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Carbon sequestration potential under tea based cropping system

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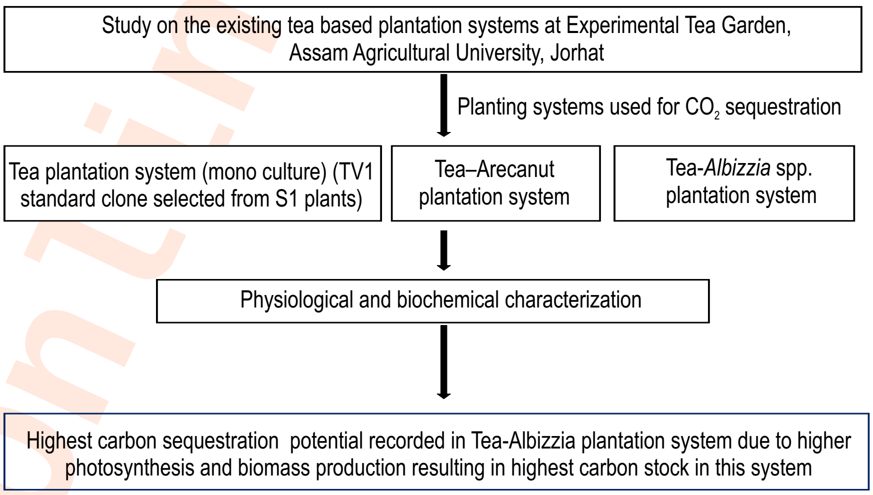
Abstract

Aim: To study the carbon sequestration process in tea based plantation system and to identify more potential carbon sequestration system amongst the tea based cropping system by studying carbon storage in different components of the plantation system.

Methodology: The experiment was carried out in the Experimental Garden for Plantation Crops of Assam Agricultural University, Jorhat, Assam. Treatments were made in an on going, long term shade experiment on mature tea bushes, adapted to three levels of shades *viz.* tea as monoculture; Tea based cropping system with Areca palm and Tea with *Albizzia odoratissima*.



Results: Among different tea plantations, tea-albizzia recorded superior performance, followed by tea-areca palm plantation in respect to biomass accumulation and carbon sequestration. Similarly, higher carbon stock was found in tea-albizzia plantations along with other physiological and edaphic parameters related to carbon sequestration attributed to an increase in carbon stock.

Interpretation: Tea-albizzia plantation system has maximum potential for carbon offsetting from the atmosphere as well as carbon storage both above and below ground in the plantation ecosystem which might be helpful for future carbon management and economy as a whole.

Key words: Biomass, Carbon sequestration, Photosynthetic rate, Plantation, Tea-albizzia

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Introduction

Plantation crops consisting of different tree species have gained attention in recent years due to carbon sequestering from the atmosphere, storing as biomass and soil organic carbon (Subramaiyam *et al.,* 2017). Such agro-forestry systems can pave the way to mitigate green house gas emissions by sequestration of carbon in the biomass (Torres *et al.,* 2017). Plantation crops, generally raised in high density multi species cropping system have a higher potential for sequestering carbon. In the recent global emission trading system, emitters that are unable to meet their targets could pay off through carbon sequestration in plantations (Subhramaniam *et al.,* 2017). The biological carbon sequestration in terrestrial ecosystem is considered as net removal of CO_2 from the atmosphere into long-lived sinks/pools of carbon (Lal, 2008).

Carbon storage dynamics in forest systems have been widely studied, however, most studies on tea emphasis on increasing production and quality (Han *et al.,* 2007; Zhang *et al.,* 2007). Studies on carbon storage in tea plantation are limited (Kamau *et al.,* 2008). CO_2 assimilation upto 50 % of atmospheric CO_2 in tea biomass has been reported, of which 5.9 to 8.6 % are released as root exudates as organic carbon (Pramanik and Phukan, 2020). Wang *et al.* (2016) reported organic that cultivation of jasmine and tea can improve soil fertility and carbon accumulation, thereby reducing industrial fertilizers usage and improving product quality without loss of economical profits. In the context of climate change, Wijeratne *et al.* (2016) emphasized the importance of environmental resilience along with obtaining higher yield by establishing and managing shade trees in tea plantations. For sustainable management of plantation crop ecosystems, in-depth study of its carbon storage and dynamics needs to be understood. Such studies on specialized ecosystems may initiate new traits in relation to carbon storage that might change the regional carbon balance due to rapid expansion throughout the world (FAO, 2007).

