STUDY ON THE IMPLEMENTATION OF A SIMPLE PROCESS-BASED MODEL ON TEA AGROFORESTRY SYSTEMS IN BANGLADESH

A THESIS
BY

NISHAT ANAN
Student No.: 1905117
Session: 2019
Thesis Semester: January-June, 2020

MASTER OF SCIENCE (M.S.)

IN

AGROFORESTRY AND ENVIRONMENT

DEPARTMENT OF AGROFORESTRY AND ENVIRONMENT

HAJEE MOHAMMAD DANESH SCIENCE AND TECHNOLOGY UNIVERSITY, DINAJPUR-5200

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Submitted to the Department of Agroforestry and Environment

Hajee Mohammad Danesh Science and Technology University, Dinajpur in partial fulfillment of the requirements for the degree of

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Approved as to style and contents by

(Professor Dr. Md. Shoaibur Rahman)	**(Professor Dr. Md. Shafiqul Bari)**
Supervisor	Co-Supervisor

(Prof. Dr. Md. Shoaibur Rahman)
Chairman of Examination Committee
&
Chairman

DEPARTMENT OF AGROFORESTRY AND ENVIRONMENT

HAJEE MOHAMMAD DANESH SCIENCE AND TECHNOLOGY UNIVERSITY, DINAJPUR-5200

JUNE, 2020

DEDICATED

TO MY

BELOVED HUSBAND

DECLARATION

I hereby declare that the work presented in this thesis titled "**STUDY ON THE IMPLEMENTATION OF A SIMPLE PROCESS-BASED MODEL ONTEA AGROFORESTRY SYSTEMS IN BANGLADESH"** has been carried out by myself and that it has not been submitted for any previous degree. All quotations have been distinguished by quotation marks and all sources of information specifically acknowledged by references to the authors.

NISHAT ANAN

Student No.: 1905117

M.S. Session 2019

Department of Agroforestry and Environment

Hajee Mohammad Danesh Science and Technology University

Dinajpur-5200, Bangladesh

ACKNOWLEDGEMENTS

*First of all, the author expresses her sincere gratitude to almighty **ALLAH** the supreme rulers of the universe forever ending blessings for the successful completion of the present research work and to prepare thesis.*

*The Author express her deepest sense of gratitude and ever indebtedness to her reverend teacher and supervisor**, Professor Dr. Md. Shoaibur Rahman**, Chairman , Department of Agroforestry and Environment, Hajee Mohammad Danesh Science and Technology University, Dinajpur, for his ingenious suggestions, encouragement, and guidance to complete this study and also for his constructive criticism and meticulous review of the manuscript.*

*The author Sincerely express her heartiest respect, deepest gratitude and the profound appreciation to her co-supervisor **Professor Dr. Md. Shafiqul Bari**, Department of Agroforestry and Environment, Hajee Mohammad Danesh Science and Technology University, Dinajpur for his co-operation and helpful suggestions to conduct the research work and in the preparation of this manuscript.*

*The Author express her profound respect and gratefulness to Lecturer **Md. Manik Ali,** Department of Agroforestry and Environment, Hajee Mohammad Danesh Science and Technology University, Dinajpur for his co-operation helpful suggestions to conduct the research work and in the preparation of this manuscript.*

*The Author wish to express deep sense to the senior laboratory Technician **Md. Iman Uddin** and Field **worker Md. Abdul Quddus and Nawshad ali**, Department of Agroforestry and Environment, for their co-operation. Finally, the Author express her sincere gratitude to her beloved husband, parents, friends, well-wishers for their inspiration and co-operation throughout the period of her study.*

June, 2020

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ABSTRACT

The present study was an attempt to develop a basic event-based process model to represent the biological process of tea agroforestry systems and their environmental effects. This model was incorporated into a tea garden including tea and shade trees, which involves competition for energy, water, and nutrients and considered the spacing, thinning, pruning, and fertilizing as factors of production. The study area for tea and shaded tree plots was selected on Ratandighi Union, Panchagarh district, Bangladesh and the study was conducted, from 2018 to 2020. The study period was divided into six quarterly events, such as event-1 (March 2018-June 2018), event-2 (July 2018-October 2018), event-3 (November 2018-February 2019), event-4 (March 2019-June 2019), event-5 (July 2019-October 2019) and event-6 (November 2019-February 2020). The weather data were obtained from the AccuWeather site from March 2018 to February 2020. The findings of this study show that the highest mean temperature was 30.27°C in the unshaded site, but the temperature was 27.52°C in the shaded side from March to June. The coldest month was January in the studied area with a temperature of 19.45°C in the open site and 19.19°C in the shaded site. The variations of temperature had a significant impact on tree wood production. Nevertheless, the trend of tree LAI is consistent, and the stem volume of shade trees grows significantly from event-1 to event-6 (March 2018 to February 2020). On the other hand, higher rainfall indicates an increase in the volume of tea production. However, the tea production was constant from event-1 to event-3 (March 2018 to February2019) due to the growth stage, and the production level increases after event-3 at the maturity stage. The findings of this study might be helpful to the policymaker and academic researcher for getting the more productive tea agroforestry system in Bangladesh.

Keywords: Tea, Process-based model, Climate, Soil, Agroforestry.

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ABBREVIATIONS

AFS	Agroforestry systems
AGB	Above ground biomass
BD	Bulk density
BGB	Below ground biomass
CG	Continuous pasture
cm	centimeter
FAO	Food and Agriculture Organization
GB	Grass buffer
ICRAF	International Council for Research in Agroforestry
km	Kilometer
LAI	Leaf area index
LLT	Leaf litter thickness
mg	milligram
PAR	Photosynthetic active radiation
RATP	Radiation absorption, transpiration, photosynthesis
RG	Rotational pasture
RLd	Root length density
Rn	Ranged
SOC	Soil organic carbon
SWAT	Soil and Water Assessment
TB	Total biomass
TE	Tea estate
WaNuLCAS	Water nutrient and light capture in Agroforestry systems

CHAPTER-I: INTRODUCTION

1.1 Background

As a part of agroforestry systems (AFS), Tea *(Camellia sinensis L.)* is grown-up in monoculture. In Bangladesh, there has been a tendency towards increasing tea in high-input monocultures in recent decades. Also, in this country, agroforestry systems are becoming more widespread. A big problem is that recently farmers are concentrating less solely on tea production and striving for a broader range of ecosystem services funded by including shade trees (Kalita *et al.,* 2020). However, it is challenging to maximize shade tree species selection and tea agroforestry system management. Tea agroforestry system (AFS) retains a multy-storey layout with an extensively maintained variety of tea, temporary and permanent shade trees. Nevertheless, tree density in AFS recognizes climate change mitigation potentiality, which provides a healthy environment for shade and tea growth. Therefore, tea agroforestry is one of the most effective land-use management systems in Bangladesh. It also combines economic profit and security of living for a mass of people (Weyesa, 2019).

Considering the importance of the tea agroforestry system in economy and living, researchers have given more emphasis to design a suitable agricultural model that will help farmers getting more production in tea. Many modeling methods can be used to direct agroforestry management decisions. However, specific modeling methods are better suited than others to solve the prediction problem under the agroforestry system and climate change. A process-based model is the mathematical representation of several processes characterizing the functioning of well-delimited biological systems of fundamental or economic interest. Process-based models, related to the theoretical knowledge of relevant environmental processes, provide a conceptual guide for incorporating specific responses to modified environmental factors. As a result, these models can provide significant advantages in forecasting the impact of global change as opposed to strictly statistical or rule-driven models based on data obtained previously. Process-based models also provide more clear predictions and more straightforward analysis than complex simulation models (Cuddington *et al.,* 2013).

The production of tea agroforestry systems may be benefited from process-based modeling. Modeling of regulated ecosystems usually has a twofold function. First, the model building and parameterization phase illustrate gaps in our knowledge, helping set the research agenda. Second, the completed model can investigate how various factors influence the tea agroforestry system's efficiency and environmental effects. For this purpose, firstly, this study discusses developing a technique for tea agroforestry systems to analyze the systems' feedback to managerial decisions (fertilization stage, pruning, thinning, shade-tree species, and density). Secondly, this study also analyses the regional variations in growing situations (soil and weather) and environmental change (climate composition). Therefore, to achieve these goals, the model needs to predict the maximum circulation of tea production, usually 10–25 years in our area of attention, Bangladesh.

1.2 Research Gap and Problem Statement

Process-based crop growth modeling began in the 1960s, followed in the early 1970s by the first forest models and another decade later by agroforestry models (Muetzelfeldt and Sinclair, 1993; Bouman *et al.,* 1996). However, some early crop models were extremely complex and prolific in parameters. For this reason, the emphasis was given to changes the simpler process-based models that show more convenient to parameterize and produce more reliable predictions (Bouman *et al.,* 1996). Previous analyses of agroforestry modeling indicate no clear evidence towards more significant models

(Muetzelfeldt and Sinclair 1993; Young 1997; Matthews *et al.*, 2004). The authors also suggest that even the most complicated generalized models of agroforestry, such as WaNulCas (Noordwijk & Lusiana 1999; Van Noordwijk *et al.*, 2004), SWAT (Mwangi *et al.*, 2016), Yield-SAFE (Crous-Duran *et al.*, 2018) and HyPar (Mobbs *et al.*, 1998) can be more optimized. Moreover, they concede that model users find it challenging to parameterize existing models implementations for their structures (Matthews *et al.*, 2004). The author also considers that the complexity of the model should be proportionate to the availability of the data. Van Oijen *et al.*, (2010) reviews the quality of quantitative knowledge about coffee agroforestry structures using a process-based model and finds that parameters are not well defined for specific physiological and ecological processes.

Up to this point, no particular model for the tea agroforestry system in Bangladesh has been designed. However, some models in coffee agroforestry systems such as 3D-architectural and STICS models have been designed for unshaded coffee plants (Dereffye 1983; Dauzat *et al.*, 2001), which rely on the effects of light and water usage by the plants throughout the season. Nevertheless, these models are too diverse to function as components of a simple full-rotation agroforestry model. Similarly, there is another coffee agroforestry architectural model for *Erythrina poeppigiana*, a typical coffee shade-tree plant, which emphasis on short-term radiation data distribution (Nygren, 1993). Despite the absence of coffee and shade-tree agroforestry models, several algorithms are typically valid for simple crop modeling (Van Oijen *et al.*, 2004, 2005). These algorithms can be used in a tea agroforestry model as elements. Therefore, this study analyzesa process-based technique to integrates the main physiological characteristics of tea and shade trees that influence their productivity and the system's environmental effect.

During the first quarter and the duration after tea pruning, tea agroforestry systems usually have a low yield of productions. Wood volume is often not constant with initially growing shaded trees but consistently decreased by pruning and thinning. The method is thus too complicated, and this study tries to find out the tea and tree growth by modeling time paths from planting to the end of the cycle period. This study will present such a model and determine whether it can explain the widely observed behavior of tea agroforestry systems in Bangladesh.

1.3 Objective

Combined research has highlighted that tea-agroforestry can reap substantial economic and environmental benefits, produce more output, and prove more sustainable than forestry or agricultural monocultures. In the present work, the following two broad objectives are set to satisfy the research needs:

I. To parameterize the mathematical equations of the shade trees and micro-climate factors.

II. To integrate the major physiological characteristics of tea and shade trees and the micro-climate factors that influencing their productivity.

1.4 Limitation

A more significant limitation than that of model simplicity at this point in software creation is possibly that of minimal model testing against the results. In this study, different explanations are presented about how the model's qualitative behavior is compatible with observations. However, no rigorous test against quantitative evidence has been done, nor has the volatility of model performance quantified.

CHAPTER-II: LITERATURE REVIEW

Tea production, tea plant cultivation, typically has been done during large-scale commercial processes. Bangladesh is an important country that produces tea, and it is the world's 10th-largest tea manufacturer. This study mainly focuses on the process-based analysis of tea agroforestry systems and their environmental impact in Bangladesh. This chapter presents an overview of the literature that relates to the work presented here. It is essential to have some awareness of the current issues highlighted in the literature.

2.1 Agroforestry System (AFS) in South Asian Countries

Several ways of describing agroforestry (Nair, 1989): The traditional concept of ICRAF is a collective term for land-use structures and operations in which woody perennials are deliberately mixed into the similar land-management part with crops and livestock. Integration may be in a spatial mix or a temporal sequence. In agroforestry, relations between woody and nonwoody components are typically both ecological and economical. This concept has worked fine and helped to identify agroforestry as a branch of farm science in its particular right (Sanchez, 1995). Agroforestry methods come in several ways but fall under two classes – concurrent ones, such as fallows, and simultaneous ones, such as alley-cropping (Cooper *et al.,* 1996). Overall, Nair (1993) has recognized some 18 different agroforestry practices, though each has an unlimited number of differences. Therefore, agroforestry is typically seen as a collection of different technologies that are composed form different land-use structures in which trees are combined serially or concurrently with crops and livestock. After evaluation and design, sharing experiments, or characterization studies, methods are applied in agroforestry research, according to the region's social, economic, and environmental issues.

