Floristic Diversity and Carbon Storage of *Gmelina arborea* (Roxb.) Plantation in Agricultural Landscape of Terai Zone of West Bengal

A thesis submitted

in partial fulfillment of the requirements

for the Degree of

MASTER OF SCIENCE

IN

FORESTRY

By

Mendup Tamang
(H-2018-14-M)

DEPARTMENT OF FORESTRY
FACULTY OF HORTICULTURE
UTTAR BANGA KRISHI VISWAVIDYALAYA
PUNDIBARI - 736 165, **Cooch Behar**, **WEST BENGAL**
2020

Dedicated to my beloved

Father, Mother, Sister, Brother

&

My sir Dr. Gopal Shukla

For their unconditional love, support and encouragement.

Mobile: 09851380707
E mail: gopalshukla12@gmail.com

UTTAR BANGA KRISHI VISWAVIDYALAYA

Faculty of Horticulture
DEPARTMENT OF FORESTRY
Pundibari-736 165, Cooch Behar
West Bengal, India

Dr. Gopal Shukla
Assistant Professor (PI, NMPB & SERB Project)

CERTIFICATE- I

Certified that the thesis entitled "**Floristic Diversity and Carbon Storage of *Gmelina arborea* (Roxb.) Plantation in Agricultural Landscape of Terai Zone of West Bengal"** submitted by Mr. Mendup Tamang bearing Registration Number H-2018-14-M towards partial fulfilment of the requirement for the award of Master Degree from the Department of Forestry under *Uttar Banga Krishi Viswavidyalaya* has been checked against plagiarism through URKUND software on 02nd September, 2020 and that the similarity index has been achieved as 04% which is below the maximum tolerable range as per stipulation of this *Viswavidyalaya.* The thesis of Mr. Tamang may be accepted for the award of the Master Degree in Department of Forestry of *Uttar Banga Krishi Viswavidyalaya.*

G Shukla

(Gopal Shukla)
Chairman
Advisory Committee

Place: Pundibari
Date: 02.09.2020

Title of the Thesis	: **Floristic Diversity and Carbon Storage of *Gmelina arborea* (Roxb.) Plantation in Agricultural Landscape of Terai Zone of West Bengal**
Name of the student and Admission No.	: Mendup Tamang (H-2018-14-M)
Major Subject	: Forestry
Name and Designation of the Chairman, Advisory Committee	: **Dr. Gopal Shukla** Assistant Professor Department of Forestry
Degree to be awarded	: M. Sc. Forestry
Year of Award of Degree	: 2020
Total pages in the thesis	: 116
Name of the University	: Uttar Banga Krishi Viswavidyalaya Pundibari-736 165, West Bengal

ABSTRACT

The potential of *Gmelina* farm forestry plantations needs to be analysed for their capability to produce biomass and store carbon for longer duration as a viable avoided emission strategy. The present work was conducted from September 2018 to February 2020 in randomly selected *Gmelina* farm forestry young unmanaged plantations categorized into ≤ 5, 5-10 and 10-15 years age class. In a plantation 10 % of the *Gmelina* trees were randomly selected, while all other trees other than *Gmelina* were selected. Stratified random nested quadrat sampling method was adopted for analyzing other vegetation forms within a plantation. Overall species richness of the plantations was 51, of which tree, shrub, herb, climber, and fern were 23, 7, 16, 2, and 3, respectively. The estimated quantitative vegetation parameters and diversity indices indicates the plant assemblages were heterogeneity with native diverse species evenly distributed with fairly higher density, frequency and abundance. Herbs were the most important species followed by shrubs and trees. With the increasing age of plantation, the richness of plant species increased but with mix trends for vegetative parameters and diversity indices. Soil physico-chemical properties were significantly influenced by the age of the plantation but exhibited no discreet trend with increasing plantation age. Total biomass density and total carbon density increased with increasing plantation age while no drastic variation in available SOC as litter production also did not vary. The overall mean total plant biomass, total available SOC and ecosystem carbon in the plantations was 199.86, 51.59 and 171.45 Mg ha^{-1}, respectively. The quantum of carbon sink in these studied *Gmelina* farm forestry plantations though lesser than the forests but has fair enough potential to convert unutilized agricultural landscape from net source of carbon to net sink or even earn carbon credits. This is because of considerable vegetation heterogeneity of these still younger plantations with no disturbance or management and if allowed full rotation period with selective logging, development of semi-natural secondary forest is expected with multiple social and ecological benefits.

CERTIFICATE –II

This is to certify that the thesis entitled, **"Floristic Diversity and Carbon Storage of *Gmelina arborea* (Roxb.) Plantation in Agricultural Landscape of Terai Zone of West Bengal"** submitted by **Mr. Mendup Tamang** (H-2018-14-M) to Uttar Banga Krishi Vishwavidyalaya, Pundibari in partial requirement for the degree of Master of Science in Forestry has been approved by the Student's Advisory Committee on 26th September 2020 after online viva-voce on the same in collaboration with an external examiner and we recommend that the thesis be accepted for the award of the degree of Master of Science in Forestry.

Dr. Gopal Shukla
Chairman, Advisory committee
Assistant Professor
Department of Forestry
UBKV, Pundibari

Dr. Sanjeev Kr. Chauhan
External Examiner
Professor & Head
Department of Forestry & NR
Punjab Agricultural University
Ludhiana

Dr. Sumit Chakravarty, Member
Professor, Forestry
UBKV, Pundibari

Dr. Shovik Deb, Member
Assistant Professor, SSAC
UBKV, Pundibari

Dr. Manoj Kanti Debnath, Member
Assistant Professor, Agril. Stat.
UBKV, Pundibari

Head
Department of Forestry
Uttar Banga Krishi Vishwavidyalaya
Pundibari

Dean
Post Graduate Studies
Uttar Banga Krishi Vishwavidyalaya
Pundibari

ACKNOWLEDGEMENT

Presentation, inspiration and motivation have always played a key role in the success of any venture. It is really a great opportunity for me to pay my tribute to ***all my teachers*** *who have imbibed in me the guest for knowledge.*

I pay my gratitude to my Chairman, Advisory committee, ***Dr. Gopal Shukla****, Assistant Professor, Department of Forestry, Uttar Banga Krishi Viswavidyalaya, Pundibari, Cooch Behar, for his immense support and guidance. His knowledge in the diverse academic arena encouraged me to be more and more curious the world around. It has been great experience to work under the supervision where, in the process I found a very good teacher in him.*

I am very grateful to ***Dr. Sumit Chakravarty****, Professor and Head, Department Forestry and knowledgeable member of my advisory committee, for his constant encouragement and valuable suggestion from time to time during the course of my research and final day of the preparation of manuscript.*

I am also thankful to ***Dr. Shovik Deb****, Assistant Professor, Dept. of Soil Science & Agril. Chem. and* ***Dr. Manoj K. Debnath****, Assistant Professor, Dept. of Agriculture Statistics, Uttar Banga Krishi Viswavidyalaya, Pundibari, Cooch Behar, for providing expertise, benevolent co-operation being member of my advisory committee.*

I express my thankful to ***Dr. A. N. Dey****, Professor, Department of Forestry and* ***Ms. Vineeta****, Assistant Professor, Department of Forestry U.B.K.V for their valuable suggestions, constant encouragement and full cooperation with helping hand during the entire period of the present studies. I would like to thank all the non-teaching staff members, Department of Forestry UBKV,* ***Mr. Anarul Hoque****, Jr. Lab Attendant, RRS (TZ), UBKV, Pundibari and Library staff of the University.*

I express my affectionate gratitude to my senior and my batch mates Biplov da, Abha di, Bishleshna di, Ubalt da, Dinesh da, Devrath da, Rickey da, Suraj da, Manish da, Abigale Di, Roman, Rufus, Pema, Avinash, Trishala, Kamal, and Kiran whose moral support has been invaluable in aiding me to complete this thesis.

Last but not the least I affectionately acknowledge the unconditional love, support and constant encouragement I received from ***my parents*** *and* ***family****, without which I could never complete my thesis work.*

I am thankful to god for keeping me in a healthy state of mind, body and soul without which I could not have completed this immense task.

(Mendup Tamang)

CONTENTS

CHAPTER	TOPIC	PAGE
1	**INTRODUCTION**	**1-2**
2	**REVIEW OF LITERATURE**	**3-11**
2.1	Phytodiversity in plantation	3
2.2	Soil physio-chemical properties	4
2.3	Biomass and carbon storage	8
3	**MATERIALS AND METHOD**	**12-18**
3.1	Site Description	12
3.2	Climate and Weather	13
3.3	Sampling and Inventory	14
3.4	Quantitative Parameters	14
3.4.1	Frequency (F)	14
3.4.2	Relative frequency (RF)	14
3.4.3	Density (D)	15
3.4.4	Relative density (RD)	15
3.4.5	Abundance (A)	15
3.4.6	Relative abundance (RA)	15
3.4.7	Important value index (IVI)	15
3.4.8	Height (ht) and Diameter	16
3.5	Diversity Indices	16
3.5.1	Species richness (S)	16
3.5.2	Species diversity index (D`)	16
3.5.3	Concentration of dominance (C`)	16
3.5.4	Shannon-Wiener diversity index (H`)	16
3.5.5	Species evenness index (EI)	16
3.6	Biomass and Carbon Stock Estimation	17
3.7	Soil Physico-chemical Characteristics	17
3.8	Statistical Analysis	18
4	**RESULTS AND DISCUSSION**	**19-52**
4.1	Phytodiversity Analysis	19
4.1.1	Diversity indices and species composition	19
4.1.2	Vegetation analysis	25
4.2	Soil Moisture, pH, Electrical Conductivity and Bulk Density	34
4.3	Soil Available Organic Carbon, Nitrogen, Potassium and Phosphorus	39
4.4	Biomass Production and Biomass Carbon Stock	46
4.5	Ecosystem Carbon Stock	50
5	**SUMMARY AND CONCLUSION**	**53-59**
5.1	Diversity indices and species composition	53
5.2	Vegetation analysis	54
5.3	Soil Moisture, pH, Electrical Conductivity and Bulk Density	56
5.4	Soil Available Organic Carbon, Nitrogen, Potassium and Phosphorus	56
5.5	Biomass Production and Biomass Carbon Stock	57
5.6	Ecosystem Carbon Stock	57
5.7	Conclusion	58
5.8	Recommendation and Future Research	58
6	**REFERENCES**	**60-116**

LIST OF TABLE

Table No.	Title	Page no.
1	Biomass and carbon storage *Gmelina arborea* in agroforestry and sole in India	8
2	Location of selected *Gmelina arborea* farm forestry plantations	12
3	Soil physico-chemical parameters with their estimation method	17
4	Diversity Indices of *Gmelina* farm forestry plantations	19
5	Plant life form in *Gmelina* farm forestry plantations	19
6	Plant species in *Gmelina* farm forestry plantations	20
7	Frequency and relative frequency of *Gmelina* farm forestry plantations	26
8	Density and relative density of *Gmelina* farm forestry plantations	28
9	Abundance and relative abundance of *Gmelina* farm forestry plantations	30
10	Important value index of *Gmelina* farm forestry plantations	33
11	Soil moisture (%) in *Gmelina* farm forestry plantations	35
12	Soil pH and EC in *Gmelina* farm forestry plantations	36
13	Soil bulk density (g cm^{-3}) in the *Gmelina* farm forestry plantations	37
14	Pearson correlation matrix of stand, soil physiochemical properties TBD and TCD	37
15	SOC (Mg ha^{-1}) in *Gmelina* farm forestry plantations	40
16	Soil available N (Kg ha^{-1}) in *Gmelina* farm forestry plantations	41
17	Soil available P (Kg ha^{-1}) in *Gmelina* farm forestry plantations	42
18	Soil available K (Kg ha^{-1}) in *Gmelina* farm forestry plantations	43
19	Biomass and carbon stock (Mg ha^{-1}) in *Gmelina* farm forestry plantations	47

LIST OF FIGURES

Figure No.	Title	Page no.
1	Meteorological data Sept. 2018-Feb. 2020	13
2	Total carbon stock (Mg ha^{-1}) in Gmelina farm forestry plantations	51

Chapter 1

INTRODUCTION

Climate change is a global concern now (Zhang *et al*., 2011; Anon., 2013; ter Steege *et al*., 2013; Jhariya 2017; Raj *et al*., 2018$_{a, b}$) and forests are vital to regulate as they are the viable option to offset terrestrial carbon dioxide emission (Trexler and Haugen, 1994; Redondo-Brenes and Montagnini, 2006; Wani *et al*., 2010; Saatchi *et al*. 2011; Chakravarty *et al*., 2012; Shukla *et al.,* 2014$_{a-c}$; Kongmeesup and Boonyanuphap, 2019). Unfortunately, forests alone are not enough to offset all the terrestrial emissions (Anon, 1995; Chakravarty *et al*., 2012) and the need is to find an alternate viable option to plug the offset gap (Chakravarty *et al*., 2019). The accepted viable alternative are trees outside forest (TOF) both at agricultural or human dominated landscape and revegetating the degraded lands not only to meet timber, industrial and livelihood demand but also for effectively and viably supplement in offsetting carbon emission with the forest ecosystems (Aggangan, 2001; Albrecht and Kandji 2003; Roshetko *et al*., 2007; Kaonga and Bayliss-Smith, 2009; Soto-Pinto *et al.*, 2010; Kumar and Nair 2011; Chidumayo, 2012; Shukla *et al.*, 2014$_b$; Rajput *et al*., 2015; Jhariya and Yadav, 2018; Jhariya *et al*., 2018; Chakravarty *et al*., 2019; Meena *et al*., 2019).