In modern day agriculture, emphasis has been made on achieving yield sustainability along with maintenance of soil fertility, increasing farm income and efficient utilization of available resources (land, water, air, light) through cropping in plantations. In Assam, areca palm plantation is a long established traditional crop and tea is one of the predominant plantation crops covering 420 thousand hectares area producing 1350.04 million kg of tea. (Tea Board of India, 2018-2019). Mono cropping of areca palm cannot generate adequate income and, therefore, generation of additional income per unit crop area is promoted by cash crop such as tea as well maintenance of ecological balance. The potential of higher carbon sequestration has been reported due to the presence of other trees in plantations (Wijeratne, 2015). Although awareness is emerging for the need of such information to support the sustainable management of plantation crops, carbon storage dynamics and its micro environment within these perennial ecosystems remain poorly understood. We hypothesize that there are opportunities on the existing tea plantation system for contribution towards mitigation of climate change through offsetting carbon by its regulation. In view of the above, this study was carried out to generate a data which would be a baseline for identification of tea along with other plantation systems that would provide a green economy in tea growing areas in near future along with ecosystem maintenance.

Materials and Methods

The experiment was carried out in the Experimental Garden for Plantation Crops, Department of Tea Husbandry and Technology, Assam Agricultural University. The research was conducted in various tea based plantation systems existing in the garden. Tea plants, TV1 (an Assam-China hybrid) clone, is a standard clone with moderately high yielding ability and good quality. It is characterized by a compact dense frame having medium erect type leaves and medium sized shoots. This clone was released by Tocklai Experimental Station in 1949. Tea was planted at a single hedge spacing of 1.05m x 0.60 m during 1995. Areca palm plants collected from Horticultural Research Station, Kahikuchi, were planted at a spacing of 3.6m x 3.15m during 1996. Shade trees (*Albizia odoratissima*) were planted in the conventional tea plot at 12m x 12m spacing during the year 1995. The above and belowground tree biomass values were quantified for each of the three planting systems. Each tree was felled; the above ground biomass was separated into leaves, large branches (that was greater than 4 cm diameter), small branches (that was less than 4 cm diameter), dried branches and tree trunks. In case of below ground biomass, 1.4 and 6.25 m^2 areas was dug out around each tree stump up to a depth of 1m.

The roots were separated from soil, followed by hand picking, sieving and finally washing. They were then separated into the root stump, primary roots, lateral roots and loose roots. Fresh weight of each component (above and below ground) was taken separately in the field. Sub-samples of 500 g fresh weight for each component were taken and used for further laboratory analyses. The plant samples were dried at 60ºC till they reached a constant weight, and fresh biomass was determined. For estimation of biomass from selective tree species, mathematical models *i.e.,* measuring diameter at breast height (DBH) directly and girth at DBH (Ravindranath and Ostwald, 2008). The above ground biomass (all living biomass above the soil) was calculated by multiplying the volume of biomass and wood density. The calculation of volume was based on diameter and height. Values for wood density for species were obtained from web (www. worldagroforestry.org). AGB (g) = Volume of biomass (cm3) × wood density (g cm^{-3}); Volume of biomass = DBH x H (diameter at breast height x height); DBH = GBH/π (3.14) (Shinde *et al.*, 2015)

Below ground biomass (all biomass of live roots excluding fine roots having <2 mm diameter) was estimated as per Chavan and Rasal (2012). The belowground biomass (BGB) was calculated by multiplying above-ground biomass taking 0.26 as the root to shoot ratio (Cairns *et al.* 1997; Ravindranath and

Ostwald, 2008). Total biomass was according to Sheikh *et al.* (2014), which is the sum of above and below ground biomass. The calculation of carbon stock as biomass consists of multiplying the total biomass by a conversion factor that represents the average carbon content in biomass. In order to account for variations in carbon content of different biomass components, the coefficient of 0.5 was used for conversion of biomass to carbon stock (Patterson, 2012). Carbon content was estimated by wet digestion following the modified method of Walkley-Black (1934). Nitrogen content in plant parts was measured by Kjeltec Auto Analyzer. (Model: Kelplus distilled EM). Leaf chlorophyll was extracted by non-maceration method using dimethyl sulphoxide (Hiscox and Isrearelstam, 1979) and optical density of extract was read at 663 and 645 nm using spectrophotometer (model: GS571055, EC India ltd). Chlorophyll content was determined by the formula given by Arnon (1949) and expressed as mg g^{-1} f.wt. The rate of photosynthesis, stomatal conductance, leaf temperature was measured on leaves using a portable Infrared Gas Analyzer (IRGA).