Bangladesh is one of the world's densely populated country with over 150 million people within a 142,776 km^2 area. In order to meet the increasing need for this overcrowded population, there is an urgent need to consider a universal system of production using land resources to achieve food and nutrition protection, meet the demand for fuel wood and timber and finally preserve biological resources. Greater adoption of planned agroforestry systems leads to the fight against the challenges of improving living conditions in every country's possible space. Leuschner & Khaleque (1987) suggest that in Bangladesh's economy, the homestead agroforestry system is essential. A significant source of fuel wood is the many wood species grown in the homes; however, they also provide forage, construction materials, and other wood sources. This homestead agroforestry system needs to be strengthened in the context of the prevailing fuelwood shortage and excessive deforestation in Bangladesh. Zoysa (2013) indicates that Sri Lanka needs to raise and maintain agricultural production to meet the increasing population demands. The combination of trees with crops is considered to be more useful and sustainable for environmental and economic reasons, particularly for more populated areas. While in certain parts of the world, the agroforestry method is not a recent adoption, on the one hand, the research and systematic study of this practice. On the other hand, the creation of new broader adoption management strategies is reasonably new. Kalita *et al.*, (2015) suggest that agroforestry has broad implications on earnings and food security for a significant fraction of the North East India community. This system also has an enormous capacity to serve as a significant renewable carbon reserve offering mitigating solutions for climate change.

2.2 Tea cultivation and Tea Agroforestry system

Tea [*Camellia sinensis* (L.) O. Kuntze] is a perennial cash crop which is handled intensively. It is one of the most commonly available drinks in the world. The tea plantations cover about three million hectares of the world's arable land (FAO 2007). Most plantations were produced at the detriment of the trees. Agroforestry systems are related to preserving the distribution of diverse habitats. Based on mutual vertical stratification, the temporal sequence and primary factors of tea ASF can be called dual-layered and coincident commercial agroforestry (AFS) structures. Tea AFS retains a multi-story structure with an actively controlled, temporary, and permanent tea functional mixture.

Islam *et al.*, (2005) examine that world tea production has shown an annual increase of 3%, while production in Bangladesh has increased by 1.84% and contributes 1.37 million Taka (Taka 80 = USD 1.00) annually to exports in the word tea trade and earns nearly 1775 million Taka. The tea industry's operations fall into two categories: tea processing and tea production & tea marketing. The crux of the issue is low productivity, reduced efficiency, and higher output costs than the dividend in the price of tea. They are seeking to concentrate on the current situation and support of the country's tea industry. Mukherjee *et al.*, (2008) show that tea is generally grown in West Bengal, India's hills, and terrain. To assess the possibility of growing tea in West Bengal's lower, they experimented at Bidhan Chandra Krishi Viswavidyalaya's Central Research Farm, Gayespur, Nadia, during 2001-2002. The result reveals that better growth and tea production should be possible underneath the microclimate conditions under which R_n ranged from 108 to 178.94 W_{m-2} and 188 to 339 1/4 E_{m-2s-1} incident PAR. The shade provided by *Acacia auriculiformis* and *Dalbergia sisoo* appears advantageous for yielding tea. Tian *et al.*, (2013) analyze the effect of agroforestry on soil fertility, organic carbon content, total nitrogen content, biomass production, and soil enzyme activity at three soil depths of Ginkgo. Research plots have been developed at Yushan Farm in Changshu Province, Jiangsu, China. These plots include two densities of tea-mixed

Ginkgo trees (G1 and G2) and tea-monoculture systems (G0). The findings indicate that growing tea with *Ginkgo* could be observed as a proper agroforestry technique that could boost soil organic matter aggregation, increase soil enzyme production, and preserve soil fertility and sustainability. Kalita*et al.*, (2015) try to establish allometric equations unique to Tea in Barak Valley of northeast India for above- and below-ground biomass estimation. The result shows that relationships were established by destructive sampling and diameter regression alone and along with the height, density of timber, crown area, count of branches with biomass. It shows the developed equation of allometric power functions and linear equivalents. By diameter alone, root biomass (BGB) and total tea biomass (TB) could estimate significantly aboveground biomass (AGB) with over 95 % precision.

Karak*et al.*, (2015) analyze the chemical soil properties of large tea (*Camellia sinensis L.*) growing areas, Dibrugarh and Tinsukia districts, in Assam State, India. For the study of its specific chemical properties, 991 surface soil samples were obtained from 15 large tea estates (TEs). Results of hierarchical clustering analysis for the homogeneous classification of the 15 TEs based on soil chemical properties reveals that the 15 TEs can be categorized into three different classes composed of 6, 8, and 1 TEs. Kalita *et al.*, (2016) investigate the distribution of soil organic carbon (SOC) stocks in different soil layers up to a depth of .1 m below an age sequence of tea agroforestry systems in Barak Valley, North East India. In the network, SOC stock ranged from 65.14 to 141.49 mg C ha^{-1} with an average of 101.39 mg C ha^{-1}. Approximately 46 % of the measured SOC is limited to a layer of 0-30 cm. On the other hand, 65 % of SOC exists in the soil layer of 0-50 cm. The next soil layer (50-100 cm) compensated for an average of 36 % of SOC. SOC decrease in all plantations with increasing size and is negatively related to bulk density (BD). Gogoi *et al.*, (2016) investigate a study on the more than 50-year-old tea plantation in Naharoni, Golaghat district of Assam. They try to understand the physicochemical properties of soil while monocropping long-term tea. A total of 48 tea bush-field soil samples from the rhizosphere were obtained from three depths, i.e., 0-20, 20-40 in four seasons, i.e., from three depths, pre-monsoon, monsoon, post-monsoon, and winter. Analysis of the soil profile has also been performed in the non-rhizosphere environment. It can be inferred from the findings that the soils are low to medium in the concentration and abundance of the primary soil nutrients and that their abundance is also imba with soil depths and seasons.

2.3 Agroforestry Modelling

Agroforestry is a dynamic mechanism that combines biophysical, socio-economic, environmental, and cultural influences. The agroforestry is both technically as well as economically dynamic. Therefore, the agroforestry system has considerable significance in sound decision-making. It applies to species collection, components (i.e., trees, crops, and livestock) collection and incorporation, but the maximum benefits of AGF have been obtained from the implementation of agroforestry modeling.

Few studies were related to agroforestry model. Oldeman (1992) has found that the approaches used in monoculture forecasting and architecture are less critical. Architectural ecosystem models have moved across the hierarchy of a modern paradigm over the last decade, demonstrating two types of architectural layering and reciprocal intervention with micro-environmental gradients that define niches. The research reveals that fractal geometry can represent output geometry mathematically, and can produce patterns that have striking correlations with patterns of forest-like structures. The finding of this study shows that the geometry approach to production is young, but comparing the architecture of agroforestry ecosystems and a fractal body shows promise, particularly when combined with other recent concepts. Noordwijk & Lusiana (1999) emphasize that tree-soil-crop interaction models in agroforestry would balance complex processes and spatial patterns of common-resource connections. This study illustrates significant observations of water, nitrogen, and light interactions in agroforestry systems underlie the WaNuLCAS model. The model has developed to tackle a wide variety of agroforestry systems: hedgerow intercropping on flat or sloping ground, fallow-crop mosaics, or isolated parkland trees, with limited parameter modification. Mialet-Serra *et al.,* (2001) design software modules for forecasting plant stands' radiative atmosphere consisting of plant 'mock-up' computers. The plant architecture has been used to quantify the radiative characteristics that are described at the level of individual organs and simulated in compliance with botanical legislation. A three-dimensional stochastic statistical mock-ups for coconut (*Cocos nucifera L.*) and cacao (*Theobroma cacao L.*) are measured using the 'AMAP' technique.

Sinoquet *et al.,* (2001) develop RATP models to predict the spatial spread of radiation and transfers of leaf-gas within plant canopies due to canopy composition, canopy microclimate within the canopy and physical and physiological properties of plants. The model uses a three-dimensional (3D) canopy representation (i.e., an assortment of 3D cells, each defined by a leaf region den. The result shows that the model simulates the intra-crown distribution of radiation regime, transpiration, and photosynthetic levels at shooting or branch levels of the tree. Prusinkiewicz (2004) uses digital plant models or 'virtual plants' which are increasingly used as a valuable method for understanding the dynamic relationships between gene expression, plant morphology, plant growth, and resulting plant type. The L-systems theory, which Lindemayer developed in 1968, has contributed to a well-established technique for simulating plant branching architecture. Many existing architecture models give insight into the plant growth pathways by integrating physiological processes, such as carbon transport and distribution. Radersma and Ong (2004) evaluate the spatial distribution of soil water quality in the soil profile in crop fields bordering tree lines and its relation to the distribution of root length density of the plants. This experiment measures the lines of four tree species at the center of maize fields in west Kenya, soil water content, and tree root-length densities in the soil profile over two years. Therefore, the findings of spatial agroforestry systems can notaccept a positive correlation between tree-water extraction and root-length density but may entail reducing the water-potential differential between root and soil together with roots with varying range to the base of the stem, particularly along the horizontal axis. Lamanda *et al.,* (2007) develop 3D architecture simulations in agroforestry systems to determine the quality of light and the root bulkiness. The simulation methodology has been used to provide metrics for determining aboveground competition for light and underground space competition to maximize intercropping in smallholdings of coconut. The modeling of light transmission through coconut stands was based on three-dimensional simulated coconut trees and a numerical light model that calculated the shade shed by coconut trees on the underlying crops. Digital 3D coconut root systems were used to determine root colonization in the interrow. Their findings show that after coconut tree planting, the intercropping with shade-tolerant species is not limited by light transmission from the 35th year. This simulation approach, which required little easily accomplished parameterization, proved to be an efficient method for suggesting trends and densities for coconut tree planting and signaling intercrop capacity based on their position in the sunniest areas with minimal root rivalry.

For herpetological diversity in Sulawesi (Indonesia), Wanger *et al*., (2009) used a two-step method to assess the relationship between ecosystem quality and management importance of cacao agroforestry. They sampled 43 cacao plantations six times for the first time, using a Bayesian model selection approach to test environmental variables that best-defined patterns in herpetofauna diversity. Depending on these findings, they have experimentally engineered variations of leaf litter thickness (LLT), several branch piles (LOGS), and LLT + LOGS in the cacao plots. Using Bayesian linear inference, they analyze the experimental results. It would mainly improve the diversity and biodiversity of disturbance-tolerant plants, which will also retain habitat functions such as pest elimination. Kumar *et al.*, (2010) plan a study to determine variations in grass buffer (GB), agroforestry buffer (AgB), rotational pasture (RG), and continuous pasture (CG) treatments in root length density (RLD) and soil carbon content. The results show that agroforestry and GB formation on grazed pasture watersheds enhances soil carbon accumulation and root parameters, which improve soil physical and chemical properties, thereby enhancing the landscape's environmental efficiency.

Mwangi *et al.*, (2016) use the Soil and Water Assessment Tool (SWAT) to model the effect of agroforestry on the water balance in East Africa's Mara River Basin (MRB). Nash – Sutcliffe Efficiency (NSE) and Kling – Gupta Efficiency (KGE) measured model efficiency. The results show that it would not necessarily be sufficient to explicitly extrapolate the observations from a small sub-catchment to a larger watershed. The results further advise watershed managers on the degree of trade-offs between decreased water supplies and other advantages provided by agroforestry (e.g., soil erosion management, increased soil productivity). Crous-Duran *et al.*, (2018) use the process-based biophysical model Yield-SAFE to measure fruit, material, and biomass energy production in a specific energy unit (MJ ha^{-1}) of four different case study systems around Europe. They also measure how the delivery of ecological resources was calculated by tree density. The modeled findings demonstrate that, in contrast with monoculture forestry, plantation, and arable systems, having trees in a plantation or arable systems increased the total accumulated energy of the system, but that the accumulated energy per tree declined as tree density increased. Sousa *et al.*, (2019) show that cocoa in most vulnerable areas of coffee could become an alternative. Agroforestry, with the tree species, currently preferred, is highly vulnerable to future climate change. The best approach to adapting most coffee and cocoa production areas may be to transform agroforestry systems by changing tree species composition. The findings highlight the importance of land use policy, taking into account the impact of climate change, and testing new varieties of agroforestry plants in Mesoamerican coffee and cocoa plantations.

2.4 Process-based Modeling

A process-based model is the mathematical (usually computer-based) description of one or more processes characterizing the operation of a well-delimited biological structure of fundamental or economic interest (Buck-Sorlin, 2013). Usually, these models consist of a series of ordinary or partial differential equations defining the nature of each process (temporal patterns of main parameters), as well as their inputs and outputs, as a result of the first principles. Dietrich *et al.*, (1995)proposed a process-based approach to estimate the spatial variability of the depth of colluvial soil. The field data indicate an accelerated decrease in soil quality, with soil depth and diffusivity of around 50 cm^2 / yr growing. The predicted sequence of thick and thin colluvium precisely fits field findings. Fournier & Andrieu (1998) have implemented a 3D architectural and process-based maize development model based on the Graphtal L-system software for evaluating microclimate, which is distributed on the 3D canopy. The result shows that environmental L-systems are a versatile method for incorporating biophysical processes from organ to canopy level, and offer a basis for modeling the growth of existing plants with local conditions and the capacity to forage resources. Challinor *et al.*, (2004) use a new process-based crop model to simulate the impact of climate on crop yield. The effect of the coefficient of correlation between measured and simulated yields was 0.76, and the square root mean error was 8.4 percent of the mean yield. The model can be applied conveniently to an annual crop to analyze the impacts of climate fluctuations (or change) on crop yield over large areas.