Tree based land use systems including those in the non-forested landscapes like agricultural land play an important role in the global carbon cycling, since these are one of the largest carbon pools which act a potential carbon sinks as well as of the major sources of CO_2 (Kaonga and Bayliss-Smith, 2009; Soto-Pinto *et al.*, 2010; Shukla *et al.*, 2014$_b$, 2018; Kumar, 2017; Chakravarty *et al*., 2019). The rate of biomass productivity of plantations is higher (3.2 Mg ha^{-1} yr^{-1}) than productivity of natural forests (1.1 Mg ha^{-1} yr^{-1}; Lal and Singh, 2000). This is because plantation forestry had an added advantage over the natural forest in terms of better silvicultural practices (Baishya *et al.*, 2009). Thus, the past decades has witnessed increased interest in tree plantations at both agricultural and non-agricultural dominated landscapes in the country with Teak (*Tectona grandis*), *Gmelina* (*Gmelina arborea*), Deccan Neem (*Melia Azadirachta*), Champa (*Michelia champaca*) and Sal (*Shorea robusta*) among the farmers and entrepreneurs as well, particularly in the sub-Himalayan i.e. terai region of West Bengal (Troup, 1975; Kumar, 2007; Orwa *et al*., 2009; Kaswala *et al*., 2012; Balu *et al*., 2015; Verma *et al*., 2017).

Gmelina (*Gmelina arborea*) native to India and a prime fast growing species at farm forestry in India has the potential to replace and act as a substitute for exotic timbers in the country (Roshetko *et al.,* 2004; Kumar 2007; Verma *et al*., 2017; Sarangle *et al.,* 2018). The species has a potential to store carbon and also remunerative due to its multiple uses (Pathala *et al.,* 2015; Pooja *et al.,* 2017). In addition to timber, wood and fuel wood needs, this species is also used for paper and pulp making and other forest based industries which makes it as one of the most promising multipurpose tree species (Swamy and Puri 2005; Verma *et al*., 2017). *Gmelina* plantations have been established and encouraged in small woodlots, homegardens and agroforestry settings in the tropics and subtropics (Ujjwala *et al.,* 2017; Verma *et al*., 2017) including the terai region of West Bengal.

There is little or very scanty information on the carbon budgets of tropical tree plantations and tree farms. The potential of these trees to offset carbon emission needs to be assessed and monitored properly for which local, regional or national inventory is required (Anon., 2003; Pandey *et al*., 2010; Chakravarty *et al*., 2019). Understanding the diverse and complex tree based land use systems has become a research interest worldwide posing fundamental questions like carbon sequestration and nutrient cycling (Puri and Nair, 2004; Walker *et al* 2008, Bombelli *et al* 2009, Epron *et al*., 2009, Chauhan *et al*., 2009, 2015). United Nations Framework Convention on Climate Change (UNFCCC) has recognized the importance of plantation forestry as a greenhouse gas mitigation option, as well as the need to monitor, preserve and enhance terrestrial carbon stocks (Updegraff *et al*., 2004; Saint-André *et al*., 2007; Anon., 2008). The detail study on biomass and carbon storage of *Gmelina* farm forestry system is lacking and very few studies were carried out for the region of West Bengal (Troup, 1975; Orwa *et al*., 2009; Kaswala *et al*., 2012; Verma *et al*., 2017). Keeping this view the present study entitled **"Floristic Diversity and Carbon Storage of *Gmelina arborea* (Roxb.) Plantation in Agricultural Landscape of Terai Zone of West Bengal"** with the following objectives:

-Assessment of phyto-diversity, biomass and carbon storage of *Gmelina* plantation.

- Assessment of soil physico-chemical parameters under *Gmelina* plantation.

Chapter 2

REVIEW OF LITERATURE

The importance of forests and tree based farming or plantations in mitigating climate change has led countries to study their carbon budgets and initiate the assessment of enhancing and maintaining carbon sequestration of their tree resource (Dunnett and Qasim, 2000; Fernandez-Juricic and Jokimäki, 2001; Nowak *et al.*, 2001; Cornelis and Hermy, 2004; Smith, 2007; Khera *et al*., 2009; Williams *et al*. 2009; Goddard *et al*., 2010; Owen, 2010; Davies *et al*. 2011; Cilliers *et al*., 2013; Vila-Ruiz *et al*., 2014; Nyambane *et al*., 2016; Cameron *et al*. 2017). Very scare or limited literature or study on tree outside forest/tree plantationswere available (Chakravarty *et al*., 2019) and most of the study were focused on importance of forest vegetation; however, only few studies were species or plantation orientated (Chavan and Rasal, 2010, $2011_{a, b}$, $2012_{a, b}$). *Gmelina* (*Gmelina arborea*) also known as white teak or Siwan is a fast growing multipurpose tree species, native to India and perfect option for farm forestry and large-scale afforestation or reforestation initiatives (Tewari, 1995; Hamilton *et al*., 1998; Kumar, 2007; Orwa *et al.*, 2009; Balu *et al*., 2015; Pooja *et al.,* 2017; Verma *et al*., 2017). It is an excellent small-holder's timber as it is easy to cultivate especially as farmer market-oriented agroforestry and land rehabilitation programs (Roshetko *et al.,* 2003, 2004). However, its contribution till now is only 0.47 % of total volume of trees under agroforestry systems in the country (Anon, 2013). The available literature on this aspect is presented under the following heads:

2.1 Phytodiversity in plantation

2.2 Soil physico-chemical properties

2.3 Biomass and carbon storage

2.1. Phytodiversity in Plantation

Studies on phytodiversity provide information on habitat site quality aspect, its carrying capacity and mechanism for sustenance of livelihood in response to sustainable management (Higgins *et al*., 1994; Chapin *et al*, 1997; Tilman *et al*., 2001; Walther *et al*, 2002; Thompson *et al*., 2003; Maity *et al*., 2004; Anon., 2005; Smith *et al*., $2006_{a, b}$; Alves and Rosa, 2007; Sedelnikov *et al*., 2008; Naeem, 2009; Müller *et al*., 2010; Sobuj and Rahman, 2011; Deka *et al*., 2012; Mace *et al*, 2012; Panskus *et al*., 2013; Addaja *et al*., 2017; Kumar *et al*., 2018). There are very less phytodiversity studies outside forests except a few from urban areas like in China (Ma and Liu, 2003); Belgrade, Serbia with

58 plant species (Grdovic and Stevanovic, 2006); Sheffield and Birmingham, United Kingdom with 822 vascular plants (Thompson and McCarthy, 2008); Paris, France with 626 vascular plant species (Muratet *et al*., 2008); Kyiv, Ukraine with 114 plant species (Yavorska, 2009); Bhubaneswar, Orissa India with 72 herb species (Kumar and Satapathy, 2011); industrial building of Warsaw, Poland with 26 plant species (Pieniak and Chylinski, 2012); Varanasi, Uttar Pradesh India with 765 plant species (Singh, 2013); and Serlbergs surroundings at Dumbi, Zaria in the northern Guinea savannah with 63 woody species (Tanko *et al*., 2013) and Rio Piedras, Puerto Rico with 383 plant species (Vila-Ruiz *et al*., 2014).

In plantations of 124 plant species represented by 109 genera and 83 families was documented, of which 48 species were herbs, 45 shrubs and 31 tree species (Iqbal *et al*., 2012). Shrub density estimated was 9.40-10.65 individuals 25 m^{-2} and herb density was 10.61-13.19 individuals m^{-2}. The density of shrubs and herbs were reported comparable to the density in forests. A total of 393 plants represented by 22 species and 11 families were documented in hot and humid conditions of Ramdurga Taluk of Belagavi district of Karnataka (Prabha *et al*., 2017). *Azadirachta indica* was reported dominant species in the study area with IVI of 117.30 followed by *Eucalyptus grandis* with IVI of 42.85 and *Tectona grandis* with IVI of 25.22. Plantations in steel city of Odisha, India was reported with 154 plant species represented by 128 genera and 55 families with 45 tree species, 49 species herbs, 28 species shrubs, 80 species climbers and only five grass species (Kumar *et al*., 2018). Family Asteraceae dominated the list with 12 species followed by Apocynaceae and Caesalpiniaceae with nine species each, Euphorbiaceae with seven species and Fabaceae and Malvaceae with six species each. Diversity and distribution of trees and shrubs in plantations of Gurara forest, Kaduna state of Nigeria comprised of 23 tree species and eight shrub species (Addaja *et al*., 2017). Plant density in the plantation was 3502 trees ha^{-1} and 642 shrubs ha^{-1}, while diversity and evenness index was 5.72 and 2.12, respectively.

2.2. Soil Physico-chemical Properties

Sustainable management of the soil improve the ability of the soil to perform effectively in providing direct and indirect ecosystem services, while reducing soil degradation as well (Ren*et al*., 2012; Thapa and Yila, 2012; Zhao *et al*., 2013; Edmondson *et al*., 2014; Ota *et al*., 2018). Trees plantations are one of the viable options of sustainable soil management that improve soil fertility through ecological and physicochemical changes i.e. increasing organic matter and microbial activity in the soil

by adding litter and through their rooted systems (Sanginga *et al*., 1992; Bulluck *et al*., 2002; Schroth *et al*., 2002; Singh *et al*., 2002; Rahman *et al*., 2012; Maeght *et al*., 2013; Lehman and Kleber, 2015; Zalamea *et al*., 2016; Ota *et al*., 2018; Tecimen *et al*., 2017, 2018). Mycorrhizal association with roots also supplement soil organic carbon within the rhizosphere (Clemmensen *et al*., 2013; Phillips *et al*., 2013).

Site preparation for planting influences soil physical properties like increase of bulk density (Blanco-Canqui and Ruis, 2018), while combination of soil tillage and tree plantation influence soil chemical properties like improved soil water holding capacity and decreased soil volume weight in plantations with shrub species improves (Su and Zhao, 2003). Plantations managed properly guard erosion and thus improve soil physical conditions (Rocheleau *et al*., 1988). Plantations were recorded with lesser acidic soils than the forests (Tecimen *et al*., 2018). Soil pH is influenced by the type of species and decomposition of by-products produced by the species as was observed after afforestation with pine trees or with other tree combinations where pH reduced due to cation saturation capacity of soil (Berthrong *et al*., 2009). Bulk density decreases with the age of plantation (Singh *et al*., 2001) but with increase in soil depth it increases (Kim *et al*., 2018). Soil moisture content is higher under vegetation and it gradually decreases with increase in soil depth (Jonston and Alongi, 1995; Haque, 1997; Chowdhury *et al*., 2007; Shaifullah *et al*., 2008). Vegetation also improves the soil structure or particle density (Watt *et al*., 2005).