The data obtained from the experiment were analyzed through RBD by following the Fisher's method of "Analysis of Variance" (Panse and Sukhatme, 1978). The significance and non-significance of given variance was determined by calculating the respective values of 'F'.

Results and Discussion

The beneficial effects of plantation along with tea cultivation have been documented by FAO (2016) improves the quality and other physiological processes in tea (Sano *et al.,* 2020). In tea cultivation, importance of other trees as a component provides a better microclimate (Huxley, 1983) besides, they help in enhancing the carbon pool of soil that can provide 50 percent to 70 percent of diffused solar insulation to the tea cultivation area (Sana, 1989). In the present study besides the carbon sequestration potential in various plantation systems, we tried to elucidate the growth, physiological and soil parameters that influence the carbon sequestration process.

A significant difference was observed in terms of total biomass as well as total carbon stock per kg of plant in different tea plantation systems (Table 1 and 2). The conventional Tea-Albizzia plantation showed highest total biomass, followed by Tea–Areca palm whereas tea grown as monoculture showed the lowest biomass. The maximum total carbon stock was recorded in Tea–Albizzia plantation system, followed by Tea–Areca palm. Tea grown as monoculture showed the lowest total carbon stock. The results of the present study revealed 79.39 and 20.63 per cent of total carbon stock being contributed from the above and below ground fraction of the system, respectively. Similarly, 79.06 percent of total biomass was contributed by above ground biomass as compared to 20.62 percent by below ground biomass. Tree along with other plantations have been reported to facilitate nutrient recycling in agro-forestry systems and helped in the production of large quantities of easily recyclable nutrient rich biomass.

Trees along with cash crop like coffee are periodically lopped or pruned to reduce shade and to transfer nutrients from

Table 1: Plant biomass under different tea plantation (kg per plant)

Plantation system	Above ground biomass			Below ground biomass			Total biomass per plant		Total biomass of plantation system
	Tea	Arecanut/ Albizzia	Total	Tea	Arecanut/ Albizzia	Total	Tea	Arecanut/ Albizzia	
Tea	7.2	None	7.2	2.1	None	2.1	9.3	None	9.3
Tea-Arecanut	8.4	11	19.1	2.8	1.4	4.2	11.2	12.4	23.6
Tea-Albizzia	9.1	39	48.1	3.5	9.6	13.1	12.6	48.6	61.2
Mean	8.23	16.67		2.80	3.67		11.03	20.33	
SEd±			1.18			0.22			
CD			2.71			0.50			

Table 2: Carbon stock under different tea plantation (kg per plant)

Plantation system	Above ground			Below ground			Total carbon stock per plant		Total carbon stock of plantation system
	Tea	Arecanut/ Albizzia	Total	Tea	Arecanut/ Albizzia	Total	Tea	Arecanut/ Albizzia	
Tea	3.96	None	3.96	1.16	None	1.16	5.15	None	5.12
Tea-Arecanut	4.62	6.05	10.67	1.54	0.77	2.31	6.16	6.82	12.98
Tea-Albizzia	5.01	21.45	26.46	1.92	5.28	7.21	6.93	26.73	33.66
SEd±			1.18			0.07			0.62
CD			2.71			0.16			1.55

Table 3: Physiological parameters under different tea plantation

Plantation system	Tea	Tea-arecanut	Tea-albizzia	Mean	SEd±	CD 5%
Photosynthetic rate (µmol CO_2 $m^{-2}s^{-1}$)	9.18	10.98	14.80	11.65	0.130	0.300
Leaf temperature (°C)	40.54	40.03	35.68	38.75	0.0021	0.004
Stomatal conductance (µmol m^{-2} s^{-1})	0.013	0.060	0.140	0.071	0.0005	0.001
RLWC (%)	40.83	42.098	42.76	41.90	0.9912	2.287
Light incidence (%)	72.77	66.82	54.26	57.95	0.473	1.08