Morin *et al.*, (2008) simulate the spread of 16 North American tree species for the 21st century on a continental scale using two IPCC scenarios, using a process-based species distribution model. The findings suggest that different animals do not pose the same threats due to climate change, as both their temperature responses and their dispersal rates vary. Morin & Thuiller (2009) equate projections of climate change distribution changes for 2100 from niche-based models with those of a process-based model for 15 boreal and temperate tree species in North America. From their contrasts, a general trend emerged: niche-based models appear to expect a more steady extinction degree and a higher colonization ratio than the process-based model. Giltrap and Saggar (2010) describe that a process-based approach, DNDC is capable of forecasting soil fluxes from all three terrestrial greenhouse gases: N_2O, carbon dioxide (CO_2), and methane (CH_4). This model is also essential for environmental and economic indicators like crop production, volatilization of ammonia (NH_3), and leaching of nitrates (NO_3).

From the review of the different methods, these are the main points to conclude. Much of this literature is not quantitative, and it remains challenging to optimize growing area selection, shade tree use, and management. To assist in this optimization, the author developed a simple process-based technique of tea agroforestry systems. In this study, various examples have shown how the qualitative behavior of the model is following observations. However, a rigorous test against detailed data has not been performed, nor has the uncertainty of model outputs been quantified.

CHAPTER-III: METHODOLOGY OF THE STUDY

3.1 Study Area and Period

The study area for tea and shaded tree plots was selected on Ratandighi Union, Panchagarh district, Bangladesh, from 2018 to 2020. Panchagarh District (Rangpur Division) covers an area of 1404.63 square kilometers, situated between 26°00' and 26°38' latitudes to the north and between 88°19' and 88°49' longitudes to the east in Bangladesh. The West Bengal state of India surrounds this district on the north, the Dinajpur and Thakurgaon districts on the Left, and the Nilphamary district on the Southeast.

The study period was divided into six quarterly events, such as event-1 (March 2018-June 2018), event-2 (July 2018-October 2018), event-3 (November 2018-February 2019), event-4 (March 2019-June 2019), event-5(July 2019-October 2019) and event-6 (November 2019-February 2020). In the first event and the events following tea pruning, tea hastypically low productions in beans. Matlab 2018a software was used for data analysis and logarithm calculations.

3.2 Experimental Design

The diagram in Figure 3.1 displays the underlying model structure. The model structure in tea should be similar to AFS with the possibility of expressing variations between shade-tree species by using various logarithm parameter standards. Thus, the model permits the prediction of tree species which grown-up solely for the shaded area and set up nitrogen or supply wood. The analysis of the result section would address the various elements of the model, which emphasizes the novelty of this study. While deciding on a model's structure, the researcher will determine which variables are taken into account and which are omitted. This study neither plan to incorporate pests, weeds, and diseases in the model, nor the soil toxicity and air quality impacts. Alternatively, this study concentrates on possible productivity, characterized as growth by factors other than the sun, water, N, and restricted only by local soil and weather conditions. Notably, the following increasing conditions should be treated as inputs to the model:

- weather conditions: rain, temperature, wind, and humidity.
- soil conditions: water retention characteristics, and initial organic matter and nitrogen content.
- tree and tea management: choice of species, rotation length, density, and pruning regime.

The model's application area is all tea agroforestry systems where the plant growth and soil dynamics are determined primarily by the input factors mentioned above. The following factors of the agroforestry system have to be identified as model outputs:

- productivity: tea yield and tree stem volume.
- environmental impact: rate of loss of organic carbon and nitrogen.

This study will present such a process-based technique and assess whether the analysis can represent the commonly observed behavior of tea agroforestry systems in the northern part of Bangladesh.

3.3 Dynamic Methods for Tea Agroforestry Systems

A graphic description of the significant inputs and relationships of tea agroforestry systems is shown in Figure 3.1(Van Oijen *et al.,* 2010). The method shows that tea agroforestry grounds are not homogeneous: when the trees are still young, a part of the tea plants would not be shaded even though trees were pruned or thinned. There will be competition for energy between trees and tea in the tree-covered portion of the area. All plant types need CO_2, light, soil, and nutrients as the most significant resources. The competition for CO_2 is marginal because of sufficient air filtering.

In comparison, the competition for light is generally unequal with tree canopies obtaining first exposure to incoming radiation and shade tea intercepting only the light released by the leaves. On the other side, there is total competition for soil capital, because at least a portion of the two plant types' root systems occupies the same volume of soil. Inadequate tree coverage transforms into corresponding variations in soil characteristics due to lack of homogeneity in tea production, individual the tree-covered portion of the field getting tree disorder, and receiving tea litter at a different degree and quality relative to the unshaded section. The main competitive processes and spatial heterogeneity must be defined by a primary dynamic method for tea agroforestry systems. It was intended to test the system's reaction to changes in environmental circumstances or management regimes.

3.4 Overall Model Structure and Implementation

The extensive growth cycle to be expected, 10–20 years, demands a model that disregards the direction of daytime and information in the architecture of tea and tree dynamics. Therefore, this study does not follow the evidence of the only dynamic models created so far for coffee, such as Dereffye's 3-dimensional functional-architectural models (Dereffye 1981, 1983) and Dauzat *et al.,* (2001), which were built to simulate coffee growth over short periods. A regular time phase model was chosen to construct the analysis, considering pre-existing sub-models for the various components in the system where possible. The arrangement in Figure 3.1 illustrates the basic model structure.

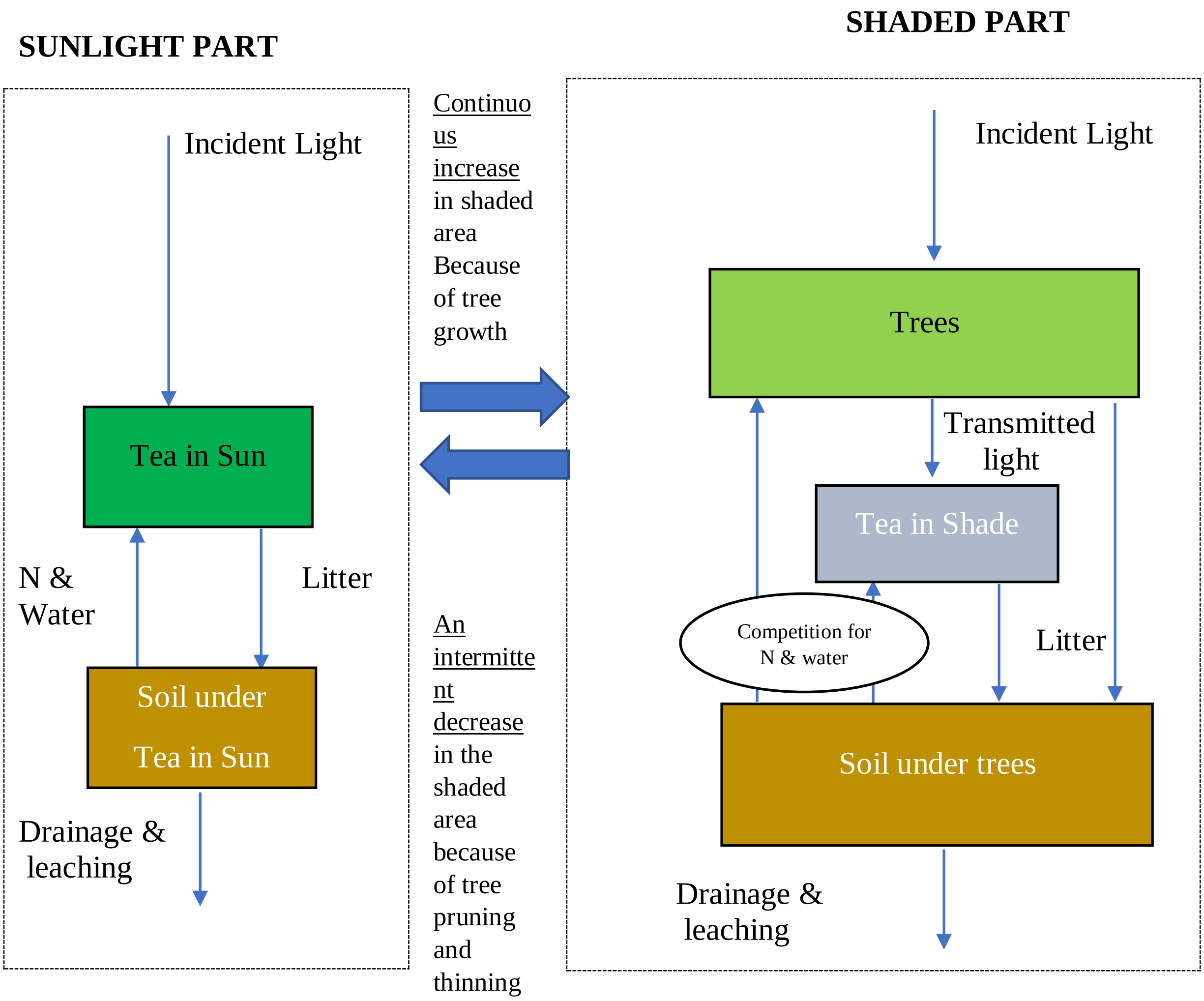


Figure 3.1: Resource model in tea agroforestry systems.

The model structure in the northern part of Bangladesh is expected to be familiar to AFS with the prospect of expressing variations between shade tree species through various parameter standards. Therefore, the model allows for the estimation of solely grown shaded tree species along with those that fix nitrogen or provide timber. However, in this research, this study shall only provide examples of prediction for four shade-tree species: *Albizia lebbeck*, *Acacia auriculiformis*, *Azadirachtaindica*, and *Swietenia macrophylla*. All four tree species are common in Bangladeshi agroforestry systems.

3.5 Weather Data

The model works on a regular time phase and takes normal weather conditions as input values: temperature, precipitation, humidity, and rain. The extended continuing time series have been selected from the bd.Free.meteo, and Bangladesh AccuWeather database with regular data for all four weather variables. The data period covers the years from March 2018 to February 2020, and the mean value hasbeen estimated for temperature 23, rain 8.6 mm d^{-1}, and wind speed 0.75 m s^{-1}. Using data from two weather website in Bangladesh on daily rainfall, we generated a basic stochastic algorithm for creating daily rainfall time series from monthly means (Van Oijen *et al.,* 2010), which can be summarized as follows:

$$f_{dry} = e^{-\lambda \sum rain} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (1)$$

$$rain_{wet} = \sum rain \,/\, (31(1 - f_{dry})) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (2)$$

$$P\ (rain > x | rain > 0) = e_{wet}^{-x/rain} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots (3)$$

Where, f_{dry} is the fraction of days without rain in anover 31 days (-); λ is a constant that estimates the consistency of rainfall distribution (mm^{-1}); rrain is total rainfall in the 31 days; $rain_{wet}$ is the average rainfall on a rainy day (mm); *P*(rain>x|rain>0) is the probability that rainfall exceeds x mm on a rainy day (-).

3.6 Tree

The trees submodel is based on the BASicFORest simulator (BASFOR), defined elsewhere in greater detail (Van Oijen *et al.,* 2005). Here, this study offers a general overview and highlights differences for the tea plants with the sub-model. For this purpose, six state variables are distinguished: carbon in leaves, branches, stems and roots (kg), nitrogen in leaves (kg N m^{-2}), and tree density (m^{-2}). All morphological variables (i.e., estimated crown area of individual trees (A_c; m^2), leaf area index (LAI_t; m^2 m^{-2}), wood volume (V; m^2 m^{-2}) and tree height (h; m) are determined as functions of the biomass variables(Van Oijen *et al.*, 2010):

$$A_c = k_{c1}(\frac{C_b}{d})^{k_{c2}} \quad \text{..}(6)$$

$$LAI = \frac{C_l SLA_t}{Min[1, A_c d]} \quad \text{..}(7)$$

$$V = \frac{C_s}{w} \quad \text{..}(8)$$

$$h = k_{hl}(\frac{C_s}{d})^{k_{h2}} \quad \text{..}(9)$$

Where C_b, C_l, and C_s are the sum of carbon in branches, leaves, and stems (kg), d is tree density (m^{-2}), SLA_t is specific leaf area (m^2 kg^{-1} C),w is wood density (kg C m^{-3}) and k_{c1}, k_{c2}, k_{h1} andk_{h2} are allometric constants. The allometry was based on biomass instead of stem diameter (Von Gadow, and Hui 1999). Since pruning breaks the relationship between stem and crown variables, biomass is the primary production pattern. For three of the four morphological equations, the division by tree density d converts the biomass variables from area-based to individual-based. The shaded fraction of the field (Fig. 3.1) is measured as the product of the tree's crown area and the tree's density (A_cd). Stem volume was estimated using the equation for the volume of a truncated cone (Jandl *et al.*, 2007):

Stem Volume (m^3) = 1/3 * πh ($r_1^2 + r_2^2 + r_1 * r_2$) ....(10)

The radius of the stem is 1.3 m above the ground (r_1), top of the stem (r_2), and height of the stem (h).