Porosity, water holding capacity, bulk density, pH, organic matter, total nitrogen, available phosphorus, exchangeable calcium, magnesium, potassium and cation exchange capacity are generally higher in the forest soil as compared with agriculture soil or plantation soil (Tanji, 1990; Ogidiolu, 1997; Osuntogun, 2001; Singh *et al*., 2001). Converting forest with plantations was reported to deteriorate the physical and chemical properties of soil (Brown and Lugo, 1990; Davidson and Ackerman, 1993; Rosell and Galantini, 1997; Batjes and Dijkshoorn, 1999; Feller *et al*, 2001; Singh *et al*., 2001; Kimmins, 2004; Idiege *et al.,* 2014) as was reported from Andaman islands, India where replacing the virgin forest with plantations of *Pterocarpus dalbergiodes*, *Shorea robusta*, *Tectona grandis* and *Elaeis guinensis* increased bulk density of surface soil (Mongia and Bandyopadhyay, 1994). However, managing the plantations with longer rotation can restore its original status of soil nutrients (Kimmins, 2004) as with longer rotation *Gmelina arborea* plantations where soil nutrients were gradually restored, slightly

depleted at 10-19 years and again back to same level with longer rotation (Idiege *et al.*, 2014).

Shorea robusta, Dipterocarpus turbinatus, Eucalyptus tereticornis, Gliricidia sepium and *Gmelina arborea* plantations were reported to improve physico-chemical properties and stabilize soil nutrients (Mishra *et al*., 2003; Rahman *et al*., 2012; Ota *et al*., 2018). Soil bulk density at *Gmelina* and *Gliricidia* plantations were reported significantly lower than the soil without these plantations (Ota *et al*., 2018). Moreover the soils of these plantations were also found with increased organic matter and nitrogen due to continuous leaf litter inputs (Onyekwelu, 2002; Swamy *et al*., 2004). Generally soil of *Gmelina* plantations was moderately acidic at the surface but strongly acidic at the subsurface layers (Okagbare *et al*., 2004; Gideon *et al*., 2016). Soil of the *Gmelina* plantations were also reported with low Ca, Mg, Na and K because of leaching and erosion caused by high rainfall (Akinrinde and Obigbesan, 2000; Uzoho *et al*., 2007; Igwe and Obalum, 2013). *Gmelina arborea* plantations in India and Nigeria were reported with significant improvement of soil nutrient status with no additional nutrient inputs as applied which indicated the species was non-exhaustive of nutrient base at the site (Chijioke, 1980; Swamy *et al*., 2004).

Soil is the largest terrestrial reservoir of organic carbon which not only is related to its fertility but also to the environment by sequestering carbon (Post *et al*., 1982; Batjes, 1996; Eswaran *et al*., 2000; Lal, 2004; Krischbaum, 2000; Smith and Heath, 2002; Sherman *et al*., 2003; Conti and Diaz, 2013; Prabha *et al*., 2014; Ruiz-Benito *et al*., 2014; Banday *et al*., 2019; Rawat *et al*., 2019). Most of the soils were reported to contain 0.3-11.5 % organic matter up to 20 cm soil depth (Islam and Weil, 2000; Poudel and Thapa, 2001; Lal, 2005). Higher organic carbon in the soil of forest and plantation was attributed to higher organic input by litter fall, root biomass and lower soil disturbance compared to crop land (Johnson *et al*., 2006; Shrestha and Singh, 2008; Dhakal *et al*., 2010; Rathore *et al*. 2010; Lal *et al*., 2012; Gosain *et al*., 2015; Ali *et al*., 2017; Ghimire *et al*., 2018; Mishra *et al*., 2019; Sahoo *et al*., 2019).

Carbon storage by the soil was reported as function of stand age, region, tree or plant species, distance from the tree trunk or canopy; soil depth, topography, slope aspect, land use, land use change, management and disturbance (Blair *et al.*, 1995; Post and Kwon, 2000; Post *et al*., 2001; Bajracharaya *et al*., 2004; Brovin *et al*., 2004; Ludwig *et al*., 2004; Pérez *et al*., 2004; Rothstein *et al*., 2004; Diekow *et al.*, 2005; Vanlauwe *et al*, 2005; O'Neill *et al*., 2006; Dawson and Smith, 2007; Takimoto *et al*., 2008; Githae *et al*.,

2011; Jeddi and Chaieb, 2012; Poeplau and Don, 2013; Dachung *et al*., 2014; Wani *et al*., 2014; Shukla *et al*. 2017; Ghimire *et al.*, 2018; Kim *et al*., 2018; Sainepo *et al*., 2018; Sahoo *et al*., 2019).

Higher the age class of the plantation, higher was the soil carbon storage (Kim *et al*. 2018), while deeper the soil lesser was the storage of carbon (Thakur and Verma, 2019). Studies indicated direct relationship of soil organic carbon and productivity with leaf nitrogen content (Bakker *et al*., 2011; Freschet *et al* 2012; Milcu *et al*., 2014; Guo *et al*., 2016; Tahmasebi *et al*., 2017; Rawat *et al*., 2019). Decomposition of the leaves after litter fall increases the nutrient availability and in turn influences the soil organic carbon content through enhanced microbial activity (He *et al*., 2014; Farrell *et al*., 2014; Khlifa *et al*., 2017). Some studies also reported reverse relationship of leaf nitrogen content with soil organic carbon (Conti and Diaz, 2013; Lin *et al*., 2016).

Carbon storage in relation to soil size fraction under tropical tree based land use system was studied and storage was reported higher (58.72 Mg ha^{-1}) in the <53 µm fraction (Saha *et al*., 2010). In Terai zone of West Bengal, fallow land and agricultural field sequester 5.86 % and 4.73 % less carbon compared to the natural plantation of *Shorea robusta* (Koul and Panwar, 2008). Soil carbon sequestration rate of agroforestry plantations at district level in India was reported as 0.03-0.51 Mg $ha^{-1}year^{-1}$ (Ajit *et al*., 2016). The rate of soil carbon sequestration in *Gmelina* (576 trees ha^{-1}) based agroforestry system in Raipur at five years of age estimated was 0.42 Mg ha^{-1} $year^{-1}$ (Swamy and Puri, 2005). Biomass and carbon storage *Gmelina* in agroforestry and sole plantation reported from different regions of India is given in table 1.

Soil organic carbon progressively increased under Eucalyptus plantations in Congo (Trouve *et al*., 1994). Highest soil organic carbon was observed at surface level of *Theobroma cacao* plantations, *Gmelina arborea* plantations and secondary forest in Nigeria with higher total N in *Gmelina* followed by *T. Cacao* (Gideon *et al*., 2016). The study also reported that Cu content was significantly and positively correlated with organic carbon and Ca^{2+} under *T. Cacao*. Electrical conductivity was low in all the studied land uses and decreased with increased soil depth. Plantations of Sal and Garjan in Bangladesh were reported with higher soil particle density thereby improving the soil binding characteristics along with higher organic matter (Rahman *et al*., 2012). Soil surface layer (0-15 cm) of *Acacia auriculiformis, Acacia mangium, Eucalyptus camaldulensis, Pinus caribea* and *Dipterocarpus costatus* plantations in Chittagong and Cox's Bazar Forest Divisions of Bangladesh was reported estimated with 0.53-0.63 %,

0.45-0.59 %, 0.50-0.72 %, 0.41-0.64 % and 0.31-0.55 % soil organic carbon content, respectively (Osman *et al*., 2002). *Erythrina poeppigiana* based alley cropping in Costa Rica increased soil organic carbon by 1.1 Mg ha^{-1} $year^{-1}$ amounting to 9.6 × 10^5 Mg ha^{-1} (Oelbermann, 2002; Oelbermann *et al*., 2004).

Table 1. Biomass and carbon storage *Gmelina arborea* in agroforestry and sole in India

System, region	Major Finding	Reference
Sole plantation, Tripura	Density- 452 trees ha^{-1}, diameter- 25.4 cm, height- 20.9 m, mean annual increment- 10.48 m^3 ha^{-1}, AGB- 164.44 Mg ha^{-1}, annual productivity- 8.2 Mg ha^{-1}	Negi (1990)
Intercrop with soyabean, central India	Total biomass- 3.65-10.89 Mg ha^{-1}	Swamy *et al*. ($2003_{a, b}$)
Intercrop with soybean and cowpea in rainy season; wheat and mustard in winter season, Chhattisgarh	Total C storage in agricultural land before planting was 26.3 Mg ha^{-1}, which increased to 33.7 Mg ha^{-1} in plantation and 45.8 Mg ha^{-1} C in agrisilvicultural system after 5 years	Swamy and Puri (2005)
Intercrop with wheat, linseed, mustard, urd Chhattisgarh	Total biomass- 6.96-13.75 Mg ha^{-1} after 5 years	Swamy *et al*. (2008)

2.3. Biomass and Carbon Storage

The rising CO_2 level has severe implication on the global functioning of physical and biological system and forcing to search the alternative sink of carbon (Chakravarty *et al*., 2020). Carbon sequestration in the form of tree biomass as well as storage/locking it in other wood/forest based items for a long period is reflected as one of the worthwhile opportunity to shrink atmospheric carbon with the help of fast growing tree species (Chauhan *et al*., 2016; 2019). Quantification of biomass measurement in forest, individual tree or whole stand/plantations is essential for understanding the potential of

carbon sequestration at regional, local or nationalscale (Hingane, 1991; Iverson *et al*., 1993; Sundriyal and Sharma, 1996; Ravindranath *et al.*, 1997; Dadhwal *et al.*, 1998; Ketterings *et al.*, 2001; Mary *et al*., 2001; Mccarl and Schneider, 2001; Gower, 2003; Houghton, 2005; Gupta and Pandey, 2008; Sharma *et al*., 2008; Houghton *et al*., 2009; Pandey *et al*., 2011; Paquette and Messier, 2011; Alonso *et al*., 2012; Vashum and Jayakumar, 2012; Yavasli, 2012; Mandal and Joshi, 2014; Salunkhe *et al*., 2014, 2016; Salunkhe and Khare, 2016; Kumar and Pandey, 2017; Poorter *et al*., 2017; Prabha *et al*., 2017; Ratcliffe *et al*., 2017; Kim *et al*., 2018; Ali *et al*., 2019$_{a, b}$; Rawat *et al*., 2019; Sheikh *et al*., 2020).

Biomass estimation above (AGB) and below ground is equally important to understand the structural and functional attributes of the forest or plantations in wide range of environmental conditions (Dudley and Fownes, 1992; Brown *et al*., 1999). Quarter of total tree carbon storage is contributed by below ground biomass (BGB) for many vegetation types and land-use systems (Santantonio *et al*., 1977; Cairns *et al*., 1997, 2003). However, datasets on BGB are very scare or still inadequate in the tropical region, mostly for plantation forests because of root sampling difficulties (Karizumi, 1974; Mokany *et al*., 2006; Kenzo *et al*., 2009; Niiyama *et al*., 2010; Ziegler *et al*., 2012; Yuen *et al*., 2013; McNicol *et al*., 2015; Waring and Powers, 2017; Yang *et al*., 2017). Biomass estimation is essential for financial assessment of afforestation programme at local, regional or national planning, implementation of decisions and intensity of management (Kumar, 2017). The carbon stock of Indian forest was 712.60 million tonnes with an increase of 42.60 million tonnes from last assessment on 2017 (Anon., 2019). Maharashtra was reported with highest growing stock (98.95) and carbon stock (29.78) followed by Andhra Pradesh and Gujarat. The total tree cover reported in West Bengal was 4018 km^2 with an amount of 33.058 million cubic meter volume and 8.78 million mega gram carbon stocks (Anon., 2019).

The capacity of forest or plantation to store carbon depends on its age, stage of succession and disturbances (Pregitzer and Euskirchen, 2004; Bellamy *et al*., 2005; Peichl and Arain, 2006, 2007). Positive correlation of tree species with its AGB and dbh was reported (Devi and Yadav, 2009). Tree height was reported a good predictor of biomass carbon (Imani *et al*., 2017). Stem wood contributes maximum biomass (54.3-76.4 %) followed by branches and leaves (Swamy *et al.*, 2003$_{a, b}$). Biomass carbon storage was found related with density, growth and age of the stand or plantation (Harmon *et al*., 1990; Zhou *et al*., 2006; Luyssaert *et al*., 2008; Kim *et al*., 2018; Shukla

and Chakravarty, 2018; Srinivas and Sundarapandian, 2018; Rawat *et al*., 2019). Aspect of slope was also reported to influence carbon stock of forest and plantation. The biomass production and carbon capacity of forests were abundantly reported (Hingane, 1991; Sundriyal and Sharma, 1996; Ravindranath *et al.,* 1997; Ketterings *et al*., 2001; Mary *et al*., 2001; Houghton, 2005; Malhi *et al*., 2006; Baishya and Barik, 2011; Gairola *et al*., 2011; Vashum and Jayakumar, 2012; Verma *et al*., 2012; Fayolle *et al*., 2013; Lewis *et al*., 2013; Mandal and Joshi, 2014; Kumar and Pandey, 2017; Shukla *et al*., 2017; Shukla and Chakravarty, 2018; Srinivas and Sundarapandian, 2018; Rawat *et al*., 2019; Thakur and Verma, 2019; Sheikh *et al*., 2020) but such studies were hardly done outside forests (Becknell *et al*., 2012; Purswani *et al*., 2019).