*Data within parentheses are in per cent change over tea plantation

tree biomass to the associated crop (Beer, 1998). This finding is in conformity with our findings where increased biomass in Tea–Albizzia plantation might be due to improved nutrient recycling which was ascertained by higher soil carbon and nitrogen content in Tea –Albizzia plantation system. Tea-rubber inter-cropping system were also found to be superior to rubber monocultures in terms of atmospheric carbon dioxide sequestration by increasing soil organic carbon levels and reducing the turnover rates of labile organic carbon (Zhang *et al.,* 2007). The increment in biomass and carbon storage in Tea –Albizzia in the present study may be due to an increase in plant density as compared to other plantations, *i.e.,* tea- arecanut where plant density was less. Even in tea monocrop minimum biomass accumulation and carbon storage have been observed when compared with Tea – Albizzia plantation system.

Similar observation was recorded in tea plantation system (Wijeratne, 2014) and in cocoa (Beer *et al.,* 1998). In other studies, doubling of cocoa biomass has also been reported when grown under *Millletia* and *Albizzia* as compared to sole crop culture (Issac *et al.,* 2007). Tea-Albizzia plantation system may resemble an agroforestry system in the present investigation due to its dense population and green canopy although tea is botanically classified as a shrub, tea plants are maintained as bushes through periodical pruning for extending its vegetative growth stage for ease of plucking (Baruah, 1989; Pramanik and Phukan, 2020), however, due to the presence of Albizzia, the plantation system is modified by regulation of canopy structure and also nutrient enhancement by both carbon and nitrogen fixation. Presence of leguminous plants in a cropping system facilitates symbiotic association with nodulating N_2-fixing bacteria and arbuscular mycorrhizal fungi which is an efficient strategy for soil reclamation and initiate natural succession (Chaer *et al.,* 2011). In all the tea plantations, a significant difference in photosynthetic rate and stomatal conductance of tea plants was observed. The highest photosynthetic rate and stomatal conductance were recorded in tea plant grown as Tea-*Albizzia* plantation followed by tea plants grown in Tea-Areca palm plantation system whereas the lowest photosynthetic rate was observed in tea grown as monoculture. Tea-*Albizzia* plantation showed 61.22 per cent increase in photosynthesis whereas Tea-Areca palm showed 9.61 per cent over tea grown as monoculture.

The increased photosynthetic rate in Tea *Albizzia* plantation might be due to increased stomatal conductance which helped in higher gaseous exchange in the leaves of all the plantation systems. It has been reported that in many deciduous and evergreen trees, there was a positive relationship between

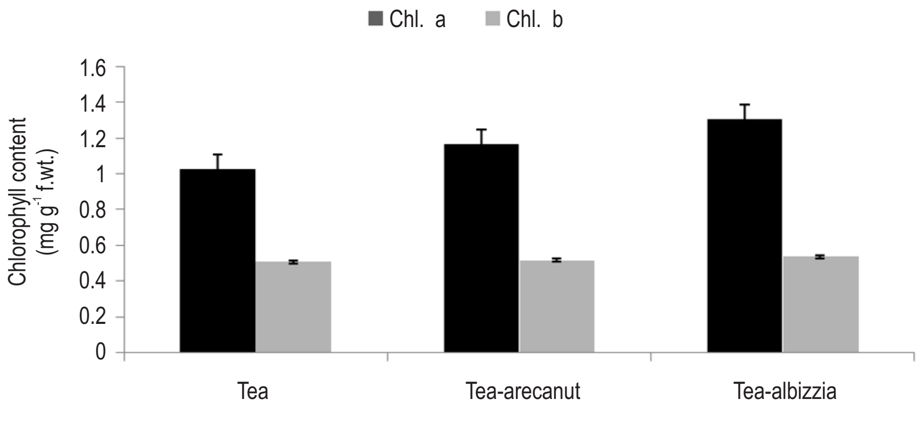

Fig. 1: Total chlorophyll content in different tea based cropping system.