Figure 3.2: Tea Plot after Pruning

3.7 Soil

The soil sub-model is a basic one-layer model with fixed density, with three variables with the state: percentage carbon and nitrogen, and percent moisture. There is a distinction between two soil compartments of constant depth, describing the shaded and unshaded areas of the ground. The soil moisture, carbon, and nitrogen balance equations read as follow (Van Oijen *et al.*, 2010):

dM_{soil}/d_t =Water gain from rainfall minus rainfall interception- water loss by transpiration, evaporation;

dC_{soil}/d_t= C-gain from plant senescence; thinning and pruning- C-loss from the decomposition of litter and organic matter;

dN_{soil}/d_t= N-gain from plant senescence; thinning; pruning; fixation and fertilization- N-loss by plant uptake; emission; leaching;

Where, $dM_{soil}/d_t$is the variation in soil water content(percent), dC_{soil}/d_t is the variation in total soil carbon in litter and organic matter (percent), and $dN_{soil}/d_t$is the change in total soil nitrogen in the litter, organic matter and mineral N (percent).

CHAPTER-IV: RESULTS AND DISCUSSION

4.1 Weather Analysis

4.1.1 Rainfall Generator for Panchagarh District

A group of observers on strategic locations submit their daily observations electronically to the Bureau every day. The average rainfall is registered every day nominally at 9 am local time. Nevertheless, various places are recording 48- or 72-hour (or even longer) total on the weekends where the observer is unable to attend. These are considered accumulated findings. In this study, observations at the vast majority of rainfall data were obtained from AccuWeather in a single average precipitation inspection at the end of each month. Historically, rainfall was measured at the nearest 0.2 mm (1 level, or 1/100th of an inch before 1970), although some measurements were reported at 0.1 mm in recent years. Any humidity that is lower than that is recorded as a trace. The following equation (A1, A2, and A3) was used to find out the dry days of a month, probability of rainfall, and average rainfall days of a month (Van Oijen *et al.*, 2010):

$$f_{dry} = e^{-0.0087\sum rain} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots(A1)$$

Where f_{dry} is the fraction of days without rain over a specified period of 31 days (-) and $\sum$rain is a minimum of 31 days of rainfall. The rainfall on rainy days assumes an almost exponential distribution with the following cumulative density function:

$$P\ (rain < x) = 1 - e_{wet}^{-x/rain} \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ (A2)$$

Where, P is the probability that rainfall is less than x mm on a given rainy day, and $rain_{wet}$ is the average rainfall on a rainy day (mm), calculated as:

$$rain_{wet} = \sum rain\ /\ (31(1 - f_{dry})) \quad \ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots\ldots.\ (A3)$$

Figure 4.1 shows that these equations were converted into a 5-step algorithm to generate daily rainfall amounts from monthly data:(i) Interpolate the monthly rainfall data to generate a day-to-day time series.(ii) Calculate the corresponding f_{dry} time series using Eq. A1.(iii) Each day, assume that it is dry if the randomly selected number between 0 and 1 is less than f_{dry}.(iv) For the remaining days, measure the estimated rain probability using A3.(v) For each rainy day, predict the volume of rain as the predicted rain time minus the randomly selected logarithm between 0 and 1.

The following figure 4.1 displays the results of 365 consecutive daily rainfall observations at 1404.63 sq km of Panchagarh district, between 26.10' and 26.00' north latitudes, and between 88.20' and 88.24' east longitudes from 1 March 2019 to 29 February 2020:

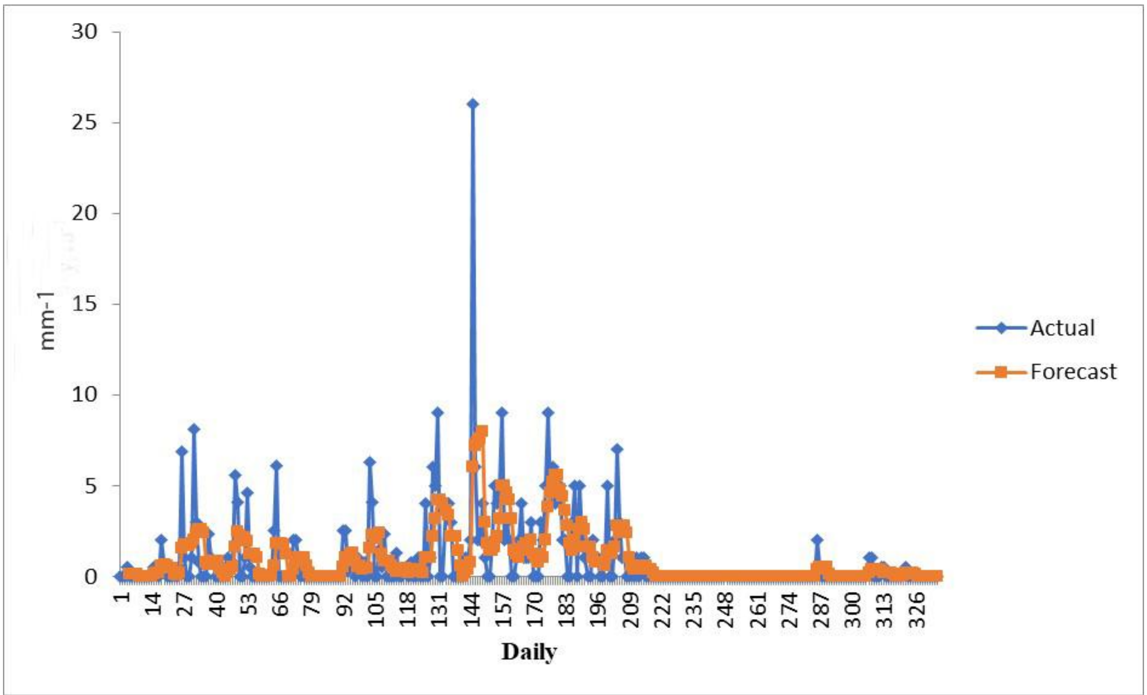


Figure 4.1: Monthly to daily rainfall data conversion and forecasting.

Since the algorithm is stochastic, it does not necessarily replicate any rain data that has been observed. More than 90% of the original time series data generated for the

AccuWeather site, however, matched the observed daily rainfall and the forecasted rainy days in a year. The algorithm's accuracy was further checked using the AccuWeather web rainfall data.

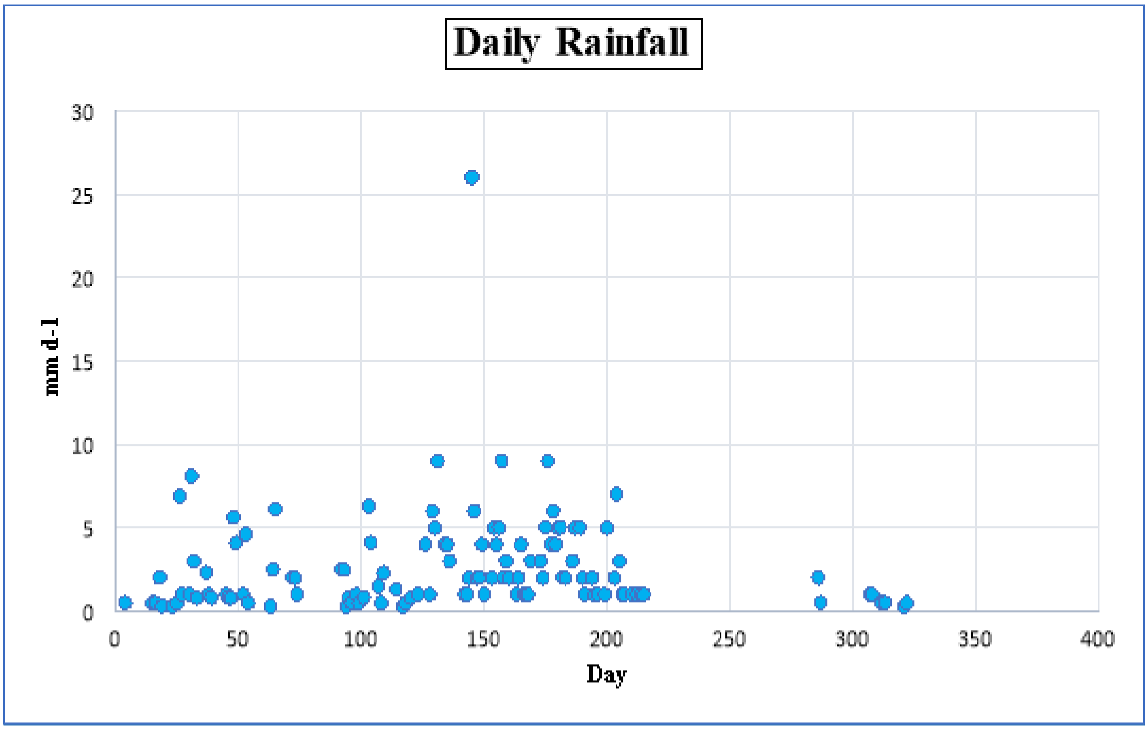


Figure 4.2: Daily rainfall data in Panchagarh District.

Mean rainfall (mm):

The cumulative amount of precipitation accumulated during a calendar month or year is arithmetically summed. Such calculations include both mean and medium rainfall, but from the meteorological point of view, the median is typically the preferred indicator of 'normal' or 'typical' rainfall. This result is due to the high daily rainfall variability-one extreme rainfall event (such as a slowly moving, severe thunderstorm) that will have less effect on the median than it will have on the arithmetical mean. Our measured average mean rainfall value is 0.93 mm, and the standard deviation is 2.198 mm. The median rainfall is 0 cm.

Highest rainfall (mm):

Figure 4.2 shows the highest amount of precipitation recorded at the site was 26 mm a day for a year.

Lowest rainfall (mm):

Figure 4.2 shows the lowest amount of precipitation at the site recorded 00 mm per day over a year.

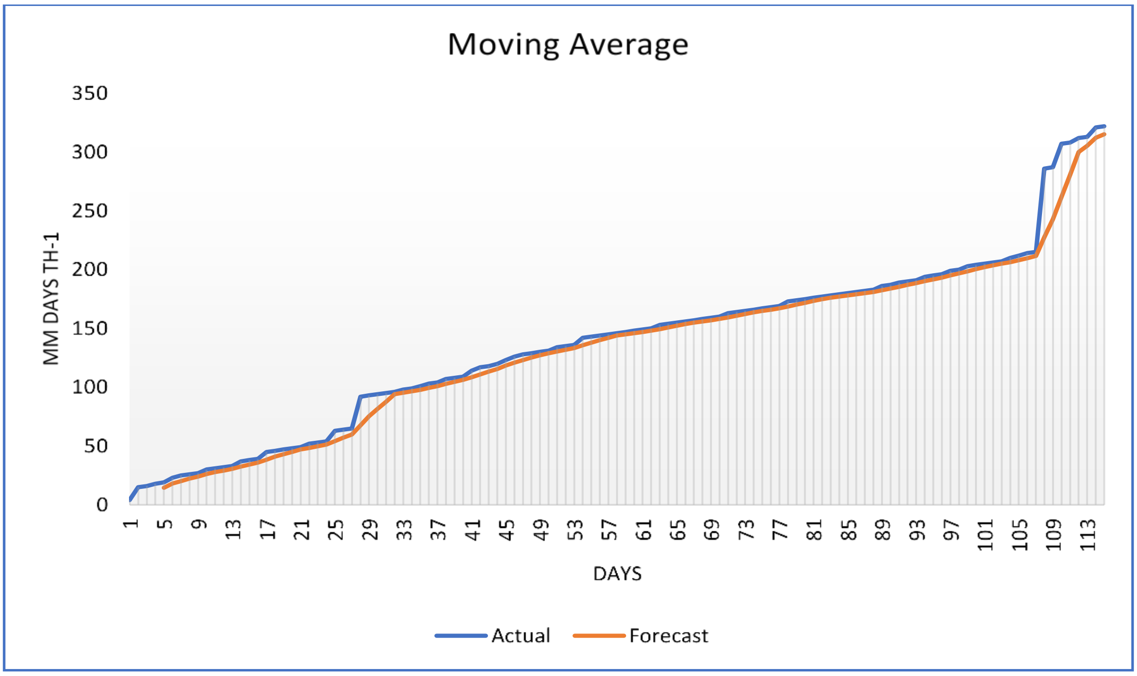


Figure 4.3: the 31-day moving average of daily rainfall

Figure 4.3 shows a moving average of order five and provides a trend-cycle approximation. In this figure, the first value is the sum of the first five observations (1 March–5 March). Each estimated value is the sum of the results based on the preceding year in the five days. Calculation in the equation notation includes the values of k=2 and m=2k+1=5 as /t. This calculation is simple to determine. For either the first two days or the last two days, there are no values, so we have no two measurements on either hand. Later on, this study will use more sophisticated trend-cycle estimation approaches that make estimates close to endpoints.

4.1.2 Microclimate

The directions range of Panchagrah district is from 26°.33' to 88°.55'. Aschematic representation of the canopies studied is shown in Fig. 4.4.The shaded site had trees of *Albizia lebbeck* at densities of 0.224 treesha^{-1} with an average height of 2.5m, *Azadirachta indica* at densities of 0.224 trees ha^{-1} with an average height of 11.4m, *Acacia auriculiformis* at densities of 0.112 trees ha^{-1} with an average height of 12.6 m, and *Swetenia macrophylla* at densities of 0.112 trees ha^{-1} with an average height of 5.6 m and crop densities of 352 tea plants in 560 m^2 with an average height of 0.73 m.

