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Original Articles

Algorithmic derivation of CO_2 assimilation based on some physiological parameters of tea bushes in North-East India

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ABSTRACT

Tea, an evergreen shrub, is commercially cultivated in dense population as bushes in tea gardens. Periodical pruning of tea bushes makes tea plants distinct from other tree plants. Tea bushes have almost constant height throughout their life-time and have more compact canopy as compared to any forest trees. Hence, established methods of elucidating carbon dioxide (CO_2) absorption in forest trees could not be employed for measuring CO_2 assimilation in tea bushes. In this study, CO_2 assimilation potentials of a high-yielding tea cultivar and a better quality producing tea cultivar had been periodically measured by closed-chamber method under field condition. Such type of experiment was not conducted before. This study revealed that tea bushes had potential to assimilate 1243.8–2526.7 kg CO_2 ha^{-1} $year^{-1}$ and the high yielding tea cultivar absorbed significantly higher amount of CO_2 as compared to better quality producing tea cultivar. Several physiological parameters namely number of branches, plucking point density, leaf area and stomatal index were positively correlated to the annual CO_2 assimilation by tea bushes. Higher CO_2 assimilation in high yielding tea cultivars can be attributed to their larger and dense canopy structure due to more branching, higher plucking point density and higher leaf area. An algorithm has been derived for computing CO_2 assimilation in tea bushes by considering the above-mentioned variable as indicators. This will enable to determine CO_2 assimilation by tea plantation over a large area by measuring the physiological indicators without exercising in-situ experiments.

1. Introduction

Carbon dioxide (CO_2) is one of the most important greenhouse gases (on volume basis) in the atmosphere (IPCC, 2007) and climate change is the consequence of anthropogenic explosion of CO_2 emissions. Since the industrial revolution, total concentration of CO_2 in the atmosphere has been enhanced by more than 40% (270 ppm–400 ppm) (Moreira and Pires, 2016). Global warming is an inevitable consequence of increased atmospheric CO_2 concentration. De Silva et al. (2015) mentioned that global temperature is raised by 0.85 °C from 1880 to 2012 and it was projected to be increased further by 1.4–5.8 °C in 2100. The International Energy Agency (IEA) has claimed that CO_2 emissions will be 63% higher than today's level in 2030, and that value will be 90% higher than what was recorded in 1990 (Ganesh, 2014).

Carbon dioxide capture from large point sources (4–14%, v/v) has attracted the attention of scientific community as a challenge to subside the atmospheric CO_2 concentration. The commonly used technologies for CO_2 capturing are chemical absorption, solid phase adsorption, membrane separation etc. However, biological capturing or CO_2 sequestration in plant biomass is sustainable, cost effective and eco-friendly technique towards atmospheric CO_2 level reduction (Pires et al., 2011). Moreira and Pires (2016) studied the efficacy of algae to absorb atmospheric CO_2 in their biomass. Carbon dioxide Sequestration by higher plants during photosynthesis is also an important technique for CO_2 capturing and storage (CCS), and the process has already been studied in various group of plants (Kell, 2012). Stewart and Hessami (2005) mentioned that the terrestrial CO_2 sequestration by plants can overcome many of the environmental and cost related concerns associated with geological and ocean stored atmospheric CO_2. Rodale Institute (2013) claimed that agricultural carbon (C) sequestration has the potential to mitigate global warming. Terrestrial CO_2 sequestration (metric ton $acre^{-1}$ $year^{-1}$) of cropland, forest, grassland and wetland were estimated within the ranges 0.2–0.6, 0.05–3.9, 0.12–1.0 and 2.23–3.71 metric ton $acre^{-1}$ $year^{-1}$, respectively. However, CO_2 capturing potentials of tea bushes had not been quantified yet and CO_2 assimilation potential of tea bushes could not be expressed within a range of data.

Tea is an evergreen plant and cultivated in dense population with

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12,000–18,000 bushes ha^{-1} (Baruah, 1989). Tea plants are maintained as bushes through periodical pruning for extending its vegetative growth stage and for the ease of plucking. Periodical pruning makes tea bushes more compact as compared to other shrubs and trees by increasing its branching and widening its canopy. Physiology of tea bushes of different cultivars varies widely and changes in their canopy structure due to pruning over years are also different (Baruah, 1989). Hence, like forest ecosystem, it is not possible to measure CO_2 assimilation and C sequestration in tea bushes by commonly used equation of Broward (2012), which considers height and stem diameter of plants for calculating the weight of biomass. In the present study, CO_2 assimilation potentials of two different tea cultivars of two age groups had been measured by close-chamber method and the results were amalgamated with different physiological parameters of tea bushes. The objectives of this study were to evaluate the potential of different tea cultivars to assimilate atmospheric CO_2 and to compute an algorithm so that CO_2 assimilation potential of any tea bush can be determined by measuring its physiological parameters as indicators.

2. Materials and methods

2.1. Experimental site

The study was conducted in two sections (Section 20: 26.8579°N and 92.7004°E and Section 24: 26.8530°N and 92.7029°E) of Kolony Tea Estate of Sonitpur district, Assam, India. Two different tea cultivars (TV1 and TV23) of 27 years (section 20) and 7 years (section 24) were selected for this study. Both the sections had both TV1 and TV23 cultivars in adjacent plots. The cultivar TV1 is a standard high quality tea producing clone, whereas TV23 is a representative of high-yielding tea cultivars. The density of tea bushes for both the cultivars in these two sections is 16,000 bushes ha^{-1}.