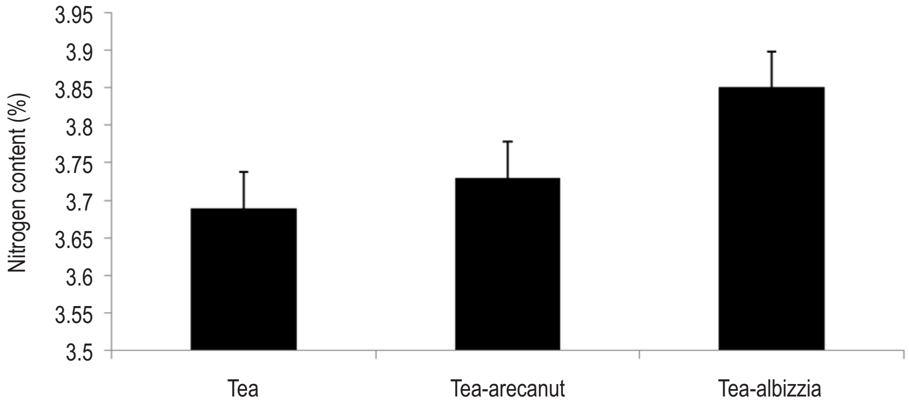

Fig. 2: Leaf nitrogen content in different Tea based cropping system.

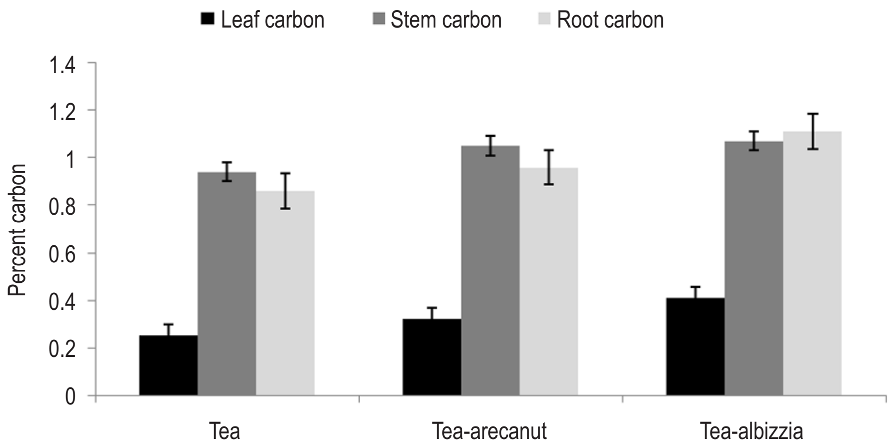

Fig. 3: Carbon content in different Tea based cropping system.

photosynthesis and carbon sequestration (Weissert *et al.*, 2017). Some specific physical parameters determines CO_2 assimilation in tea plants eg. CO_2 flows in leaves are mostly related to photosynthesis, respiration and decomposition of organic matter and are largely conditioned by physical processes ((Phukan *et al.*, 2018; Nunes *et al.* 2020). In the present study, a significant difference was also observed in terms of stomatal conductance of tea plants (Table 3). The highest stomatal conductance was recorded in Tea-*Albizzia* plantation followed by Tea-Areca palm plantation while the lowest was recorded in tea grown as monoculture. The higher photosynthetic rate was possible due to high stomatal conductance in tea leaves under Tea-*Albizzia* plantation. Similar results have been reported De Costa *et al.* (2007) and Wijeratne *et al.* (2008). Wijeratne *et al.* (2008) and Rajkumar *et al.* (1999) reported that medium shade favored a higher photosynthetic rate than in non-shaded and highly shaded in tea plants. Another cause for increase in photosynthesis in Tea-*Albizzia* plantation might be due to maintenance of higher level of chlorophyll pigments, as evident in this study (Fig. 1). The maintenance of higher level of pigment and photosynthetic rate in Tea-*Albizzia* plantation may be due to higher level of leaf nitrogen higher biomass and carbon in different plant parts (Fig. 2). The nitrogen content of tea leaves under different tea plantations differed significantly. In Tea-*Albizzia* plantations, tea leaves had the highest nitrogen content. In Tea-*Albizzia* system, *Albizzia* can fix atmospheric nitrogen by nodule formation in later stages and during nodule senescence, they release nitrogen in the soil. The main crop tea is therefore benefitted in this system. A prat from providing shade, the role of shade trees in replenishing nitrogen loss has also been reported (Pangging and Mandal, 2017). Nitrogen-fixing tree species have larger effects on forest soils than other species, and these effects include a consistent increase in soil organic matter, carbon and nitrogen in Eucalyptus foliage (Dean *et al.,* 1989). Similarly, the role of various plantation tree species in recycling soil nutrient has been reported for restoring degraded lands (Faming *et al.,* 2010). A non-significant difference in RLWC was noted amongst the various plantation systems (Table 3).