Maximum (T_{max}) and minimum (T_{min}) air temperatures during the year show a similar trend, but their magnitudes are very different (Fig. 4.5). T_{max} was significantly higher in the open plantation throughout the year (average 32.5°C). In April (the hottest month), temperatures went up to 32.5°C and 25°C in open and shaded sites. Therefore, height temperature was recorded in the unshaded side was (30.5) in May. The lowest temperatures were registered in January at both sites at shaded and unshaded; however, the temperature in the open plantation (23°C), but the variation between the shaded side is 2°C higher than the air temperature under shade.

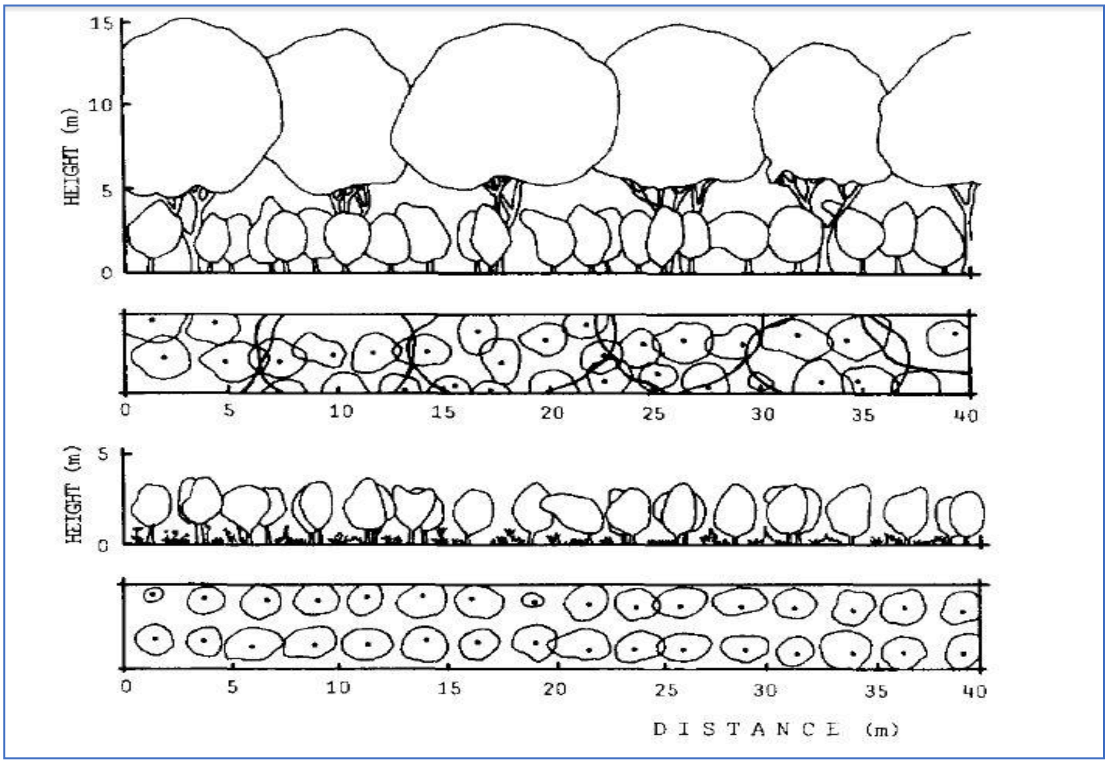


Figure 4.4: Canopies of shaded and unshaded part of tea plots (Van Oijen*et al.*, 2004)

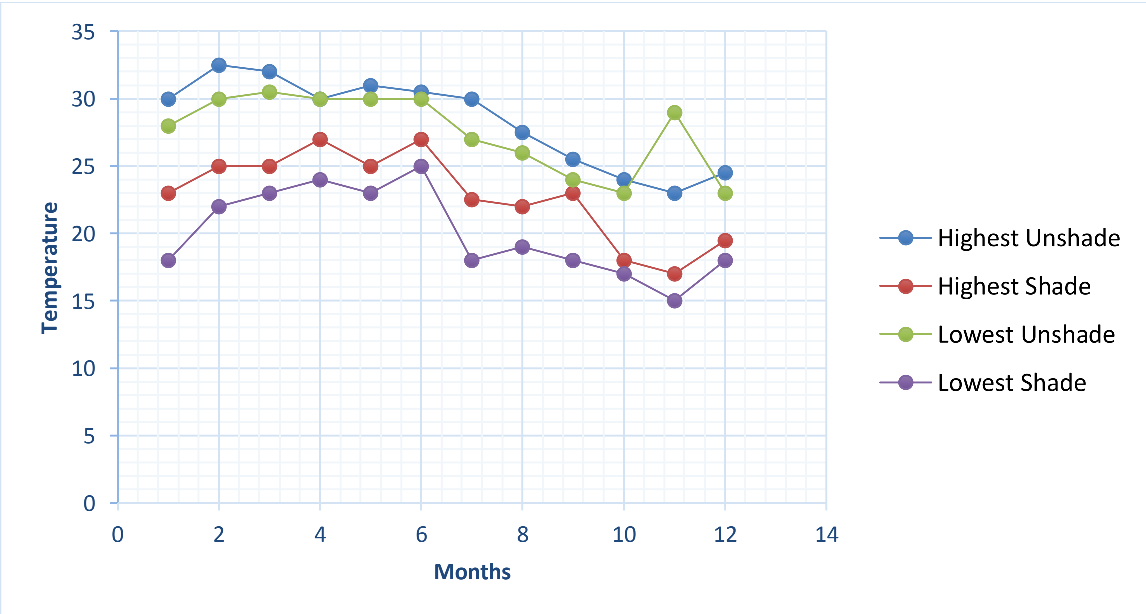


Figure 4.5: Maximum and Minimum air temperature in the shaded and unshaded plots in the experiment field

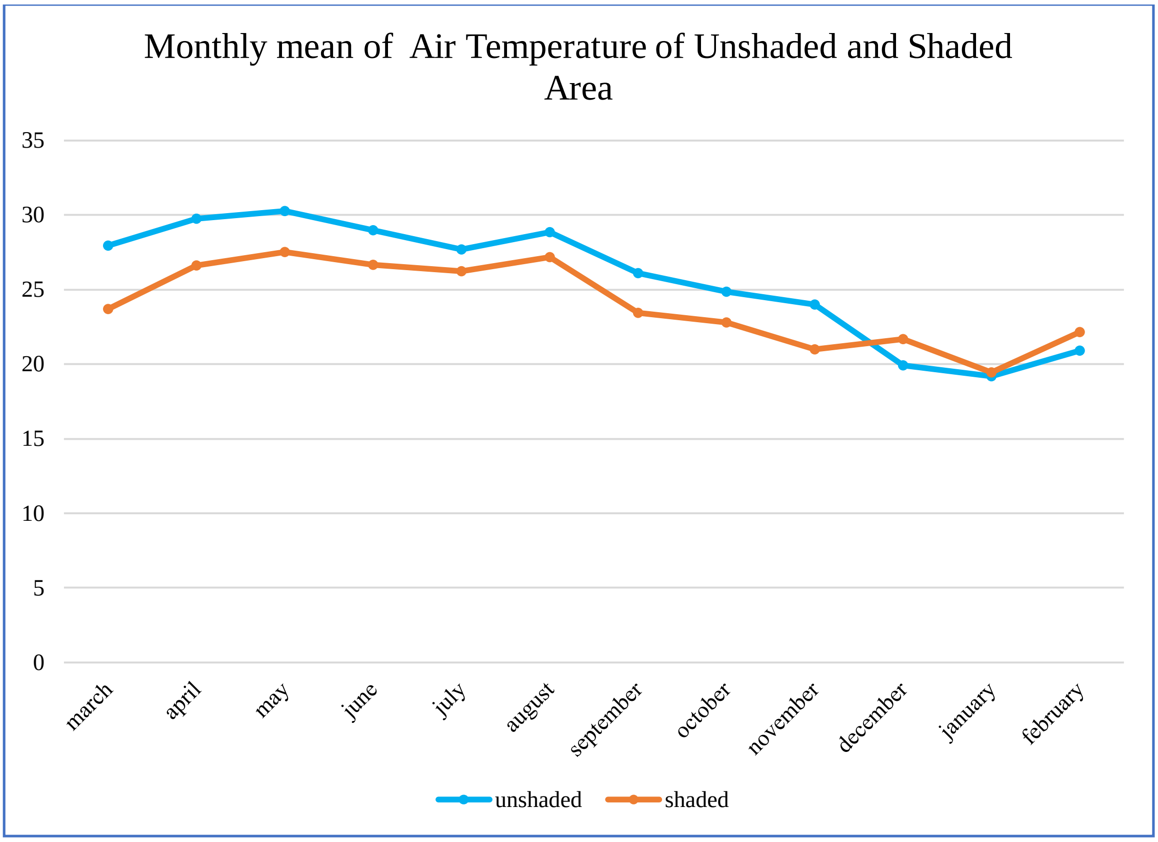


Figure 4.6: Monthly mean air temperature of shaded and unshaded experimental plots.

Figure 4.6 shows that from March to June (Event-1) highest mean temperature was 30.27°C in the unshaded side, but the temperature was 27.52°C in the shaded side. In July to October (Event-2), the open temperature was significantly higher than in the shaded site. The highest mean temperature in event-2 was recorded at approximately 28.85°C in the unshaded part. There wereno significant differences among the mean temperature registered in the event-3 (November to February). The highest T_m was registered in May, with no differences observed for this variable between the two sites this month. The coldest month was January with a T_m of 19.45°C in the open site and 19.19°C in the shaded site. During the winter months, T_m was lower in the open than in the shaded plantation. Maximum differences in T_m between the two sites were registered in summer (Event-1). The higher frequency was found in the open site between 32.5 and

23°C and ranged from 23 to 17°C. The range was much smaller in the shaded than in the open plantation.

4.2 Tree parameter

Table 4.1 shows the four shade trees with one of the four target species were chosen for the study (*Albizzia lebbeck; Acacia auriculiformis; Swietenia macrophylla;* and *Azadirachta indica*). There was no full detail about the distinction between these species. Therefore,there were species-specific parameterization for the crown area(Ac), Tree density (Td),height(h), breast height diameter (DBH), wood density(W_d),and allometry of the tree.

Table 4.1: Parameterization value of four shaded tree species.

Parameters	***Albizzia lebbeck***	***Acacia auriculiformis***	***Swietenia macrophylla***	***Azadirachta indica***
$A_c(m^2)$	2.5	7.0	5.5	6.0
h (m)	2.4	11.4	10.0	12.6
V	0.048	4.18	3.67	2.50
DBH (cm)	8	70	80	60
$T_d(m^2)$	0.224	0.112	0.112	0.224
W_d kg/cm^3	660	756	530	690
LAI	6.92	9.55	15.09	7.03

With these species differences, *Acacia auriculiformis* and *Swietenia macrophylla* growth rate were moderate. In contrast, *Albizzia lebbeck* grew best, with only *Azadirachtaindica* having a significant negative impact on tea growth (Table 4.1). This study also found that *Azadirachtaindica* reduced tea yields considerably more than *Acacia auriculiformis*, and *Swietenia macrophylla* did. C-sequestration was the strongest for *Acacia auriculiformis* and *Swietenia macrophylla*, the two fastest-growing plants. Tree maintenance aimed at reducing shade levels (lower tree height, and another thinning operation, twice-year pruning) both increased tea yield though at the cost of wood production, with higher N and soil losses.