2.2. CO_2 flux measurement

Transparent acrylic chambers having length, breadth and height of 4′ × 4′ × 4′ i.e., 1.22 m × 1.22 m × 1.22 m were used for estimating CO_2 assimilation potentials (Fig. 1). Firstly, battery-operated CO_2 monitoring sensors were attached to the inner side-wall of each chamber keeping the monitor of the sensor outward for recording periodical changes in CO_2 level inside the chamber. Then the chambers were placed covering two tea bushes and base of chambers were sealed with soil or mud for restricting air circulation from outside. No CO_2 was injected externally in the chambers and ambient CO_2 concentration was the initial (zero minute) reading in this study. Changes in CO_2 concentration inside the chambers were periodically recorded at 3-min interval for 15–30 min depending on weather conditions. The flux (F) of CO_2 gas in chambers i.e., CO_2 assimilation by tea bushes within a definite time interval was calculated using following equation (Rolston, 1986):

$$F = \rho \times \left(\frac{V}{A} \times \frac{\Delta c}{\Delta t} \times \frac{273}{T}\right) \quad (1)$$

where F is the CO_2 flux ($mg\,CO_2\,m^{-2}\,h^{-1}$), ρ is the density of CO_2 at NTP (1.98 $mg\,cm^{-3}$), V is the volume of chamber (m^3), A is the surface area of chamber (m^2), $\Delta c/\Delta t$ is the rate of decrease of CO_2 gas concentration in the chamber ($mg\,m^{-3}\,h^{-1}$) and T (absolute temperature) is 273 + mean temperature in (°C) of the chamber.

The study was continued for one year at 15 days interval. The CO_2 assimilation readings in each interval were recorded in triplicates and points of CO_2 fluxes in Fig. 2 represented the average of 3 replications with standard error (shown as vertical lines). In this study, it was hypothesized that CO_2 flux recorded at a certain point of time represented the flux of preceding 15 days. Total CO_2 assimilation by tea bushes in a year was calculated as mentioned by Singh et al. (1999):

$$Total\ CO_2\ flux = \sum_{i}^{n} (R_i \times D_i) \quad (2)$$

where, R_i is the CO_2 flux ($g\,m^{-2}\,d^{-1}$) on the ith sampling, D_i is the number of days in the ith sampling interval, and n is the number of sampling.

2.3. Physiological parameters of tea bushes

The girth (collar diameter at 3 cm above the ground) of tea bushes was measured using Vernier slide callipers. The area of detached leaves of tea cultivars was measured using the leaf-area-meter. The stomata of tea leaves were characterized using compound microscope following the below mentioned protocol:

For studying leaf anatomy, fresh leaves were fixed in 0.1 M sodium phosphate buffer containing 2.5% (v/v) glutaraldehyde for 24 h. Samples were dehydrated through alcohol series, followed by resin-alcohol grades and embedded in acryl resins. Semi-thin sections of 1 µm thickness were obtained using standard Rotary microtomy technique (Murgatoryd, 1976) and stained with Toluidine blue O (Burne and St John, 1978). Photomicrographs were taken under 10x and 20x objectives of the fluorescence microscope (Axiolab, Ziess, MC 80 Dx Camera). Thickness of mesophyll tissue and the entire leaf thickness were measured with an ocular micrometer.

2.4. Organic C fractions in soil

Soil organic carbon (C) content was estimated by the standard dichromate oxidation method of Nelson and Sommers (1982). Hot-water extractable C (HWEC) and dissolved organic C (DOC) were extracted and measured from fresh soil samples following the methods of Lu et al. (2011). Soil samples were homogenized with double distilled water (soil:water = 1:5, w/v basis) by shaking at 120 rpm for 1 h and the suspension was centrifuged at 4000 rpm for 15 min. The supernatant was used for DOC determination by standard dichromate oxidation method. For HWEC estimation, soil suspension was warmed at ~90 ± 1 °C for 30 min followed by shaking for 1 h. Thereafter, same protocol of DOC estimation was followed to measure HWEC in soil.

2.5. Statistical analyses

In this experiment, data were analyzed using standard statistical methods following the procedures of Gomez and Gomez (1984). Differences between treatments were determined by analysis of variance (ANOVA) and least significant differences (LSD) test using SPSS 14.0 statistical software. All statistical considerations were based on $P < 0.05$ significant level.

Various plant physiological parameters were used as the factors which were correlated to the may potentially influence CO_2 assimilation by tea bushes. The analysis suggested that several factors namely number of branches, plucking point density, leaf area and stomatal index in the leaf are significantly related to the CO_2 assimilation by the tea bushes (Table S.1). A multiple regression analysis using SPSS 14.0 statistical software had been performed considering 'CO_2 assimilation' in tea bushes as the dependent on all the above-mentioned variables. Thereafter, the following multi-variant equation had been derived from the outcome (Table S.2) of another regression analysis comparing CO_2 assimilation against all the significantly related factors

$$CO_2\ assimilation\ (C_{assi.}) = 0.288 \times B + 0.045 \times P + 0.616 \times L + 0.172 \times S - 1.074 \quad (3)$$

where, B is number of branches, P is plucking point density, L is leaf area and S is the stomatal index in the leaves.