The leaf temperature of different tea plantations differed significantly (Table 3). In Tea-*Albizzia* plantation, least leaf temperature (11.99 per cent) was observed in tea grown as monoculture. Tea grown as monoculture recorded a maximum leaf temperature as compared to other plantation systems under study, which indicated maximum light energy dissipation as wasteful energy that might have disrupted the electron flow from PSI to PSII resulting in decreased photosynthetic process. Similar reduction in leaf temperature due to various shade intensities of trees in plantation systems have been reported in tea (Wijeratne *et al.,* 2008). The favorable light intensity and leaf temperature prevailing under *Albizzia* in tea might have resulted in enhanced rate of photosynthesis in leaves and an increase in leaf carbon content (Fig. 3) and can be directly related to the leaf biomass. Leaf carbon content of different plantation was also significantly different. In Tea-*Albizzia* plantation, the leaf carbon content was significantly higher in comparison to tea grown as monoculture.

Plantations under Tea-*Albizzia* could have facilitated greater uptake of nutrients, higher photosynthesis and, which favoured synthesis of carbohydrates and facilitated the partitioning into different sinks because of optimum light intensity. The optimum light intensity is necessary for the plant system as plant anatomy, morphology, chemistry, physiology, growth and reproduction are affected by daily light integral (DLI; mol photons m^2d^1) as reported by Poorter *et al.*, 2019. The direction and degree of trait change adheres with responses to plant density and vertical light gradients within plant canopies. This synthesis provides a strong quantitative basis for understanding plant acclimation to light, from molecular to whole plant responses, but also identifies the variables that currently form weak spots in our knowledge, such as respiration and reproductive characteristics that might have brought about a significant increase in leaf carbon content (Pareek and Yadav, 2011, Poorter *et al*., 2019). Piato *et al.,* 2020 also reported that using shade trees might have protected against temperature variability, erosion and excessive radiation but there may be trade-offs in productivity and quality in robusta coffee .Similar trend was observed in case of root carbon content of tea plants under different plantation systems. Different organic sources of carbon from leaf litter of tea and *Albizzia* might have lead to greater utilization of nutrients resulting in proper vegetative and root growth and an increase in the root carbon content. Higher carbon content of both root and shoot in this study indicates enhancement of both above and below ground terrestrial carbon sequestration processes which ultimately reflect the whole carbon sequestration processes in tea plantation.

Amongst the various Tea based cropping system, Tea-*Albizzia* plantation system was more efficient in terms of carbon sequestration in north-east India, where tea is a major cash crop. But Tea- arecanut system may also be a possible cropping system and can be suggested where tea is grown by marginal farmers (small tea growers) in the homestead yard. This study may help in developing models related to carbon sequestration for sustainable development and may provide a baseline data for future research and pave for carbon offsetting.

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Add-on Information

Authors' contribution: S. Alom: Carried out the experiment; **R. Das:** Planning and monitoring; **U. Baruah:** Data acquisition; **S. Das:** Date analyses; **R.P. Bhuyan:** Script prepration.

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References

Arnon, D.I.: Copper enzymes in isolated chloroplasts. Polyphenol oxidase in *Beta vulgaris*. *Plant Physiol.,* **24**, 1-10 (1949).

Baruah, D.N.: Science and practice in tea culture. Jorhat: Tea Research Association, pp. 56– 58 (1989).

Beer, J.: Litter production and nutrient cycling in coffee (*Coffea arabica*) or cacao (*Theobroma cacao*) plantations with shade trees. *Agrofor. Syst.,* **7**, 103-114 (1988).

Beer, J., R. Muschler, D. Kass and E. Somarriba: Shade management in coffee and cacao plantations. *Agrofor. Syst.,* **38**, 139-164 (1998).

Chaer, G.M., A.S. Resende, E.F.C. Campello, M.D.F. Faria and R.M. Boddey: Nitrogen-fixing legume tree species for the reclamation of severely degraded lands in Brazil. *Tree Physiol.,* **31**, 139-149 (2011).

Chavan, B.L. and G.B. Rasal: Sequestered standing carbon stock in selective tree species grown in University campus at Aurangabad, Maharashtra, India. IJEST, **2**, 3003-3007 (2010).

Chavan B.L. and G.B. Rasal: Potentiality of carbon sequestration in six year ages young plant from University campus of Aurangabad, *Global J. Res. Engine.*, **11**, 15-20 (2011).