Proportion of stem biomass to total tree biomass in Mongolian Pine plantations of different age sequence at Horqin Sandy Land, China increased with age of the plantation (22.2 % in the 12^{th} year to 54.2 % in the 58^{th} year) but proportion of understorey biomass to total ecosystem biomass decreased (Zhang *et al*., 2019). In a study at foothill forest plantation of four species in eastern Himalaya, teak was reported to produced highest litter followed by sal, champa and least by jarul (Shukla *et al*., 2017). In another study from the same region, the biomass of natural teak was estimated at 1938.28 Mg ha^{-1} with total carbon of was 911.27 Mg ha^{-1} (Shukla *et al*., 2014_b). Estimated AGB of *Quercus mongolica* was highest in stem, followed by branches and leaves, while the amount of carbon storage in each component increased as age class increased (Kim *et al*., 2018). The total carbon storage in *Q. Mongolica* was 132.2, 241.1 and 374.4 Mg ha^{-1} for age classes three, five and seven years stand, respectively. Highest biomass carbon and total sequestration of 9.54 and 11.03 Mg ha^{-1} yr^{-1}, respectively was estimated in *Terminalia arjuna* and least of 3.44 Mg C ha^{-1} yr^{-1} in *Melia azedarach* plantations with SOC at 0-15 cm depth was 8.10-14.88 Mg ha^{-1} (Chauhan *et al*., 2019). The rate of carbon sequestration in these plantations was reported 95 % more than tree less areas.

Carbon allocation in above and below ground component of poplar plantation was 78.68 and 21.32 % of the total tree biomass carbon (Singh and Lodhiyal, 2009). The total biomass carbon in a year of a tree of *Paulownia tomentosa*was 4.52 ± 0.53 Kg, while average yearly biomass carbon was 135.68 ± 16.1 Kg (Magar *et al*., 2018). Biomass in an agroforestry system was 9.9-21.4 Mg $ha^{-1}$with an input of 6.8-11.9 % carbon content to the soil (Swamy and Mishra, 2014). Woody species in homegardens of Cooch Behar, West Bengal were estimated with 7482.67 Mg biomass with offset value of total live biomass at 507.94 Mg CO_{2e} (Pala *et al*., 2020).

Short rotation species like including *Gmelina arborea* did not achieve high carbon storage as compared to longer rotation species like *Swietenia mahogany* (Dewar and Cannell, 1991). The net biomass accumulation in 10 year old *Gmelina* plantation was 371.54 Mg ha^{-1} (Bohre *et al*., 2013). AGB estimated in five years old *Gmelina* plantation was 83.2 M ha^{-1}, while it was 394.9 Mg ha^{-1} in 21 years age plantation (Onyekwelu, 2004). Carbon density of a *Gmelina* farm quantified was 0.98-63.94 $Mgha^{-1}$ (Agus, 2003). *Gmelina* plantation of three years old in a good site produced AGB of 51 Mg ha^{-1} while plantations of four, six and eight years old in a moderate site produced AGB of 46, 86 and 117 Mg ha^{-1}, respectively (Agus *et al*., 2004). Four year old *Gmelina* based agrisilvicultural system in central India produced total biomass of 3.69-10.89 to 3.69 Mg ha^{-1} depending on its tree density (Chaturvedi *et al.*, 2016). Amongst the different multipurpose tree species in Jharkhand, India, highest biomass was produced by *Gmelina arborea* (190.98 Mg ha^{-1}) followed by *Dalbergia sissoo* and *Leucaena leucocephala* (172.47 Mg ha^{-1}each) and least by *Sapindus mukorossi* with 41.92 Mg ha^{-1} (Das *et al*., 2019).

MATERIAL AND METHODS

The present study entitled, **"Floristic Diversity and Carbon Storage of *Gmelina arborea* (Roxb.) Plantation in Agricultural Landscape of Terai Zone of West Bengal"** was carried out in Cooch Behar district of West Bengal from September 2018 to Feb. 2020. The detailed description about experimental site, materials and methodology adopted during the study is given below.

3.1. Site Description

The study site is Cooch Behar district (sub-Himalayan region) under northern part or terai region of West Bengal which lies between 26° 30' and 26° 56' N latitude and 88° 7' and 89° 53' E longitude. The area around (within 10 kms) of the university campus was surveyed for sampling plantations of *Gmelina*. *Gmelina* based farm forestry plantations in farmer's fields were randomly selected with GPS locations and based on availability three age classes were categorized (Garmin 72; table 2).

Table 2. Location of selected *Gmelina* arborea farm forestry plantations

Plantation code	GPS location	Plantation code	GPS location
≤ 5 years age class (AC I)		AC II P 4	26°24'40''N 89°22'55''E
AC I Bt 1	26°25'01.8''N 89°20'17.5''E	AC II P 5	26°24'54''N 89°22'27''E
AC I Bt 2	26°25'00.1''N 89°20'18.4''E	AC II P 6	26°24'40''N 89°22'57''E
AC I Bt 3	26°25'01.2''N 89°20'21.7''E	AC II Bt 7	26°25'00.1''N 89°20'18.4''E
AC I B 4	26°55'09.2''N 89°20'23.0''E	**10-15 years age class (AC III)**	
AC I S5	26°24'53.4''N 89°21'16.6''E	AC III Bt 1	26°25'01.2''N 89°20'22.3''E
AC I S6	26°24'54.2''N 89°21'18.6''E	AC III S 2	26°24'4.4''N 89°21'37.5''E
AC I S 7	26°30'04''N 89°22'19''E	AC III Bt 3	26°24'01.7''N 89°20'23.7''E
5-10 years age class (AC II)		AC III B 4	26°55'07.3''N 89°20'26.3''E
AC II Pd 1	26°24'09''N 89°22'49''E	AC III S 5	26°24'39.7''N 89°21'36.6''E
AC II P 2	26°24'09''N 89°22'04''E	AC III So 6	26°30'09.2''N 89°22'21.6''E
AC II P 3	26°24'28''N 89°22'42''E	AC III P 7	26°23'59.1''N 89°23'05.2''E

AC- age class; Bt- Bahannagar near Torsa; B- Bahannagar; S- Sajerpar, So- Sonapur; Pd- Pitcherdanga; P- Pundibari

Gmelina was found not abundantly planted by the farmers in their crop land except some scattered plantations. The area of the plantations was in addition to the crop land of the owner not much suitable for annual cropping and was kept fallow till the planting of *Gmelina*. *Gmelina* was densely planted with squared geometry of 3 m x 3 m. The plantations were not at all silviculturally managed after they were planted as was evidenced from gaps in the canopy along with dense undergrowth including other tree species also. The plantations were surrounded by cropping area of rice based cropping system with potato and/or fallow. Moreover, the cropping system is not intensive in the area. The area of the plantations was at least one acre except one at Pundibari (AC III P3) which was about four acres.

3.2. Climate and Weather

The climate of the study area is moist tropical (Anon., 2001). The average minimum and maximum temperature varied from 22.82^{0}C during winter (January) to 32.32^{0}C during September. On an average, the annual rainfall varied from 2000 mm to 3500 mm, bulk of which was received during pre-monsoon and monsoon period i.e. from May to September. The relative humidity varied from 55 to 90 %. The area is warm and humid except with a sort spell of winter from December to March. The average meteorological data of the study site for the year 2018 to 2020 is graphically illustrated in fig.1.

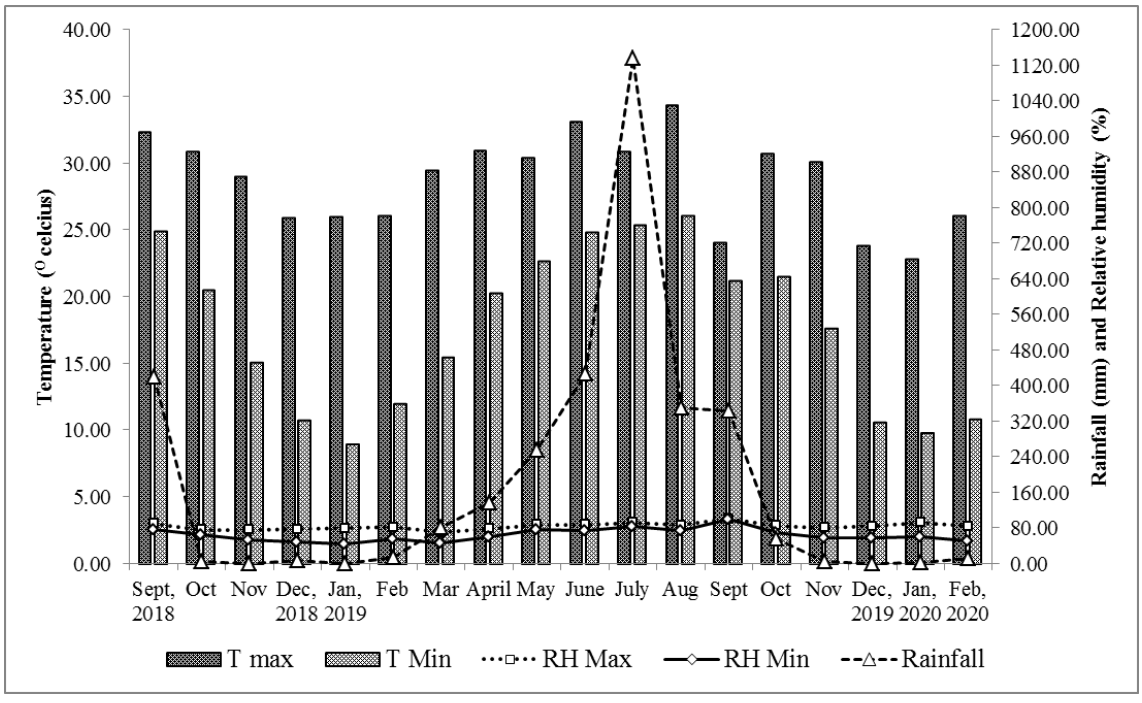

Figure 1. Meteorological data from Sept. 2018 to Feb. 2020

3.3. Sampling and Inventory

All the plantations of *Gmelina* were selected purposively as there were not many to be sampled randomly. In a plantation, 10 % of the *Gmelina* trees with dbh ≥ 10 cm were selected randomly to measure their height and dbh. All the other tree species with dbh ≥ 10 cm in the plantation were also selected to measure their height and dbh. Shrubs and herbs were sampled following stratified random nested method where two 5 m x 5 m quadrates were marked at diagonal corners of the plantation, while for herbs five 1 m x 1 m plots were marked at all corners and one at centre of the plantation. Most of the plant species were identified at the field itself, while which couldn't be identified was preserved by mounting in herbarium sheets following standard procedures for identification. The mounted specimens were cross checked with the available herbarium in the Department of Forestry UBKV Pundibari, West Bengal. Full inventory of the plant species found at the plantations was prepared including trees, shrubs and herbs. Biomass of the plantations was separately estimated for trees, shrubs and herbs. Tree biomass was estimated separately for all the species. Litter samples were collected once during the month of January from ten 1 m x 1 m plots distributed throughout the plantation. Composite soil samples were collected once with the help of Dutch augur separately for 0-20, 20-40 and 40-60 cm soil depth from the litter collected spots to estimate the plantation soil physico-chemical parameters. Prior to estimation, collected soil samples were air dried in shade, grinded with wooden pestle, passed through 2 mm sieve and stored in cloth bags for analysis.

3.4. Quantitative Parameters

For each plantation the numbers of individuals for each species were recorded for their quantitative parameters following standard procedures mentioned below.