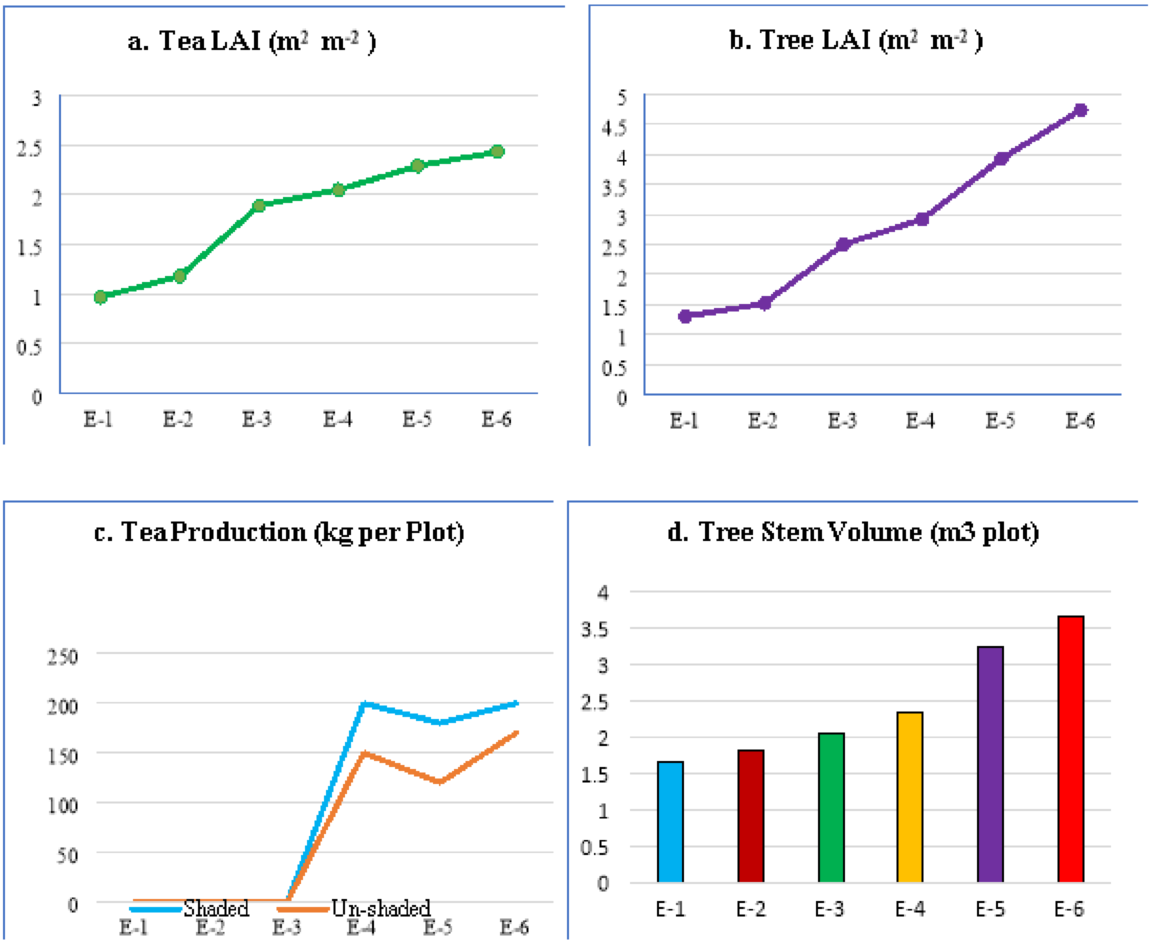


Figure 4.7: Event analysis of tree dynamics. Continuous lines: agroforestry system with tea grown under 4 trees m^2 of a shade tree species under climatic in Panchagrah, Bangladesh.

Event analysis of the model, with shaded and unshaded trees area, are shown in Figures4.7. The results were calculated on an event basis. A total of 3 events (event-4, event-5, and event-6) were estimated as base periods (from March 2019 to February 2020), and each event contained four months intervals. On the other hand, event-1 to event-3 were calculated based on the ratio method. The first tea production has been recorded at the end of the event-3, 2018 (Fig. 4.7 c). Then yields differ between events due to variations in plants, soil, and environment, averaging about 250 kg of dry matter per acre, with yields in the shaded system being around 20–30 percent higher. Lower yields have been estimated under the full sun than shade system. The stem volume increases continuously from the start except for the thinningevent-3 after 1.5 years (Fig.4.7 d). The pruning alsocauses the irregular pattern over time of tree LAI. Every calendar year, the dry season triggers a decrease in soil water content. Generally, however, Panchagrah's dry season is relatively mild and has no effect on tea and tree LAI (Fig.4.7 a & b).

Table 4. 2: Carbon and Biomass estimation of four shaded tree species.

Parameters	***Albizzia lebbeck***	***Acacia auriculiformis***	***Swietenia macrophylla***	***Azadirachta indica***
Total biomass (kg)	9.58	4610	3300	2740
Mass (kg)	5.94	2864.99	2051.1	1725
C_b(kg/cm^2)	0.495	250	181.5	150
C_s(kg/cm^2)	2.95	1425	1023	860
C_l(kg/cm^2)	0.045	20	16.5	10
C_r(kg/cm^2)	1.17	595	429	350
B_b(kg)	0.99	500	363	300
B_s(kg)	5.9	2850	2046	1720
B_l(kg)	0.09	40	33	20
B_r(kg)	2.34	1190	858	700

Table 4.2 shows that *Albizzia lebbeck* had a stem with biomass of 5.9 kg, roots of 2.34 kg, branches of 0.99 kg, and leaves of 0.09 kg, giving total biomass of 9.58 kg. *Acacia auriculiformis* had estimated a stem with biomass of 2850 kg, roots of 1190 kg, branches of 500 kg,and leaves of 40 kg, giving total biomass of 4610 kg. On the other hand, *Swietenia macrophylla* value shows a stem with biomass of 2046 kg, roots of 858 kg branches of 363kg, and leaves of 33 kg giving total biomass of 3300 kg. Finally,

Azadirachta indica had a stem with biomass of 1720 kg, roots of 700 kg, branches of 300 kg, and leaves of 20 kg giving total biomass of 2740 kg.

These percentages have been used to measure the tree's overall productivity without needing to dig roots or hack branches off. The carbon content of woody material (stem, branches, and roots) and that of leaves is about 50% of their biomass. Multiplying the gross biomass by the percentage of the biomass, which is oil, provides an approximation of the overall volume of carbon contained in the forest, which was precisely 1 tonne in this situation. Each ton of carbon corresponds to about 3.67 tons of CO_2.

When trees photosynthesize, they use ambient carbon dioxide (CO_2) with rain or irrigation water, and soil nutrients to form carbohydrates that constitute the tree's biomass. The amount of carbon produced by a tree depends on its height, which is determined by factors like nature, local environmental conditions, and how it is handled. This study used a typical forestry technique to measure the amount of carbon found within the stem, limbs, roots, and leaves of a mature tree with the diameter and stem height.

First, this study was weighed the various sections of the tree, and from these measurements; and it was determined their amounts, which were then used to quantify the biomass (the density of living matter in plant tissues):This study used established relationships between the stem's biomass and the biomass of roots, limbs, and leaves to approximate the tree Stem's total biomass volume using a formula for the volume of a truncated cone: carbon in the tree equation that produced an average stem volume.

So, using the equation, the total mass was calculated:

Mass = Density × Volume

The biomass of the four trees' stems, limbs, and leaves is estimated to be around 26 percent, 11 percent, and 1 percent, respectively, of the overall biomass (Fig. 4.8). These proportions were used to measure the tree's overall biomass without finding roots or removing branches.

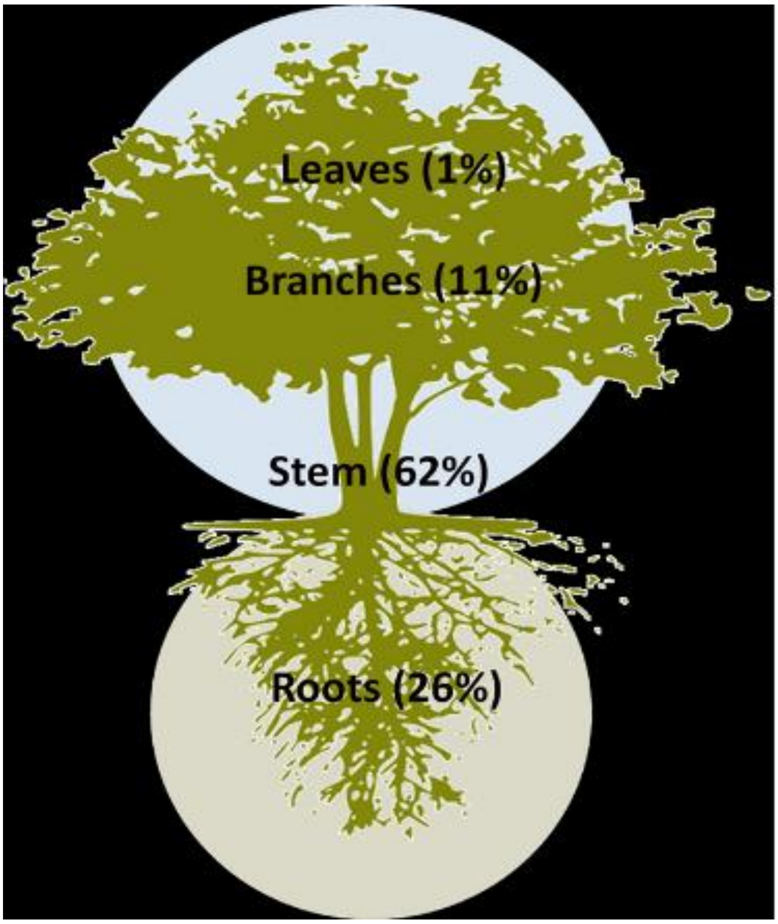


Figure 4.8: Allocation of biomass percentage for shaded tree species (Jandl *et al.*, 2007).

4.3 Soil

Changing the plot structure has only significantly affected soil depletion, but the degree of erosion is still low. Many improvements to the climate had significant effects. Rainfall proved to be very important, and the result indicates that the amount of rain in the plot area is at the top of what the machine is capable of handling. Doubling the rainfall rate hindered development and C-sequestration and resulted in higher N and soil losses. Even unexpectedly, increased rainfall lowered the soil's N-emission since the soil was highly water-saturated. This effect was due to the extra water flow through the system, which reduces the mineral N concentration in the soil. Finally, the result of doubling the ambient CO_2 content was shown to be the only adjustment that was favorable to both accounts: improved production of tea and tree and C-sequestration with lower N and soil losses. In Fig. 4.9, the estimated result shows that higher N-fertilization levels can be justified at the doubled CO_2 concentration.

In Fig. 4.9.a, water gain from rainfall and rainfall interception have a similar ratio both in shaded and unshaded plots. On the other hand, water loss by transpiration, evaporation, drainage, and run-off is estimated at 0.65% in the shaded portion that is more than twice percent (1.71%) in the unshaded portion. The result of soil carbon represents in Fig. 4.9 b, which shows that C-gain from plant senescence, thinning, and pruning have smaller variations in shaded and unshaded plots. The calculated value of shaded plots is 1.24%, and the unshaded part is 1.17%. C-loss from the decomposition of litter and organic matter and a run-off in the unshaded part is approximately 35% higher than shaded parts. For soil nitrogen in Fig 4.9.c, N-gain from plant senescence; thinning; pruning; fixation and fertilization have been estimated 0.112% in shaded part and 0.007% in the unshaded part. This result indicates that the shaded part contains more nitrogen gain from plant senescence than the unshaded part. However, the unshaded part contributes 0.087% of nitrogen for N-loss by plant uptake, emission, leaching, and in run-off area that shows the unshaded part loss more nitrogen. Therefore, N-fertilization may be more beneficial to tree wood volume production than tea yield.