De Costa, W.A.J.M., A.J. Mohotti and M.A. Wijeratne: Ecophysiology of tea. *Braz. J. Plant Physiol.,* **19**, 299-332 (2007).

Faming, W., L. Zhian, X. Hanping, B. Xia, N. Zou and Z. Weixing: Effects of nitrogen-fixing and non-nitrogen-fixing tree species on soil properties and nitrogen transformation during forest restoration in southern China. *Soil Sci. Plant Nutri.,* **56**, 297-306 (2010).

Food and Agriculture Organization. Report of the Working Group on Climate Change of FAO Intergovernmental Group on Tea, United

Online copy

Nations, Rome (2016).

Han, W., S.J. Kemmit and P.C. Brookes: Soil microbial biomass and activity in Chinese tea gardens of varying stand age and production. *Soil Biol. Biochem.,* **39**, 1468-1478 (2007).

Hiscox, J.D. and G.F. Israelstam: A method for the extraction of chlorophyll from leaf tissue without maceration. *Can. J. Bot.,* **57**, 1332-1334 (1979).

Huxley, P.A.: The role of trees in agroforestry. In: Plant Research in Agroforestry. Proceedings of Consultative meeting, Nairobi, Kenya. *Int. Cou. Res. Agrofor.,* (1983).

Isaac, M.E., V.R. Trimmer and S.J.Q. Sam: Shade tree effects in an 8-year-old cocoa agroforestry system: Biomass and nutrient diagnosis of *Theobroma cacao* by vector analysis. *Nutri. Cycli. Agroecosys.,* **78**, 155–165 (2007).

Kamau, D.M., D.M.J.H.J. Spiertz and O. Oenema: Carbon and nutrient stocks of tea plantations differing in age, genotype and plant population density. *Plant Soil.,* **307**, 29–39 (2008).

Kursten, E. and P. Burschel: CO_2 mitigation by agroforestry. *Water Air Soil Pollut.,* **70**, 533-544 (1993).

Lal, R.: Carbon sequestration. *Trans. R. Soc. B.* **363**, 815-830 (2008). https://doi.org/10.1098/rstb.2007.2185

Mokany, K., R.J. Raison and A.S. Prokushkin: Critical analysis of root: Shoot ratios in terrestrial biomass. *Global Chan. Biol.,* **11**, 1-3 (2006).

Nunes, J. R. L; C. I. R. Meireles, C.J.P Gomes and N.M.C.A. Ribeiro: Forest contribution to climate change mitigation: Management oriented to carbon capture and storage. *Climate*, **8**, 21 (2020). doi:10.3390/cli8020021 (2020)

Pangging, G. and S. Mandal: Assessment of shade trees and socio-economic condition of the tea workers: A case study of tea estate around Banderdewa forest range. *Bull. Arunachal For. Res.,* **32**, 62-65 (2017).

Panse, V.G. and P.V. Sukhatme: Statistical Methods for Agricultural Workers. 2nd Edn., ICAR, New Delhi (1985).

Pareek, N. and B.L. Yadav: Effect of organic manures on soil physicochemical properties, soil microbial biomass and yield of mustard under irrigation of difference residual sodium carbonate waters. *J. Indian Soc. Soil Sci.,* **59**, 336-342 (2011).

Patterson, H., S. Holm, G. Stahl, D. Alger, J. Fridgman, A. Lehtonen, A. Lundstom and R. Makipaa: Individual tree biomass equations or biomass expansion factors for assessment of carbon stock changes in living biomass – A comparative study. *Forest Ecol. Manage.,* **270**, 78-84 (2012).

Piato, K., F. Lefort, C. Subía, C. Caicedo, D. Calderón, J. Pico and L. Norgrove: Effects of shade trees on robusta coffee growth, yield and quality. A meta-analysis. *Agron. Sustain. Dev.,* **40**, 38 (2020). https://doi.org/10.1007/s13593-020-00642-3

Phukan, M., D. Savapondit, A. Hazra, S. Das and P. Pramanik: Algorithmic derivation of CO_2 assimilation based on some physiological parameters of tea bushes in North-east India. *Ecol. Indicat.,* **91**, 77–83 (2018).