3.4.1. Frequency (F)

Frequency is the degree of dispersion of an individual species in a community. It is expressed in per cent and represents the chance of occurrence of species in a given habitat.

$$\text{Frequency (F)} = \frac{\text{No. of quadrats in which a species occurs}}{\text{Total no. of quadrats studied}} \times 100$$

3.4.2. Relative frequency (RF)

RF can be determined by using the following formula by the data obtained by the quadrate methods:

$$\text{Relative frequency (RF)} = \frac{\text{No. of occurrence of a species}}{\text{No. of occurrence of all species}} \times 100$$

3.4.3. Density (D)

This indicates the abundance of a species in a unit area. Density of a species expresses the numerical strength in a community. This parameter gives an idea about the dominance and rarity of a species and is also an indicator of the standing biomass and productivity of the region.

$$\text{Density (D)} = \frac{\text{Total no. of individuals of a species}}{\text{Total no. of quadrats studied}}$$

3.4.4. Relative density (RD)

RD shows the percentage of representation of the species in term of number of individuals in comparison to all other species in a community.

$$\text{Relative density (RD)} = \frac{\text{No. of individuals of the species}}{\text{No. of individuals of all species}} \times 100$$

3.4.5. Abundance (A)

It is the number of individuals of a species occurring in all the sampled area of a particular vegetation type. This parameter fairly gives an idea about the commonality of a species in a habitat under consideration.

$$\text{Abundance (A)} = \frac{\text{Total no. of individuals of the species occurs}}{\text{No. of quadrats in which a species occurs}}$$

3.4.6. Relative abundance (RA)

RA is the ratio of the species to number of quadrate studied for given vegetation type.

$$\text{Relative abundance (RA)} = \frac{\text{Abundance of a species}}{\text{Sum of the abundance of all species}} \times 100$$

3.4.7. Importance value index (IVI)

This is a statistical quantity which gives an overall picture of a species and indicates their importance in the plant community. IVI is sum of RF, RD and RA as suggested by Curtis (1959), Phillips (1959), Mishra (1968), Kershaw (1973) and Cintron

and Novelli (1984). It helps in understanding the sociological structure of a species in a community.

IVI = RF + RD + RA

3.4.8. Height and diameter

The height of the selected trees was measured with help of a Ravi's Multimeter, while their diameter at breast height was measured with a tree calliper.

3.5. Diversity Indices

Various diversity indices were studied to understand the diversity of communities in space and time. These serve as important surrogates for measuring biodiversity. Out of numerous indices formulated by different workers for diversity study, the commonly used diversity indices were adopted.

3.5.1. Species richness (S)

Species richness is the expression of diversity and was described by the number of species in a quadrate or habitat.

3.5.2. Species diversity index (D′)

Menhinick's index (1964) is based on the total number of species and the total number of individuals of all species (N). D′: = S/ √N. This index unlike Shannon-Wieners index gives more weightage to the rare species.

3.5.3. Concentration of dominance (C)

This was calculated to evaluate the level of dominance of a species within a community (Simpson, 1949). Simpson's index was used to measure the concentration of dominance. This relates to the number of chance of a particular species that could be encountered during sampling. Its maximum value ranges between 0-1. This value is inversely proportional to Shannon and Wiener index i.e. a higher value is indicative of less diverse community.

$C = \sum (n_i/N)^2$ (where n_i = number of individuals of a species)

3.5.4. Shannon-Wiener diversity index (H′)

This index (Shannon and Weaver, 1949; Shannon and Wiener, 1963) was used to determine the species diversity. This is the expression of community structure and that indicates the complexity of a habitat. It is also used to describe the landscape diversity by many landscape ecologists. A high index value is suggestive of more diverse community.

$H' = \sum n_i/N \times \ln n_i/N$

3.5.5. Species evennessindex (EI)

This was calculated as EI = H′/ ln N (Pielou, 1966).

3.6. Biomass and Carbon Stock Estimation

Indirect or non-destructive method was adopted for above ground biomass estimation of the trees using a recent allometric model developed for different forest types of north east India (Nath *et al*., 2019).

$AGB = 0.18D^{2.16} \times 1.32$; where D is diameter at breast height.

Below ground biomass (BGB) was estimated as 15 % of the AGB (MacDicken, 1997; Subba *et al*., 2017; 2018; Shukla and Chakravarty, 2018; Shukla *et al*., 2018; Pala *et al*., 2020). Total tree biomass was summation of AGB and BGB which was estimated for each individual tree in the sampled area and then summed up. The total of herb, shrub and total tree biomass was converted into carbon by multiplying with a factor of 0.50 (Woomer, 1999; Subba *et al*., 2017, 2018; Shukla and Chakravarty, 2018; Shukla *et al*., 2018; Pala *et al*., 2020).

3.7. Soil Physico-chemical Characteristics

Estimation methods followed for soil physico-chemical parameters are givenin table 3.

Table 3. Soil physico-chemical parameters with their estimation method

	Parameter	Method
1	Bulk density	Core sampler method (Piper, 1950)
2	Moisture	Volumetric method (Piper, 1966)
3	EC	Soil water suspension (Jackson, 1967)
4	pH (1:2 soil: water suspension)	Beckman's pH meter (Jackson,1967)
5	Organic C %	Walkley and Black's rapid titration method (Jackson,1967)
6	Available N kg ha^{-1}	Modified Kjeldahl method (Jackson, 1967)
7	Available P_2O_5 kg ha^{-1}	Bray's method– Bray and Kurtz, 1945 (Jackson, 1967)
8	Available K_2O kg ha^{-1}	Flame Photometer method (Jackson, 1967)

Soil organic carbon stock was estimated by multiplying the organic carbon with weight of the soil (bulk density and depth) for a particular depth and expressed as mega grams per ha^{-1} ($Mgha^{-1}$) as given by Joao Carlos *et al*. (2001).

3.8. Statistical Analysis

The data were analysed using software package Gen Stat Eleventh Edition (VSN International, Oxford, UK). One way analysis and Duncan multiple range test (DMRT) test was also employed

Chapter 4

RESULTS AND DISCUSSIONS

The result of the present study entitled, "**Floristic Diversity and Carbon Storage of *Gmelina arborea* (Roxb.) Plantation in Agricultural Landscape of Terai Zone of West Bengal**" is presented below:

4.1. Phytodiversity Analysis

4.1.1. Diversity indices and species composition

Diversity indicesof *Gmelina* farm forestry plantation is given in table 4, 5 and 6. The overall richness of plant assemblages in the studied *Gmelina* farm forestry plantation was 51 species including *Gmelina* (table 4), of which four species remained unidentified. Identified species were represented by 51 genera and 33 families (table 6). The number of species in the plantations representing the tree, shrub, herb, climber, and fern were 23, 7, 16, 2, and 3, respectively.

Table 4. Diversity Indices of *Gmelina* farm forestry plantations

Parameters	**Overall**	**Age Classes (Year)**		
		≤5	**5-10**	**10-15**
Species richness	51	35	37	43
Genera richness	51	35	35	42
Family richness	33	25	25	30
Species diversity index	1.18	0.54	0.62	0.59
Concentration of dominance	0.03	0.04	0.05	0.04
Shannon-Wiener index	1.29	1.54	1.59	2.00
Evenness index	8.69	3.35	3.92	3.65

Table 5. Plant life form in *Gmelina* farm forestry plantations

Life form	**≤ 5 year**			**5-10 year**			**10-15 year**		
	SR	**FR**	**GR**	**SR**	**FR**	**GR**	**SR**	**FR**	**GR**
Tree	11	9	11	11	9	11	18	17	18
Herb	13	9	11	10	8	10	13	11	13
Shrub	7	2	3	7	2	3	7	2	3
Climber	1	1	1	1	1	1	2	2	2
Fern	3	3	3	3	3	3	3	3	3

SR- species richness; FR- family richness; GR- genera richness

Table 6. Plant species in *Gmelina* farm forestry plantations

F/SN/VN	LF	Age Class		
		≤ 5	5-10	10-15
Amaranthaceae				
Alternanthera bettzickiana; *Jal-sachiba*	H	+	+	+
Apocynaceae				
Tabernaemontana divaricata; *Tagor*	S	+	+	+
Araceae				
Colocasia esculenta; *Kachu*/*Taro*	H	+	+	+
Asteraceae				
Ageratum conyzoides; *Uchunti*	H	+	+	+
Ageratum houstonianum; *Gandho Jhaar*	H	+	+	+
Mikania micrantha; *Taralata*	C	+	+	+
Athyriaceae				
Diplazium esculentum; *Dhekia*	F	+	+	+
Bombacaceae				
Bombax ceiba; *Semul*	T	+	+	+
Boraginaceae				
Ehretia acuminata; Koda gaach	T	-	-	+
Cannabaceae				
Trema orientalis; *Jiban*	T	-	-	+
Elaeocarpaceae				
Elaeocarpus floribundus; *Jalpai*	T	+	-	+
Euphorbiaceae				
Macaranga pustulata; *Nonawti*	T	-	-	+
Fabaceae				
Dalbergia sissoo; Sissoo	T	+	-	-
Erythrina crista-galli; Coral tree	T	-	-	+
Laminaceae				
Lucas aspera; *Kan sisa*	H	+	+	+
Lauraceae				
Litsea monopetala; *Meda*	T	-	-	+
Lythraceae				
Lagerstroemia speciosa; *Jarul*	T	-	+	-

Malvaceae				
Abroma augusta; *Ulat Kambal*	S	+	+	+
Urena lobata; *Benochoura*	S	+	+	+
Meliaceae				
Melia azedarach; *Ghora neem*	T	+	+	+
Chukrasia tabularis; *Chukrasia*	T	+	+	+
Swietenia macrophylla; Mahagony	T	+	-	-
Mimosaceae				
Albizia lebbeck; *Kala siris*	T	+	-	-
Acacia auriculiformis; *Akashmoni*	T	-	+	-
Moraceae				
Moringa oleifera; *Sajana*	T	+	-	-
Ficus glomerata; *Udumbara*	T	-	-	+
Myrtaceae				
Syzygium cumini; *Kaala jam*	T	-	+	+
Onocleaceae				
Matteuccia struthiopteris; Ostrich fern	F	+	+	+
Oxalidaceae				
Oxalis corniculata; *Amrulshak*	H	+	+	+
Poaceae				
Cynodon dactylon; *Dubra/Dhoob*	H	+	+	+
Paspalum distichum; *Gitla gash*	H	+	+	+
Echinochloa muricata; *Burashama*	H	+	+	-
Poa annua; Poa	H	+	+	+
Polygonaceae				
Polygonum hydropiper; *Diskutli*	H	+	+	+
Primulaceae				
Maesa indica; *Ramjani*	S	+	+	+
Rosaceae				
Fragaria vesca; *Jangali strawberry*	H	+	+	+
Rubiaceae				
Anthocephalus cadamba; *Kadam*	T	+	+	+
Rutaceae				

Murraya koenigii; *Curry patta*	T	-	+	-
Simaroubaceae				
Ailanthus grandis; *Gokul*	T	+	+	+
Solanaceae				
Solanum viarum; *Kantakari*	S	+	+	+
Sterculiaceae				
Sterculia villosa; *Seto odal*	T	-	-	+
Thelypteridaceae				
Phegopteris hexagonoptera; Beech fern	F	+	+	+
Uritaceae				
Pouzolzia zeylanica; *Kullaruki*	H	+	+	+
Verbenaceae				
Gmelina arborea; *Gmelinai*	T	+	+	+
Tectona grandis; *Segun*	T	-	+	+
Lantana camara; *Banmara, Chotra*	S	+	+	+
Clerodendron infortunatum; *Ghentu*	S	+	+	+
UN-1	C	-	-	+
UN-2	H	-	-	+
UN-3	H	-	-	+
UN-4	H	-	-	+

F- family; SN- scientific name; VN- vernacular name; LF- life form; UN- unidentified

Amongst the plant species found associated with *Gmelina* plantation, herbs dominated followed by trees, ferns and least by climbers in terms of their species richness. Highest age class (10-15 years) was associated with 15 tree species other than *Gmelina*, 15 herb species, seven shrub species, three fern species and two climber species, whereas in the lower two age classes (≤ 5 and 5-10 years) the species richness of the different life forms were equal (table 5). Similar studies on associated plant species diversity in agricultural landscape tree plantations were earlier reported with either shrubs or herbs dominating (Nicholson and Monk, 1974; Harmer *et al*., 2001; Martin *et al*., 2004; Flinn and Vellend, 2005; Manhas *et al*., 2011; Udayana *et al*., 2019). Dominance of one stratum generally suppresses the diversity of another (Whittaker, 1972).