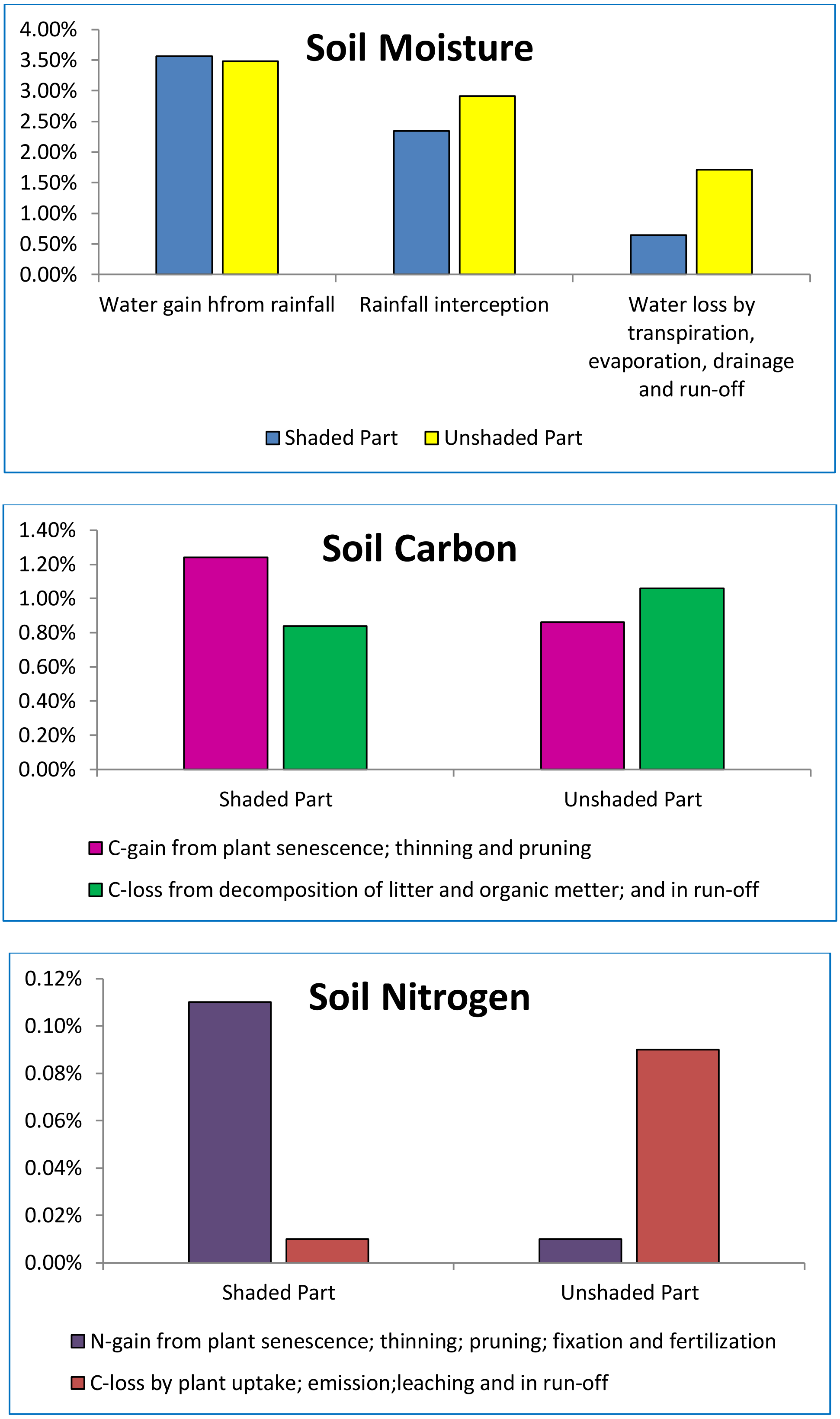
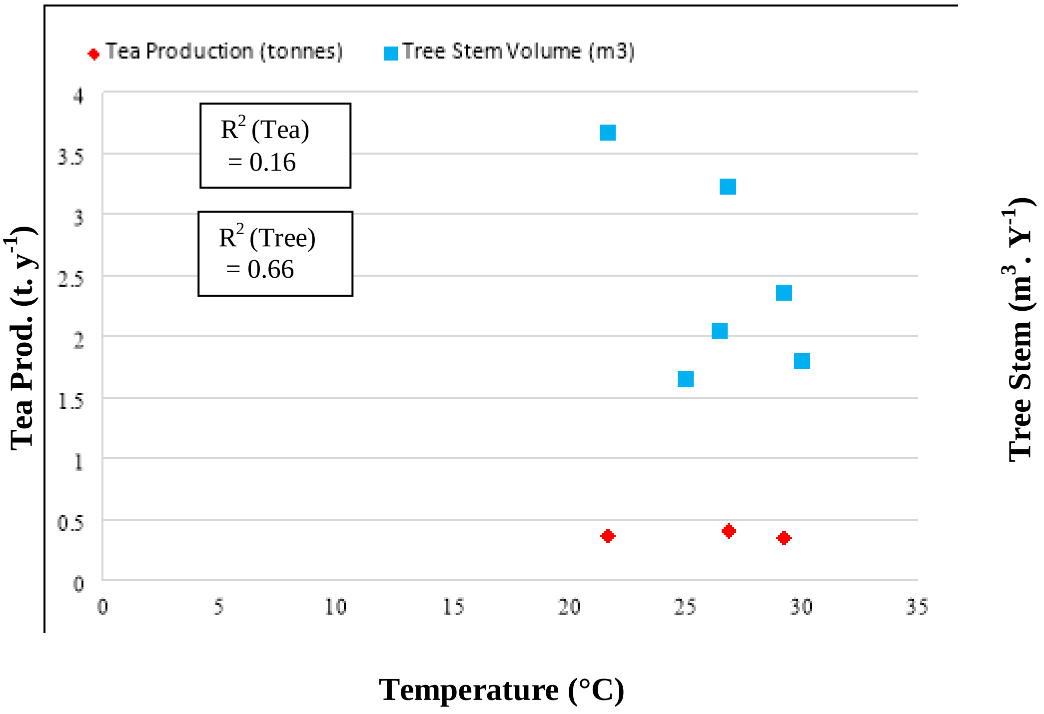


Figure 4.9: Soil dynamics of shaded and unshaded tea plots.

In tea agroforestry systems, the degree of N-leaching is very high, and this is difficult to improve by any management operation other than the reduction of N-fertilisation.

4.4 Regression Model Analysis

a. Temperature, Tea and Tree Production:



b. Rainfall, Tea and Tree Production:

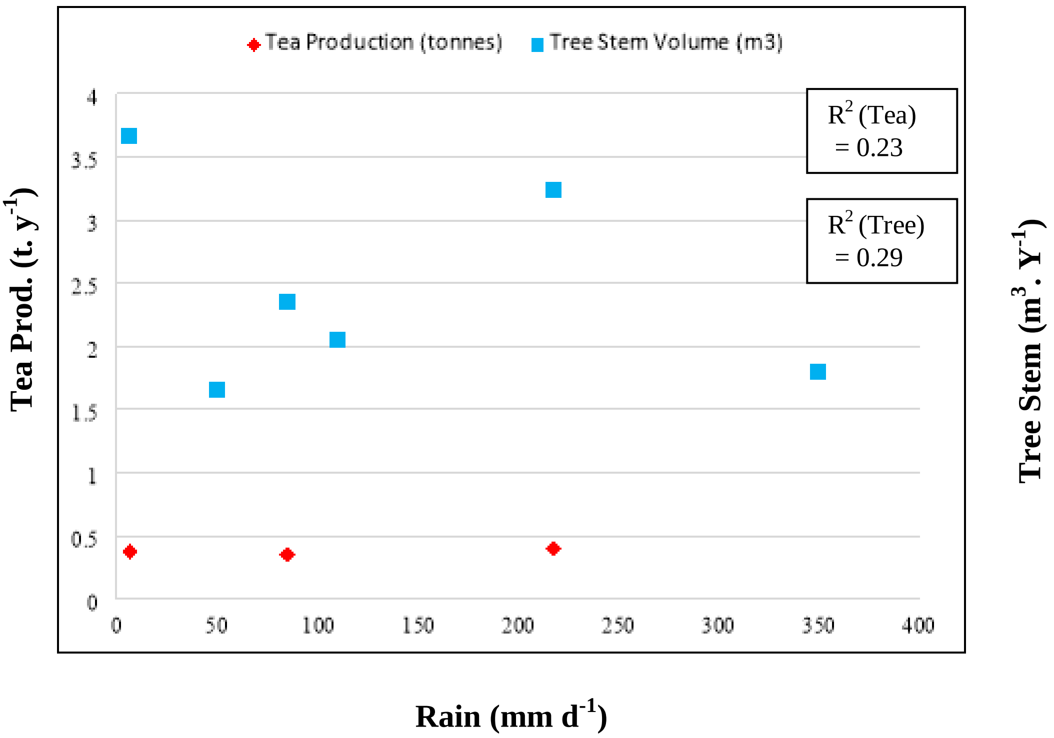


Figure 4.10: R-square value of event analysis for the tea agroforestry system and weather data.

Figure 4.10 presents the regression analysis of the quarterly event of tea and tree production with weather data. Figure 4.10. a. shows the linear relationship between temperature and tea production. The highest tea yield of 0.4 tons has been recorded at an average temperature of 26.86°C. The R^2 value 0.16 indicates that tea productions and temperature have a weak relationship during this period. However, 3.67 m^3 tree stem volume is estimated at an average temperature of 21.67°C. The R^2 value 0.66 indicates that temperature has a significant impact on tree stem production.

Figure 4.10. b shows the impact of rainfall on tea and tree production under the tea agroforestry system. The height tea production is recorded at 218 mm quarterly rainfall. The growth of tree stem volume is estimated in the winter session when the average rainfall is generally low. The R^2 value 0.29 indicates that high rainfall has a lower impact on tree production.

CHAPTER-V: CONCLUSION

5.1 Summary

Assessment of model consistency and availability of data compared with crop modeling, agroforestry modeling is still in its initial stages. The method described in this study is one of the primary models to predict and analyze a system of subtropical agroforestry. The model using a tree agroforestry system estimates the mass balance of carbon, nitrogen, and water moisture. Therefore, the model is kept simple because there is inadequate analytical evidence to construct a complicated model rich in parameters, as the literature review has shown. Application simplicity further increases the likelihood that it can be beneficial in decision-making, and does not persist a testing device solely like other models built for subtropical agroforestry systems.Nonetheless, the role of environmental factors in tea agroforestry is not entirely apparent. Simultaneously, the method is sensitive to features of established significance, such as variety and management of shade tree types, temperature, and soil conditions, including the availability of nitrogen.

For some essential metrics of tea agroforestry programs' performance, i. e., the production of tea yields and tree timber, the model shows no outcomes, and the effect of management decisions on biodiversity. Nevertheless, the method is highly complex to allow partial evaluation of the strengths and weaknesses between growing the profitability of tea and between optimizing productivity and reducing the program's environmental effect (Kalita, 2014). The model subdivides space into two sections for shade trees structures: the shaded and not the shaded portion of the ground. It is achieved continuously, with the shaded area growing with tree crowns and declining with the pruning of tree branches. A more simplified model can be anticipated, in which only one area is separated with a degree of shade equivalent to the whole field average. Our framework is a representation of a compromise between the extremes. By implying that shade schemes increased the crown-covered landscape, most of the field was shaded much of the time, limiting our model substantially to choosing one location.There is a lack of evidence about whether spatial variability can be overlooked in this way. However, the results indicate that it is safer to have several well-pruned trees that are closely spaced than a few dense leafy trees.

A more significant limitation than that of the model's simplicity at this point in software creation is that the minimal model is testing against the results. In this study, the author presented different explanations of how the model's qualitative behavior is compatible with observations. However, no rigorous test against quantitative evidence was done, nor was the volatility of model performance quantified.

The only partial parameterization of the model built here is feasible, provided the limited knowledge available on tea and trees. Nevertheless, as shown in the previous section at different points, model actions tend to be qualitatively compatible with the machine efficiency literature and the nitrogen and water balance. Our N-fertilization study could be more valuable for the development of tree wood volume than for the tea yield. The yield of tea decreases with the density of the crop, while the trees are N-fixers. However, tree pruning appears to improve the production of tea, along with some loss in tree production (Barradas & Fanjul, 1986). In contrast to four tree species, the *Acacia auriculiformis; and Swietenia macrophylla* provide the best wood production, but only *Azadirachta indica* significantly hampering the growth of the tea plants. The sum of N-fixation leguminous trees is typically just a small flux in the overall N-budget system but large enough to have a significant impact on productivity. The contribution of tea agroforestry systems to greenhouse gas emissions in the form of a gaseous N-emission is small. Carbon sequestration levels are not very high in tea agroforestry schemes and relatively indifferent to management choices (Gifford, 1980). Tree pruning reduces the land cover, and soil erosion rates are expected to rise but not too extremely high levels.

5.2 Overall Conclusion

The results of this study show that the highest mean temperature was 30.27°C in the unshaded site, but the temperature was 27.52°C in the shaded side from March to June. The coldest month was January in the studied area with a Temperature of 19.45°C in the open site and 19.19°C in the shaded site, respectively. The variations of temperature had a significant impact on tree wood production. On the other hand, higher rainfall indicates an increase in the volume of tea production.

Water gain from rainfall and rainfall interception have a similar ratio both in shaded and unshaded plots. Nevertheless, water loss by transpiration, evaporation, drainage, and run-off is estimated at 0.65% in the shaded portion that is more than twice percent (1.71%) in the unshaded portion. The result of soil carbon represents that C-gain from plant senescence, thinning, and pruning have smaller variations in shaded and unshaded plots.

The R^2 value 0.16 indicates that tea productions and temperature have a weak relationship during this period. However, the R^2 value 0.66 indicates that temperature has a significant impact on tree stem production. The growth of tree stem volume is estimated in the winter session when the average rainfall is generally low. The R^2 value 0.29 indicates that high rainfall has a lower impact on tree production.

5.3 Recommendations

This study is relevant to academics, researchers, and tea industries who are interested in continuing research about the development of tea agroforestry systems. Based on this research, this study recommends some valuable guidelines for the development of tea agroforestry in Bangladesh.

I. Based on the calculated result, the shaded tea tree plot might be suitable in the area where the temperature level is high, and the rainfall is moderate. To increase the level of tree wood production, N-fertilization is more beneficial for trees, but it does not immensely helpful for tea yield. However, tea yield tends to decrease with tree density, even if the trees are N-fixers. Nevertheless, tree pruning inclines to benefit tea productivity but with some decrease in tree wood productivity.

II. For the tree species selection, *Acacia auriculiformis* and *Swietenia macrophylla* are very suitable because their growth rate is high. C-sequestration is the strongest for *Acacia auriculiformis* and *Swietenia macrophylla*, the two fastest-growing plants. In contrast, *Albizzia lebbeck*also grows best, with only *Azadirachta indica* having a significant negative impact on tea growth. Tree maintenance aimed at reducing shade levels (lower tree height, and another thinning operation of twice-year pruning) will increase tea yield though at the cost of wood production, with higher N and soil losses.

III. The drainage of water to the groundwater is essential in the tea process-based modeling system, and only marginally smaller drainage at sites with steep slopes should be considered where run-off rates are higher than elsewhere. High fertilization levels also are of benefit as they guarantee large, protective ground cover.

It is better to view this collection of experimental results as working hypotheses before further data is collected for parameterization and testing of the model. Our calculation indicates that in Panchagrah, Bangladesh, the balance between the profitability and environmental effects of tea agroforestry systems can be altered in a variety of ways — and a process-based model can help render the multipletrade-offs explicit. Follow-up articles will concentrate on the study of complexity using evidence from recent field studies, and use the model to improve management in Bangladesh tea production.

REFERENCES

Barradas VL and Fanjul L. 1986. Microclimatic characterization of shaded and open-grown coffee (*Coffea arabica* L.) plantations in Mexico. Agricultural Forestry Meteorology. 38: 101–112.

Bouman BAM, Van Keulen H, Van Laar HH and Rabbinge R. 1996. The 'School of de Wit' crop growth simulation models: a pedigree and historical overview. Agricultural System. 52: 171–198.