Poorter, H. N., U. Nikolaos Ntagkas , A. Siebenk, M. Maarit, M. Shizue and L. Thijs: Pons New Phytologist A meta-analysis of plant responses to light intensity for 70 traits ranging from molecules to whole plant performance. **223**, 1073–1105 (2019). doi: 10.1111/nph.15754

Pramanik, P. and M. Phukan: Potential of tea plants in carbon sequestration in North-east India. *Environ. Monit. Assess.,* **192**, 211 (2020).

Rajkumar, R., S. Marimuthu and N. Muraleedharan: Tea leaf photosynthesis in relation to light. *J. Plant. Crops,* **27**, 93-98 (1999).

Ravindranath, N.H. and M. Ostwald: Carbon Inventory Methods Handbook for Greenhouse Gas Inventory, Carbon Mitigation and Roundwood Production Projects (2008). DOI:10.1007/978-1-4020-6547-7

Sana, D.L.: Tea Science. Ashrafia Boi. Ghar. Dhaka, pp. 7-81 (1989).

Sano, S., T. Takemoto, A. Ogihara, K. Suzuki, T. Masumura, S. Satoh, K. Takano, Y. Mimura and Morita: Stress responses of shade-treated tea leaves to high light exposure after removal of shading. *Plants,* **9**, 302 (2020).

Seikh, A.Q., B.M. Skinder, A.K. Pandit and B.A. Ganai: Terrestrial carbon sequestration as a climate change mitigation activity. *J. Pollut. Eff. Cont.,* **2**, 110 (2014).

Shinde S.M., P.D. Turkhade, S.B. Deshmukh and G.W. Narkhede: Carbon sequestration potential of some fruit trees in Satara district of Maharashtra India. *Eco. Env. Cons.,* **21,** 359-362 (2015).

Subramaniyan, P., J. Jeeve and S.M. Shoba: Carbon sequestration in plantation crops. *Int. J. Scien. Develop. Res.,* **2**, 95-101 (2017).

Tea Board of India, Tea Statistics, Government of India, Under Ministry of Commerce & Industry, 2014 (accessed on17.07.14),http://teaboard.gov.in.

Torres, C.M.M.E., G. Jacovin, S.N.de O. Neto, C. Fraisse, C.P.B. Soares, F. de C. Neto, L.R. Ferreira, J.C. Zanuncio and P.G. Lemes: Greenhouse gas emissions and carbon sequestration by agroforestry systems in southeastern Brazil. *Sci Rep.,* **7**, 16738 (2017).

Walkly, A. and I.A. Black: An exogenous degtjareff method for determining soil organic matter and a proposed modification of the chromic acid and titration method. *Soil Sci.,* **37**, 29-38 (1934).

Wang, Y.S., L. Gao, Y. Shan, Y.Z. Liu and T. Xia: Influence of shade on flavonoid biosynthesis in tea (*Camellia sinensis* (L.) O. Kuntze). *Scientia Horticul.,* **141**, 7-16 (2012).

Wang, W., Q. Min and J. Sardans, C. Wang, D. Asensio, M. Bartrons and J. Penuelas: Organic cultivation of jasmine and tea increases carbon sequestration by changing plant and soil stoichiometry. *Agron. J.,* **108** (2016).

Weissert, L.F., J.A. Salmond and L. Schwendenmann: Photosynthetic CO_2 uptake and carbon sequestration potential of deciduous and evergreen tree species in an urban environment. *Urban Ecosyst.,* **20**, 663–674 (2017).

Wijeratne, T.L., W.A.J.M. De Costa and M.A. Wijeratene: Carbon Sequestration Potential of Tea Plantations in Sri Lanka, 2014. Conference paper 228th Experiment and Extention Forum, Colombo, Sri Lanka (2014).

Wijeratne, T.L., A.J. Mohotti and S.P. Nissanka: Impact of long term shade on the physiological, anatomical and biochemical changes in tea (*Camellia sinensis* (L.) O. Kuntz). *Trop. Agric. Res.,* **20**, 376–387 (2008).

Wijetratne, T.L.: Carbon sequestration of tea plantations as an adaptation for climate change. 4th International Conference on Climate Change Adaptation, Srilanka (2015).

WMO: Greenhouse Gas Bulletin: The State of Greenhouse Gases in the Atmosphere Using Global Observations through 2007. World Meteorological Organization, Geneva, Switzerland (2008).

Zhang, M., X.U. Fu, W.T. Feng and X. Zou: Soil organic carbon in pure rubber and tea-rubber plantations in South-western China. *Trop. Ecol.,* **48**, 201-207 (2007).

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