The overall values estimated for species diversity or Menhinick's index, concentration of dominance, Shannon and Wiener index and evenness (table 4) of the studied *Gmelina* farm forestry plantations are 1.18, 0.03, 1.29 and 8.69, respectively.

These indices in the age class I (≤ 5 years)**,** II (5-10 years) and III (10-15 years) estimated was 0.54, 0.62 & 0.59; 0.04, 0.05 & 0.04; 1.54, 1.59 & 2.0 and 3.35, 3.92 & 3.65, respectively. Overall the plant assemblages in the plantations were more diverse, evenly distributed, heterogeneous and stable than the plantations of different age classes studied. The species diversity index was calculated based on total number of species and total number of individuals of all the species in the plantations and as per this index *Gmelina* plantation having age of 5-10 years were more diverse than the 10-15 year or ≤ 5 years old plantations in the study area. The concentration of dominance in the all the age classes estimates was very less but was similar indicating similar chances of encountering a species during sampling in the plantations. Lower the value, higher was the chance of encountering a species during sampling. Shannon and Wiener index that determine diversity was found inversely proportional to concentration of dominance and the corresponding value estimated was highest (2.00 vs 0.04) in 10-15 year old *Gmelina* plantation followed by 5-10 year old plantation (1.59 vs 0.05) and lowest (1.54 vs 0.04) in ≤ 5 years old plantation. This index reflects community structure and heterogeneity of the plant assemblage in an ecosystem i.e. higher the index value, more diverse and stable the community is. The index values estimated for the plantations of different age group indicate that with increasing age the plantations became more diverse i.e. heterogeneous and more stable. The evenness of different age group plantations estimated was 3.92 for 5-10 year old plantation, 3.65 for 10-15 year old plantation and 3.35 for ≤ 5 years year old plantation which indicate that the species were more or less evenly distributed in the plantations. Inverse relationship between concentration of dominance and Shannon and Wiener index by the species in the plant assemblages of different age class *Gmelina* plantations was also earlier reported for both forest ecosystem and plantations as well (Dash *et al*. 2009; Shukla *et al*., 2014$_{a, c}$; Shukla *et al*., 2019).

This is a considerably a higher diversity of associated plant community developed in the *Gmelina* farm forestry plantations as there were no disturbances. The plantations were not managed silviculturally by the owners after planting as they were kept aside as such. Similar increase in plant diversity was also reported from farm forestry plantations or other non-forested landscapes when not managed or kept aside (Pande *et al*., 1988; Manhas *et al*., 2011). The diversity of the associated species in the *Gmelina* plantations increased with the increasing plantation age reflecting compatibility of the associated species with *Gmelina* which is in contrast to the studies reported for teak plantation due to its allelopathic effect (Brown *et al*., 2003; Manimegalai, 2012; Shukla and

Chakravarty, 2012_a; Biswas and Das, 2016; Rai, 2017; Udayana *et al*., 2019). Moreover, due to canopy gaps in the plantation allowed enough sunlight favourable for understorey growth for early successional species (Whitmore, 1991). The undisturbed *Gmelina* farm forestry plantations in terai zone of West plantations aided rehabilitation of fallow crop land in an agricultural landscape allowing homeostatic capability of the system (Odum, 1971).

The studied *Gmelina* undisturbed farm forestry plantations with increasing age promoted succession along with resetting of many ecosystem processes like improving microclimate, soil fertility through litter input, microbial diversity and activity, biomass production and sequestration capacity (Krishnaswamy and Puri, 1954; Mathur and Soni, 1983; Rajvanshi *et al*., 1983; George *et al*., 1993; Lugo, 1997; Webb and Shah, 2003; Manhas *et al*., 2011). Studies had confirmed succession in sole tree species plantation resetting the disrupted processes associated with diversity (Guevara *et al*., 1986; Parrotta, 1995; Guariguata and Ostertag, 2001; Ingle, 2003; Ludwig *et al*., 2004; Lamb *et al*., 2005; Muscarella and Flaming, 2007; Wang *etal*., 2008; Babweteera and Brown, 2010; Campos-Arceiz and Blake, 2011). Species richness listed in the plant assemblages of the *Gmelina* farm forestry plantations was comparable with an earlier study involving plantations of *Tectona grandis*, *Shorea robusta*, *Michelia Champaca* and *Lagerstroemia speciosa* but lesser than miscellaneous species stands in Chilapatta Reserve forest not more than 10 kms from the present study sites (Rai, 2017).

Generally tree plantations outside forest were recolonized with forest species of regional species pool (Martin *et al*., 2004; Flinn and Vellend, 2005) promoting rehabilitation because of improved site quality factors suitable for growth of native species (Jones and Richards, 1977; Binkley and Valentine, 1991; Parrotta, 1992, 1995; Harrington and Ewel, 1997; Hartley, 2002; Manhas *et al*., 2011). It was advocated in all these above quoted earlier studies that on absence of disturbance, structural homogeneity of the plantation with succession gradually convert into heterogeneous multi-layered secondary forests with more heliophytes and sciophytes as understorey. In the present study, overall 50 plant species including trees, shrubs, herbs, climbers and fern was documented from the *Gmelina* farm forestry plantations and if continued to grow undisturbed till their natural rotation more heterogeneous secondary forest can be expected in this agricultural landscape. Rehabilitation of landscapes is a time taking process which needs atleast as long as 100 years to reset back like the earlier native forest (Harmer *et al*., 2001; Flinn and Vellend, 2005; Brunet, 2007) but not exactly the same in

terms of its species richness and structure (Saldarriaga *et al*., 1988; Denslow and Guzman, 2000; Guariguata and Ostertag, 2001; Manhas *et al*., 2011; Santoso, 2012; Udayana *et al*., 2019). This study with support from other earlier studies are evidences to support policy decisions to restore degraded agricultural landscapes particularly not suitable for annual cropping with tree plantations of *Gmelina* or other timber species for biodiversity, ecosystem functions, sustainable forestry and ecosystem services (Lugo, 1997; Parrotta *et al*., 1997; Powers *et al*., 1997; Ashton *et al*., 2001; Guariguata and Ostertag, 2001; Carnevale and Montagnini,2002; Martin *et al*., 2004; Flinn and Vellend, 2005; Hooper *et al*., 2005; Lamb *et al*., 2005; Ruiz-Jaén and Aide, 2005; Chapin *et al*., 2006; Aerts and Honnay, 2011; Manhas *et al*., 2011; Stanturf *et al*., 2014; Lamb, 2018; Udayana *et al*., 2019).

4.1.2. Vegetation analysis

Frequency and relative frequency of the studied *Gmelina* farm forestry plantations is presented in table 7. The overall frequency and relative frequency of the associated species plantations was in the range of 5.0-100.0 % and 0.25- 4.95, whereas *Gmelina* was estimated with 100 % and 4.95, respectively. The overall frequency of trees (other than *Gmelina*), shrubs, herbs, climbers and ferns respectively was in the range of 5.0-80.0 %, 5.0-95.0 %, 30.0-100.0 %, 5.0-75.0 % and 45.0-85.0 %. In central and eastern Himalayan forests, frequency of tree layer was reported with range of 10-100 %, shrub layer 10-80 %, herbaceous layer 10-100 % (Negi and Nautiyal, 2005; Shukla and Chakravarty, 2012_a, 2014; Shukla *et al*., 2016, 2017, 2019). Similar frequency range was also observed for the species in the present study. The species documented in the study sites were native species of the region and were mostly used by the local people for food, medicine and fodder (Shukla and Chakravarty, $2012_{a, b}$).

Frequency or the degree of distribution of the species indicates the chance of occurrence of a species while sampling. *Acacia auriculiformis*, *Albizia lebbeck* and 15 other species had lowest representation in the sampled plots, while *Ageratum houstonianum* had highest representation. Correspondingly these species were also observed with lowest and highest relative representation, respectively while sampling. Generally, the representation of species and their relative representation during sampling increased initially i.e. from AC I to AC II but then decreased from AC II to AC III.

Table 7. Frequency and relative frequency of *Gmelina* farm forestry plantations

Species	F				RF			
	Oa	Age class (years)			Oa	Age class (years)		
		≤ 5	5-10	10-15		≤ 5	5-10	10-15
A. houstonianum	100.0	100.0	100.0	100.0	4.95	4.86	5.07	4.92
A. augusta	35.0	42.86	28.57	33.33	1.73	2.08	1.45	1.64
A. auriculiformis	5.0	14.29	14.29	-	0.25	0.69	0.72	-
A. bettzickiana	35.0	42.86	42.86	16.67	1.73	2.08	2.17	0.82
A. cadamba	20.0	14.29	28.57	16.67	0.99	0.69	1.45	0.82
A. conyzoides	95.0	100.0	100.0	83.33	4.70	4.86	5.07	4.10
A. grandis	30.0	42.86	14.29	33.33	1.49	2.08	0.72	1.64
A. lebbeck	5.0	14.29	-	-	0.25	0.69	-	-
B. ceiba	80.0	100.0	57.14	83.33	3.96	4.86	2.90	4.10
C. dactylon	80.0	71.43	85.71	83.33	3.96	3.47	4.35	4.10
C. esculenta	85.0	85.71	85.71	83.33	4.21	4.17	4.35	4.10
C. infortunatum	95.0	85.71	100.0	100.0	4.70	4.17	5.07	4.92
C. velutina	35.0	42.86	42.86	16.67	1.73	2.08	2.17	0.82
D. esculentum	85.0	71.43	85.71	100.0	4.21	3.47	4.35	4.92
D. sissoo	5.0	14.29	-		0.25	0.69	-	
E. muricata	30.0	42.86	42.86	-	1.49	2.08	2.17	-
E. acuminata	5.0	-	-	16.67	0.25	-	-	0.82
E. crista-galli	15.0	-	-	50.0	0.74	-	-	2.46
E. floribundus	10.0	14.29	-	16.67	0.50	0.69	-	0.82
F. glomerata	5.0	-	-	16.67	0.25	-	-	0.82
F. vesca	80.0	71.43	100.0	66.67	3.96	3.47	5.07	3.28
G. arborea	**100.0**	**100.0**	**100.0**	**100.0**	**4.95**	**4.86**	**5.07**	**4.92**
L. aspera	85.0	85.71	85.71	83.33	4.21	4.17	4.35	4.10
L. camara	90.0	71.43	100.0	100.0	4.46	3.47	5.07	4.92
L. monopetala	5.0	-	-	16.67	0.25	-	-	0.82
L. speciosa	5.0	-	14.29	-	0.25	-	0.72	-
M. struthiopteris	70.0	71.43	71.43	66.67	3.47	3.47	3.62	3.28
M. azedarach	30.0	57.14	14.29	16.67	1.49	2.78	0.72	0.82
M. indica	45.0	42.86	71.43	16.67	2.23	2.08	3.62	0.82
M. koenigii	5.0	-	14.29	-	0.25	-	0.72	-

M. micrantha	75.0	71.43	71.43	83.33	3.71	3.47	3.62	4.10
M. oleifera	5.0	-	-	-	0.25	-	-	-
M. pustulata	5.0	-	-	16.67	0.25	-	-	0.82
O. corniculata	60.0	71.43	57.14	50.0	2.97	3.47	2.90	2.46
P. annua	30.0	28.57	28.57	33.33	1.49	1.39	1.45	1.64
P. distichum	60.0	71.43	57.14	50.0	2.97	3.47	2.90	2.46
P. hexagonoptera	45.0	57.14	42.86	33.33	2.23	2.78	2.17	1.64
P. hydropiper	50.0	71.43	28.57	50.0	2.48	3.47	1.45	2.46
P. zeylanica	75.0	71.43	71.43	83.33	3.71	3.47	3.62	4.10
S. villosa	55.0	-	14.29	16.67	2.72	-	0.72	0.82
S. cumini	20.0	-	28.57	33.33	0.99	-	1.45	1.64
S. macrophylla	5.0	14.29	-	-	0.25	0.69	-	-
S. viarum	30.0	42.86	-	33.33	1.49	2.08	-	1.64
T.divaricata	80.0	85.71	85.71	66.67	3.96	4.17	4.35	3.28
T. grandis	25.0	-	42.86	33.33	1.24	-	2.17	1.64
T. orientalis	5.0	-	-	16.67	0.25	-	-	0.82
U. lobata	5.0	71.43	42.86	50.0	0.25	3.47	2.17	2.46
UN-1	5.0	-	-	16.67	0.25	-	-	0.82
UN-2	5.0	-	-	16.67	0.25	-	-	0.82
UN-3	5.0	-	-	16.67	0.25	-	-	0.82
UN-4	5.0	-	-	16.67	0.25	-	-	0.82

F- frequency; RF- relative frequency; Oa- overall; UN- unidentified

The range of representation of associated species with their relative representation during sampling in the AC I, II and III was 14.29-100 % & 0.69-4.86; 14.29-100 % & 0.72-5.07 and 14.29-100 % & 0.82-4.92, respectively. In all the age classes *Ageratum houstonianum*, a herb was the most represented associated species during sampling in the *Gmelina* farm forestry plantations.