Buck-Sorlin G. 2013. Process-based Model. In W. Dubitzky, O. Wolkenhauer, K.H. Cho, and H. Yokota (Eds.), Encyclopedia of Systems Biology (pp. 1755–1755). Springer.

Challinor AJ, Wheeler TR, Craufurd PQ, Slingo JM and Grimes DIF. 2004. Design and optimization of a large-area process-based model for annual crops. Agricultural and Forest Meteorology, 124: 99–120.

Cooper PJM, Leakey RRB, Rao, MR and Reynolds L. 1996. Agroforestry and the mitigation of land depletion in the humid and sub-humid tropics of Africa. Experimental Agriculture. 32: 235-290.

Crous-Duran J, Graves AR, Paulo JA, Mirck J, Oliveira TS, Kay S, Jalon SJ and Palma JH. 2018. Modelling tree density effects on provisioning ecosystem services in Europe. Agroforestry Systems. 93: 1985-2007.

Cuddington K, Fortin MJ, Gerber LR, Hastings A, Liebhold A, O'Connor M and Ray C. 2013. Process-based models are required to manage ecological systems in a changing world. Ecology. 4: 1-12.

Dauzat J, Rapidel B and Berger A. 2001. Simulation of leaf transpiration and sap flow in virtual plants: model description and application to a coffee plantation in Costa Rica. Agricultural and Forest Meteorology. 109: 143–160.

Dereffye P.1981. Random mathematical model and simulation of growth and structure of the coffee tree Robusta. 1. Study of behavior of meristems and growth of the vegetative axes. Cafe Cacao The. 25: 83–102.

Dereffye P. 1983. Random mathematical model and simulation of growth and structure of the coffee tree Robusta. 4. Programming of a 3-dimensional drawing of the structure of a tree for a micro-computer—application to the coffee tree. Cafe Cacao The. 27: 3–20.

Dietrich WE, Reiss R, Hsu ML and Montgomery DR. 1995. A process-based model for colluvial soil depth and shallow land sliding using digital elevation data. Hydrological Processes, 9: 383–400.

FAO. 2007. Safety Evaluation of Certain Food additives and contaminants, Series: 59, Geneva: Switzerland.

Fournier C and Andrieu B. 1998. A 3D architectural and process-based model of maize development. Annals of Botany, 81: 233–250.

Gifford R. 1980. Carbon storage in the biosphere. In: Pearman G (ed) Carbon dioxide and climate. Australian Academy of Sciences. Canberra. 167–181.

Giltrap DL, Li C and Saggar S. 2010. DNDC: A process-based model of greenhouse gas fluxes from agricultural soils. Agriculture, Ecosystems & Environment, 136: 292–300.

Gogoi S, Mishra G and Deka AK. 2016. Soil nutrient dynamics in tea agroforestry ecosystem of Golaghat district of Assam. Agricultural Science Digest - A Research Journal. 36: 185-190.

Islam GMR, Iqbal M, Quddus KG and Ali MY. 2005. Present status and future needs of tea industry in Bangladesh. Proceeding Pakistan Academy Science. 42: 305–314.

Jandl R, Lindner M, Vesterdal L, Bauwens B, Baritz R, Hagedorn F and Byrne KA. 2007. How strongly can forest management influence soil carbon sequestration? Geoderma, 137: 253-268.

Kalita RM, Das AK and Nath AJ. 2014. comparative study on growth performance of two shade trees in tea agroforestry system. Journal of Environmental Biology. 35: 699–702.

Kalita R M, Das A K and Nath A J. 2015. Allometric equations for estimating above- and below-ground biomass in Tea (*Camellia sinensis* (L.) O. Kuntze) agroforestry system of Barak Valley, Assam, northeast India. Biomass and Bioenergy. 83: 42–49.

Kalita R M, Das A K and Nath A J. 2016. Assessment of Soil Organic Carbon Stock Under Tea Agroforestry System in Barak Valley, North East India. International Journal of Ecology and Environmental Sciences. 42: 175–182.

Kalita R M, Das A K, Sileshi G W and Nath A J. 2020. Ecosystem carbon stocks in different aged tea agroforestry systems: Implications for regional ecosystem management. Tropical Ecology. 61: 203-214.

Karak T, Paul RK, Boruah R K, Sonar I, Bordoloi B, Dutta A K and Borkotoky B. 2015. Major Soil Chemical Properties of the Major Tea-Growing Areas in India. Pedosphere. *25*: 316–328.

Kumar S, Udawatta R P and Anderson S H. 2010. Root length density and carbon content of agroforestry and grass buffers under grazed pasture systems in a Hapludalf. Agroforestry Systems. 80: 85–96.

Lamanda N, Dauzat J, Jourdan C, Martin P and Malézieux E. 2007. Using 3D architectural models to assess light availability and root bulkiness in coconut agroforestry systems. Agroforestry Systems. *72*: 63–74.

Leuschner W A and Khaleque K. 1987. Homestead agroforestry in Bangladesh. Agroforestry Systems. *5*: 139–151.

Matthews R, Van Noordwijk M, Gijsman AJ and Cadisch G .2004. Models of below-ground interactions: their validity, applicability and beneficiaries. In: Van Noordwijk M, Cadisch G, Ong CA (eds) Below-ground interactions in tropical agroecosystems. CAB International, Wallingford. 41–60.

Mialet-Serra, Dauzat J and Auclair D. 2001. Using plant architectural models for estimation of radiation transfer in a coconut-based agroforestry system. Agroforestry Systems. 53: 141–149.

Mobbs DC, Cannell MGR, Crout NMJ, Lawson GJ, Friend AD and Arah J. 1998. Complementarity of light and water use in tropical agroforests—I. Theoretical model outline, performance and sensitivity. For EcolManag. 102: 259–274.

Morin X and Thuiller W. 2009. Comparing niche-and process-based models to reduce prediction uncertainty in species range shifts under climate change. Ecology, 90:1301–1313.

Morin X, Viner D and Chuine I. 2008. Tree species range shifts at a continental scale: New predictive insights from a process-based model. Journal of Ecology, 96:784–794.

Mukherjee A, Banerjee S, Nanda M and Sarkar S. 2008. Microclimate study under agroforestry system and its impact on performance of tea. Journal of Agrometeorology. 10: 99–105.

Muetzelfeldt RI and Sinclair FL. 1993. Ecological modelling of agroforestry systems. AGRIS. 6:207–247.

Mwangi HM, Julich S, Patil SD, Mcdonald MA and Feger K. 2016. Modelling the impact of agroforestry on hydrology of Mara River Basin in East Africa. Hydrological Processes. 30: 3139-3155.

Nair PKR. 1989. Agroforestry defined. P. 13-18. *In:* PKR Nair (ed) Agroforestry Systems in the tropics, Dordrecht, Netherlands: Kluwer Academic Publishers.

Nair PKR. 1993. An introduction to agroforestry, Dordrecht, Netherlands: Kluwer Academic Publishers.

Noordwijk MV and Lusiana B. 1999. WaNuLCAS, a model of water, nutrient and light capture in agroforestry systems. Agroforestry Systems. 217–242.

Nygren P. 1993. Simulation of the shading pattern of periodically pruned trees in agroforestry systems. Pesqui Agropecu Bras. 28:177–188.

Oldeman RAA. 1992. Architectural models, fractals and agroforestry design. Agricultural Ecosystems Environment. 41: 179-188.

Prusinkiewicz P. 2004. Modeling plant growth and development. Current Opinion in Plant Biology. 7: 79–83.

Radersma S and Ong C K. 2004. Spatial distribution of root length density and soil water of linear agroforestry systems in sub-humid Kenya: implications for agroforestry models. Forest Ecology and Management. *188*: 77–89.

Sanchez PA. 1995. Science in agroforestry. Agroforestry Systems. 30: 5-55.

Sinoquet H, Roux X L, Adam B, Ameglio T and Daudet F A. 2001. RATP: a model for simulating the spatial distribution of radiation absorption, transpiration and photosynthesis within canopies: application to an isolated tree crown. Plant, Cell and Environment. 24: 395–406.

Sousa KD, Zonneveld M V, Holmgren M, Kindt R and Ordoñez JC. 2019. The future of coffee and cocoa agroforestry in a warmer Mesoamerica. Scientific Reports. 9:1-7.

Tian Y, Cao F and Wang G. 2013. Soil microbiological properties and enzyme activity in Ginkgo–tea agroforestry compared with monoculture. Agroforestry Systems. 87: 1201–1210.

Van Noordwijk M, Rahayu S, Williams SE, Hairiah K, Khasanah N and Schroth G. 2004. Tree root architecture. In: VanNoordwijk M, Cadisch G, Ong CA. Belowground interactions in tropical agroecosystems. CAB International, Wallingford: 83–107.

Van Oijen M, Dreccer MF, Firsching K-H, Schnieders BJ. 2004. Simple equations for dynamic models of the effects of CO2 and O3 on light-use efficiency and growth of crops. Ecol Model 179: 39–60.

Van Oijen M, Rougier J and Smith R. 2005. Bayesian calibration of process-based forest models: bridging the gap between models and data. Tree Physiology. 25: 915–927.

Van Oijen M, Dauzat J, Harmand J-M, Lawson G and Vaast P. 2010. Coffee agroforestry systems in Central America: I.A review of quantitative information on physiological andecological processes. Agroforestry System. 80: 361-378.

Von Gadow K and Hui G. 1999. Modelling forest development. Kluwer, Dordrecht: The Netherlands.

Wanger TC, Saro A, Iskandar DT, Brook BW, Sodhi NS, Clough Y and Tscharntke T. 2009. Conservation value of cacao agroforestry for amphibians and reptiles in South-East Asia: combining correlative models with follow-up field experiments. Journal of Applied Ecology. 46: 823–832.

Weyesa GW. 2019. Aboveground Live Carbon Storage in Woody Agroforestry Systems of Sokoru District, Jimma Zone, Southwest Ethiopia. International Journal of Economy, Energy and Environment. 4: 11-17.

Young A. 1997. Agroforestry for soil management. 2nd edition.CAB International. Wallingford. viii 320: EU.

Zoysa MD. 2013. Agroforestry Systems In Sri Lanka: A Sustainable Resource Management Approach. Proceedings of International Forestry and Environment Symposium.

APPENDICES

Appendix I(a) Event Analysis of Temperature Data

Event	Temperature	Tea Production (ton)	Tree Stem Volume (m^3)
E-1	25.00	0	1.65
E-2	30.00	0	1.80
E-3	26.50	0	2.05
E-4	29.24	0.35	2.35
E-5	26.86	0.40	3.23
E-6	21.67	0.37	3.67

Appendix I (b) Average Monthly Temperature in Shaded and Unshaded Area

Month	**Unshaded**	**Shaded**
March	27.95	23.69
April	29.75	26.62
May	30.27	27.52
June	29.00	26.67
July	27.68	26.23
August	28.85	27.16
September	26.09	23.43
October	24.84	22.81
November	24.01	21.00
December	21.06	19.94
January	19.45	19.19
February	22.16	20.89
SD	3.86	3.47

Source: bd.free.meteo.com

Appendix I (c) Highest and Lowest Temperature in Shaded and Unshaded Area

Month	**Shaded**		**Unshaded**	
	Highest	**Lowest**	**Highest**	**Lowest**
March	28.00	18.00	30.00	23.00
April	30.00	22.00	32.50	25.00
May	30.50	23.00	32.00	25.00
June	30.00	24.00	30.00	27.00
July	30.00	23.00	31.00	25.00
August	30.00	25.00	30.50	27.00
September	27.00	18.00	30.00	22.50
October	26.00	19.00	27.50	22.00
November	24.00	18.00	25.50	23.00
December	23.00	17.00	24.00	18.00
January	29.00	15.00	23.00	17.00
February	23.00	18.00	24.50	19.50

Source:bd.free.meteo.com

Appendix II: Precipitation of Rain Fall Data

Month	AVG	DRY	WET
March	21.6mm	20days	11days
April	24.5mm	17days	13days
May	14.4mm	24days	7days
June	24 mm	14days	16days
July	82mm	12days	18days
August	92mm	4days	26days
September	42mm	13days	17days
October	2mm	28days	2days
November	0mm	0days	0days
December	2.5mm	29days	2days
January	3.8mm	25days	6days
February	0mm	0days	0days

Source: AccuWeather

Appendix III: The calculated value of Soil Data

Soil Moisture:

	Shaded part	Unshaded part
Water gain from rainfall	3.56%	3.48%
Rainfall interception	2.91%	1.77%
Water loss by transpiration, evaporation; drainage, and run-off	0.65%	1.71%

Soil carbon:

	Shaded part	Unshaded part
C-gain from plant senescence; thinning and pruning	1.24%	1.16%
C-loss from the decomposition of litter and organic matter; and in the run-off	0.84%	1.06%

Soil Nitrogen:

	Shaded part	Unshaded part
N-gain from plant senescence; thinning; pruning; fixation and fertilization	0.112%	0.007%
N-loss by plant uptake; emission; leaching; and in run-off	0.005%	0.087%

Source: Author's Own source

Appendix IV: Some Plates of Research Activities

Plate1: Measuring height of the tree

Plate 2: Measuring DBH of the tree

Plate 3: Collecting soil sample.