitude and carbon storage[14,15]. Poor plant performance of the cultivars at higher altitudes may be due to lower SOC as a result of decreased rate of mineralization and nitrification by microbes[16]. The quantity and turnover rate of soil organic matter were determined by the vegetation and altitude[17]. Biomass is affected by both genetic and environmental characters[3]. In the present study we selected banana suckers for each of the cultivars from a single mother plant to minimize the genetic variation. Thereafter, we attribute the variation in biomass to environmental factors. The Kyoto Protocol (1997) has introduced the concept of carbon credit, wherein a country that sequesters carbon will be reimbursed by those releasing carbon; India is a

**Table 5.** Carbon sequestration potential of *Musa* cultivar Aot Mungo cultivar along an altitudinal gradient

| Site | Sucker | Bulk density ($g\ cm^{-3}$) | Organic carbon (%) | DBH (cm) | No. of functional leaves | Height (cm) | Biomass (kg) | Carbon stock (kg C/plant) | Soil carbon storage ($Mg\ ha^{-1}$) |
|---|---|---|---|---|---|---|---|---|---|
| I | $4.50^a$ | $1.33^a$ | $3.23^a$ | $42.25^b$ | $8.25^a$ | $262.75^a$ | $90.40^a$ | $41.58^a$ | $63.34^a$ |
| II | $4.25^a$ | $1.34^a$ | $2.37^a$ | $52.75^a$ | $7.87^a$ | $339.75^b$ | $144.94^b$ | $66.67^b$ | $51.97^a$ |
| III | $5.00^a$ | $1.39^a$ | $3.25^a$ | $58.50^b$ | $12.66^b$ | $340.00^b$ | $180.26^b$ | $82.81^b$ | $72.78^b$ |

*Values in the same column with different superscripts are significantly different at 5% level by Duncan's multiple range test.

signatory member[18]. It is important to note that banana management does not involve burning biomass and removing plant residues which depletes SOC[19]. Such practices not only help in climate mitigation, but also provide other ecosystem services[20]. If India can capture about 10% of the global Clean Development Mechanism under the Kyoto Protocol, it would generate about 10–300 million USD[18]. Banana also provides shade to crops such as coffee, and rubber acts as a vital source of livelihood to farmers and simultaneously increases $CO_2$ stock in degraded lands when incorporated in agroforestry systems[21].

*Conflict of interest:* The authors declare no conflict of interest.


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