Higher chance of occurrence of the associated plant species in *Gmelina* farm forestry plantations also generally increased the numerical strength and abundance of the species which resulted to easier establishment of these species in the plantations. These species were initial colonisers as they adapted well as understorey strata in the *Gmelina* farm forestry plantations. Density and relative density of the listed species in the plantations is given in table 8.

Table 8. Density and relative density of *Gmelina* farm forestry plantations

Species	D				RD			
	Oa	Age class (years)			Oa	Age class (years)		
		≤ 5	5-10	10-15		≤ 5	5-10	10-15
A. houstonianum	5.2	4.71	4.71	6.33	3.96	3.59	3.62	4.76
A. augusta	0.95	1.29	0.71	0.83	0.72	0.98	0.55	0.63
A. auriculiformis	0.05	-	0.14	-	0.04	-	0.11	-
A. bettzickiana	1.3	1.71	1.57	0.5	0.99	1.31	1.21	0.38
A. cadamba	0.40	0.43	0.43	0.33	0.30	0.33	0.33	0.25
A. conyzoides	4.3	4.0	4.57	4.33	3.27	3.05	3.51	3.26
A. grandis	1.10	1.86	0.71	0.67	0.84	1.42	0.55	0.50
A. lebbeck	0.05	0.14	-	-	0.04	0.11	-	-
B. ceiba	2.00	1.86	1.57	2.67	1.52	1.42	1.21	2.01
C. dactylon	4.65	4.14	5.43	4.33	3.54	3.16	4.17	3.26
C. esculenta	2.4	2.71	2.43	2.0	1.83	2.07	1.87	1.5
C. infortunatum	7.65	6.14	7.57	9.50	5.82	4.68	5.82	7.14
C. velutina	1.10	1.29	1.43	0.5	0.84	0.98	1.1	0.38
D. esculentum	4.0	3.0	3.71	5.5	3.05	2.29	2.85	4.14
D. sissoo	0.05	0.14	-	-	0.04	0.11	-	-
E. muricata	1.30	1.43	2.29	-	0.99	1.09	1.76	-
E. acuminata	0.20	-	-	0.67	0.15	-	-	0.50
E. crista-galli	0.30	-	-	1.0	0.23	-	-	0.75
E. floribundus	0.20	0.29	0.33	-	0.15	0.22	-	0.25
F. glomerata	0.30	-	-	1.0	0.23	-	-	0.75
F. vesca	3.25	2.86	4.57	2.17	2.47	2.18	3.51	1.63
G. arborea	**55.8**	**58.43**	**54.86**	**54.0**	**42.5**	**44.5**	**42.1**	**40.60**
L. aspera	3.00	2.86	3.43	2.67	2.28	2.18	2.63	2.01
L. camara	4.15	2.86	5.14	4.50	3.16	2.18	3.95	3.38
L. monopetala	0.40	-	-	1.33	0.30	-	-	1.0
L. speciosa	0.05	-	0.14	-	0.04	-	0.11	-
M. struthiopteris	2.00	2.14	2.0	1.83	1.52	1.63	1.54	1.38
M. azedarach	0.85	1.29	0.71	0.5	0.65	0.98	0.55	0.38
M. indica	1.15	1.0	1.86	0.5	0.88	0.76	1.43	0.38
M. koenigii	0.30	-	0.86	-	0.23	-	0.66	-

M. micrantha	2.7	2.0	2.0	4.33	2.06	1.53	1.54	3.26
M. oleifera	0.05	0.14	-	-	0.04	0.11	-	-
M. pustulata	0.25	-	-	0.83	0.19	-	-	0.63
O. corniculata	2.10	2.71	2.0	1.5	1.60	2.07	1.54	1.13
P. annua	1.40	1.29	1.14	1.83	1.07	0.98	0.88	1.38
P. distichum	2.35	3.14	2.0	1.83	1.79	2.4	1.54	1.38
P. hexagonoptera	1.75	2.57	1.57	1.0	1.33	1.96	1.21	0.75
P. hydropiper	1.85	3.29	1.0	1.17	1.41	2.51	0.77	0.88
P. zeylanica	2.6	2.57	2.57	2.67	1.98	1.96	1.98	2.01
S. villosa	1.85	-	-	0.67	1.41	-	-	0.50
S. cumini	0.45	-	1.0	0.33	0.34	-	0.77	0.25
S. macrophylla	0.10	0.29	-	-	0.08	0.22	-	-
S. viarum	0.70	1.29	0.14	0.67	0.53	0.98	0.11	0.50
T.divaricata	2.75	3.0	3.0	2.17	2.09	2.29	2.31	1.63
T. grandis	0.70	-	1.43	0.67	0.53	-	1.10	0.50
T. orientalis	0.35	-	-	1.17	0.27	-	-	0.88
U. lobata	0.20	2.29	1.43	1.83	0.15	1.74	1.1	1.38
UN-1	0.10	-	-	0.83	0.08	-	-	0.63
UN-2	0.25	-	-	0.67	0.19	-	-	0.50
UN-3	0.20	-	-	0.50	0.15	-	-	0.38
UN-4	0.15	-	-	0.33	0.11	-	-	0.25

D- density; RD- relative density; Oa- overall; UN- unidentified

The overall density and relative density of the associated species in the plantation was 0.05-7.65 and 0.04-5.82, respectively, while the corresponding values estimated for *Gmelina* was 55.8 and 42.5, respectively. *Dalbergia sissoo*, *Lagerstroemia speciosa*, *Albizia lebbeck*, *Acacia auriculiformis* and *Moringa oleifera* (all trees) was estimated with lowest density, while *Clerodendron infortunatum*, a shrub with highest density in the plantations amongst the associated species. Correspondingly, these species also were overall relatively lowest and highest density. Among the life forms overall range of density for trees (other than *Gmelina*) was 0.05-2.0 (*Bombaxceiba* highest) shrubs was 0.20-7.65 (*Urena lobata-C. infortunatum*), herbs 1.30-5.20 (*Alternanthera bettzickiana-Ageratum houstonianum*), ferns 1.75-4.0 (*Phegopteris hexagonoptera-Diplazium esculentum* and climbers 0.1-2.70 (UN 1-*Mikania micrantha*). The species which were found with overall lowest and highest density and relative density were also estimated

with highest and lowest density and relative density at all the three age classes. The range of density and relative density estimated in the plantations of AC I-III was 0.14-6.14 & 0.11-4.68; 0.14-7.57 & 0.11-5.82 and 0.33-9.5 & 0.25-7.14, respectively, while for *Gmelina* the values estimated were 58.43 & 44.5, 54.86 & 42.1 and 54.0 & 40.6, respectively. Species density varies with forest community type, forest age class, tree species, size class, site history, site quality factors and disturbance (Kumar *et al*., 2006).

The abundance and relative abundance of species in the studied plantations is given in table 9.

Table 9. Abundance and relative abundance of *Gmelina* farm forestry plantations

Species	**A**				**RA**			
	Oa	**Age class (years)**			**Oa**	**Age class (years)**		
		≤ 5	**5-10**	**10-15**		**≤ 5**	**5-10**	**10-15**
A. houstonianum	5.2	4.71	4.71	6.33	2.21	2.71	2.61	2.97
A. augusta	2.71	3.0	2.5	2.5	1.15	1.73	1.38	1.17
A. auriculiformis	1.0	-	1.0	-	0.42	-	0.55	-
A. bettzickiana	3.71	4.0	3.67	3.0	1.58	2.3	2.03	1.41
A. cadamba	2.0	3.0	1.5	2.0	0.85	1.73	0.83	0.94
A. conyzoides	4.53	4.0	4.57	5.2	1.92	2.3	2.53	2.44
A. grandis	3.67	4.33	5.0	2.0	1.56	2.49	2.77	0.94
A. lebbeck	1.0	1.0	-	-	0.42	0.58	-	-
B. ceiba	2.5	1.86	2.75	3.2	1.06	1.07	1.52	1.5
C. dactylon	5.81	5.8	6.33	5.2	2.47	3.34	3.51	2.44
C. esculenta	2.82	3.17	2.83	2.4	1.2	1.82	1.57	1.12
C. infortunatum	8.05	7.17	7.57	9.5	3.42	4.12	4.19	4.45
C. velutina	3.14	3.0	3.33	3.0	1.34	1.73	1.85	1.41
D. esculentum	4.71	4.2	4.33	5.5	2.0	2.42	2.4	2.58
D. sissoo	1.0	1.0	-	-	0.42	0.58		
E. muricata	4.33	3.33	5.33	-	1.84	1.92	2.95	
E. acuminata	4.0	-	-	4.0	1.7	-	-	1.87
E. crista-galli	2.0	-	-	2.0	0.85	-	-	0.94
E. floribundus	2.0	2.0	-	2.0	0.85	1.15	-	0.94
F. glomerata	6.0	-	-	6.0	2.55	-	-	2.81
F. vesca	4.06	4.0	4.57	3.25	1.73	2.3	2.53	1.52
G. arborea	**55.8**	**58.4**	**54.9**	**54.0**	**23.7**	**33.6**	**30.4**	**25.31**

L. aspera	3.53	3.33	4.0	3.2	1.5	1.92	2.21	1.5
L. camara	4.61	4.0	5.14	4.5	1.96	2.3	2.85	2.11
L. monopetala	8.0	-	-	8.0	3.4	-		3.75
L. speciosa	1.0	-	1.0	-	0.42	-	0.55	
M. struthiopteris	2.86	3.0	2.8	2.75	1.21	1.73	1.55	1.29
M. azedarach	2.83	2.25	5.0	3.0	1.2	1.29	2.77	1.41
M. indica	2.56	2.33	2.6	3.0	1.09	1.34	1.44	1.41
M. koenigii	6.0	-	6.0	-	2.55	-	3.32	-
M. micrantha	3.6	2.80	2.8	5.2	1.53	1.61	1.55	2.44
M. oleifera	1.0	1.0	-	-	0.42	0.58	-	-
M. pustulata	5.0	-	-	5.0	2.12	-	-	2.34
O. corniculata	3.5	3.8	3.5	3.0	1.49	2.19	1.94	1.41
P. annua	4.67	4.50	4.0	5.5	1.98	2.59	2.21	2.58
P. distichum	3.92	4.4	3.5	3.67	1.66	2.53	1.94	1.72
P. hexagonoptera	3.89	4.5	3.67	3.0	1.65	2.59	2.03	1.41
P. hydropiper	3.7	4.0	3.5	2.33	1.57	2.65	1.94	1.09
P. zeylanica	3.47	3.6	3.6	3.2	1.47	2.07	1.99	1.5
S. villosa	3.36	-	-	4.0	1.43	-	-	1.87
S. cumini	2.25	-	3.5	1.0	0.96	-	1.94	0.47
S. macrophylla	2.0	2.0	-	-	0.85	1.15	-	-
S. viarum	2.33	3.0	1.0	2.0	0.99	1.73	0.55	0.94
T.divaricata	3.44	3.5	3.5	3.25	1.46	2.01	1.94	1.52
T. grandis	2.80	-	3.33	2.0	1.19	-	1.85	0.94
T. orientalis	7.0	-	-	7.0	2.97	-	-	3.28
U. lobata	4.0	3.20	3.33	3.67	1.7	1.84	1.85	1.72
UN-1	2.0	-	-	5.0	0.85	-	-	2.34
UN-2	5.0	-	-	4.0	2.12	-	-	1.87
UN-3	4.0	-	-	3.0	1.7	-	-	1.41
UN-4	3.0	-	-	2.0	1.27	-	-	0.94

A- abundance; RA- relative abundance; Oa- overall; UN- unidentified

The overall range of abundance and relative abundance of the associated species in the *Gmelina* plantations estimated was 1.0-8.05 % and 0.42-3.42, respectively; while for *Gmelina* the estimated values were 55.8 % and 23.7, respectively. *Acacia auriculiformis, Albizia lebbeck, Dalbergia sissoo, Lagerstroemia speciosa,* and *Moringa*

oleifera were least abundant, while *Clerodendron infortunatum*, a shrub was most abundant associated species in the plantations. Among the associated tree species *Litsea monopetala* was the most overall abundant species (8.0 %). Among the shrubs, *Solanum viarum* was least abundant (2.33 %) in the plantations. The overall range of herbs, ferns and climbers was 2.82-5.81 % (*Colocasia esculenta-Cynodon dactylon*); 2.86-4.71 % (*Matteuccia struthiopteris-Diplazium esculentum*) and 2.0-3.6 % (UN 1-*Mikania micrantha*). The overall range of relative abundance estimated for associated trees, shrubs, herbs, ferns and climbers in the plantations was 0.42-3.4, 1.09-3.42, 1.2-2.47, 1.21-2.0 and 0.85-1.53, respectively. The associated species estimated with overall lowest and highest abundance and relative abundance in the plantations was also estimated with lowest and highest abundance and relative abundance in the different age class plantations. The range of abundance and relative abundance in ≤ 5, 5-10 and 10-15 years *Gmelina* farm forestry plantations estimated was 1.0-7.17 % & 0.58-4.12, 1.0-7.57 % & 0.55-4.19 and 1.0-9.5 % & 0.94-4.45, while values estimated for *Gmelina* was 58.4 % & 33.6; 54.9 % & 30.4 and 54.0 % and 25.31, respectively.

Overall IVI estimated for *Gmelina* in the plantations was 71.2 and in age class series I-III was 83.03, 77.59 and 70.83, respectively; while for the associated plant species the overall IVI was in the range of 0.71-13.95 and in age class series I-III was 1.38-12.97, 1.39-15.08 and 20.1-16.51, respectively; indicating importance of a particular species in the plantation (table 10). The most important of all the species associated with *Gmelina* plantations was *Clerodendron infortunatum*, a shrub and the least was *Acacia auriculiformis, Albizia lebbeck, Dalbergia sissoo, Lagerstroemia speciosa* and *Moringa oleifera*. The other important associated species in the plantations were *Clerodendron infortunatum* (shrub-13.95), *Ageratum houstonianum* (herb- 11.12), *Cynodon dactylon* (herb- 9.97), *Ageratum conyzoides* (herb- 9.90), *Lantana camara* (shrub- 9.57), *Diplazium esculentum* (fern- 9.25), *Fragaria vesca* (herb- 8.16), *Lucasaspera* (herb- 7.99), *Tabernaemontana divaricata* (shrub- 7.51), *Mikania micrantha* (climber- 7.30), *Colocasia esculenta* (herb- 7.23), *Pouzolzia zeylanica* (herb- 7.16), *Bombax ceiba* (tree- 6.55), *Paspalum distichum* (herb- 6.42), *Matteuccia struthiopteris* (fern- 6.20) and *Oxalis corniculata* (herb- 6.06). Based on the higher IVI values of these species as compared to other recorded species, it can be concluded that these species were successful primary colonizers in the *Gmelina* farm forestry plantations forming a definite structure with vertical understorey strata comprising trees, shrubs and herbs (Odum, 1971).

Table 10. Important value index of *Gmelina* farm forestry plantations

Species	Overall	Age class (years)		
		≤ 5	5-10	10-15
A. houstonianum	11.12	11.17	11.30	12.65
A. augusta	3.61	4.79	3.38	3.44
A. auriculiformis	0.71	-	1.39	-
A. bettzickiana	4.30	5.69	5.41	2.60
A. cadamba	2.14	2.75	2.61	2.01
A. conyzoides	9.90	10.21	11.12	9.79
A. grandis	3.88	5.99	4.04	3.08
A. lebbeck	0.71	1.38	-	-
B. ceiba	6.55	7.35	5.63	7.60
C. dactylon	9.97	9.97	12.02	9.79
C. esculenta	7.23	8.06	7.78	6.73
C. infortunatum	13.95	12.97	15.08	16.51
C. velutina	3.91	4.79	5.12	2.60
D. esculentum	9.25	8.18	9.60	11.63
D. sissoo	0.71	1.38	-	-
E. muricata	4.32	5.09	6.88	-
E. acuminata	2.10	-	-	3.20
E. crista-galli	1.82	-	-	4.15
E. floribundus	1.50	2.06	-	2.01
F. glomerata	3.02	-	-	4.38
F. vesca	8.16	7.95	11.12	6.43
G. arborea	**71.20**	**83.03**	**77.59**	**70.83**
L. aspera	7.99	8.26	9.20	7.60
L. camara	9.57	7.95	11.87	10.41
L. monopetala	3.95	-	-	5.57
L. speciosa	0.71	-	1.39	-
M. struthiopteris	6.20	6.83	6.71	5.95
M. azedarach	3.34	5.05	4.04	2.60
M. indica	4.19	4.19	6.49	2.60
M. koenigii	3.02	-	4.70	-
M. micrantha	7.30	6.61	6.71	9.79

M. oleifera	0.71	1.38	-	-
M. pustulata	2.56	-	-	3.79
O. corniculata	6.06	7.73	6.37	4.99
P. annua	4.53	4.96	4.54	5.60
P. distichum	6.42	8.40	6.37	5.56
P. hexagonoptera	5.21	7.33	5.41	3.80
P. hydropiper	5.46	8.62	4.16	4.43
P. zeylanica	7.16	7.50	7.59	7.60
S. villosa	5.56	-	-	3.20
S. cumini	2.29	-	4.16	2.36
S. macrophylla	1.17	2.06	-	-
S. viarum	3.01	4.79	1.39	3.08
T.divaricata	7.51	8.47	8.59	6.43
T. grandis	2.96	-	5.12	3.08
T. orientalis	3.49	-	-	4.98
U. lobata	2.10	7.06	5.12	5.56
UN-1	1.17	-	-	3.79
UN-2	2.56	-	-	3.20
UN-3	2.10	-	-	2.60
UN-4	1.64	-	-	2.01

UN- unidentified

4.2. Soil Moisture, pH, Electrical Conductivity and Bulk Density

Soil moisture (table 11) and EC (table 12) decreased gradually with increase in soil depth from 0-20 cm to 40-60 cm in plantations of all age class series but soil pH (table 12) exhibited reverse trend, while soil bulk density (table 13) exhibited mixed trend. All these soil physical parameters showed no discreet trend with increased plantation age which is also evidenced from the staggered relationship observed between plantation of different age classes and its soil physical parameters (table 14). This indicates that the soil of *Gmelina* plantations were highly inconstant in nature and had unstable characteristics as these were planted on agricultural landscapes (Schleuss *et al*., 1998; Hope *et al*., 2005; Pouyat *et al*., 2007, 2010).

Table 11. Soil moisture (%) in *Gmelina* farm forestry plantations

Plantation in age classes	0-20 cm	20-40 cm	40-60 cm
AC I1	23.92a	21.20a	18.98a
AC I2	30.40bc	24.73b	19.06a
AC I3	31.18c	26.57	24.49c
AC I4	30.25b	24.57b	19.89b
AC I5	24.49a	21.90a	19.98b
AC I6	27.43	24.90b	21.37
AC I7	29.97b	28.09	24.81c
Mean	**28.23**	**24.56**	**21.22**
AC II1	21.30a	18.76a	17.86a
AC II2	24.80a	19.09ab	19.01ab
AC II3	26.70a	26.21d	22.10e
AC II4	30.80a	28.84	26.47
AC II5	29.80a	25.46cd	21.53de
AC II6	25.10a	20.04b	19.55bc
AC II7	30.10a	25.16c	20.54cd
Mean	**26.94**	**23.36**	**21.01**
AC III1	29.42	24.45b	20.26
AC III2	32.22a	28.91	25.02a
AC III3	32.37a	30.24	28.24
AC III4	32.36a	25.05bc	20.87
AC III5	25.38	21.48a	19.16
AC III6	28.18	25.06bc	22.03
AC III7	27.18	25.68c	24.92a
Mean	**29.59**	**25.84**	**22.93**
Overall mean	**28.25**	**24.59**	**21.72**
SEM	**1.10**	**1.15**	**1.02**
CD	**3.38**	**3.54**	**3.13**
CV	**9.52**	**11.45**	**11.46**

AC I (Age class I- ≤5 years); AC II (5-10 years); AC III (10-15 years)

Table 12. Soil pH and EC in *Gmelina* farm forestry plantations

Plantation in age classes	pH			EC (m mhos cm^{-1})		
	0-20 cm	20-40 cm	40-60 cm	0-20 cm	20-40 cm	40-60 cm
AC I1	6.44	6.63	6.88	0.57_{b}	0.55	0.54
AC I2	5.49	5.83	6.44	0.23_{a}	0.19_{b}	0.083_{b}
AC I3	5.33_{b}	5.41_{a}	6.20_{b}	0.20	0.19_{b}	0.085_{b}
AC I4	5.31_{b}	6.32_{b}	6.16_{b}	0.24_{a}	0.10_{a}	0.092_{b}
AC I5	5.07_{a}	5.50_{a}	5.96_{a}	0.56_{b}	0.23_{b}	0.11
AC I6	5.32_{b}	6.13_{b}	6.21_{b}	0.15	0.07_{a}	0.049_{a}
AC I7	5.98	7.50	8.27	0.26	0.71	0.19
Mean	**5.56**	**6.19**	**6.59**	**0.31**	**0.29**	**0.17**
AC II1	4.66_{a}	5.35_{a}	6.29_{b}	0.39	0.22	0.071_{ab}
AC II2	6.15	6.16_{b}	6.92	0.18_{b}	0.18	0.12
AC II3	5.21	5.41	5.85	0.18_{b}	0.15_{a}	0.13
AC II4	4.87_{b}	5.35_{a}	6.13_{a}	0.30	0.16_{a}	0.13_{c}
AC II5	5.40	5.67	6.15_{a}	0.2303	0.12	0.079_{b}
AC II6	5.73	6.12_{b}	5.98	0.12_{a}	0.079	0.067_{a}
AC II7	4.93_{b}	5.43_{a}	6.36_{b}	0.34	0.24	0.075_{ab}
Mean	**5.28**	**5.65**	**6.24**	**0.25**	**0.16**	**0.09**
AC III1	6.41	6.38	6.73_{d}	0.64	0.52	0.62
AC III2	5.26_{b}	5.57	5.78_{a}	0.12_{a}	0.11_{a}	0.059_{a}
AC III3	4.75_{a}	5.44	6.01_{ab}	0.16	0.22	0.11_{bc}
AC III4	5.34_{b}	6.10	6.16_{bc}	0.29_{b}	0.18	0.11_{c}
AC III5	5.43_{b}	5.70_{a}	6.11_{b}	0.11_{a}	0.09_{a}	0.067_{a}
AC III6	5.29_{b}	5.77	6.44_{cd}	0.33_{b}	0.14_{b}	0.10_{b}
AC III7	5.21_{b}	5.69_{a}	6.63_{d}	0.333	0.15_{b}	0.097_{b}
Mean	**5.39**	**5.81**	**6.27**	**0.28**	**0.20**	**0.17**
Overall mean	**5.42**	**5.88**	**6.37**	**0.28**	**0.22**	**0.14**
SE	**0.22**	**0.21**	**0.19**	**0.05**	**0.05**	**0.05**
CD	**0.66**	**0.65**	**0.59**	**0.15**	**0.17**	**0.15**
CV	**9.74**	**8.73**	**7.37**	**41.47**	**60.55**	**83.02**

AC I (Age class I- ≤5 years); AC II (5-10 years); AC III (10-15 years)

Table 13. Soil bulk density (g cm^{-3}) in the *Gmelina* farm forestry plantations

Plantation in age classes	0-20 cm	20-40 cm	40-60 cm	Mean
≤ 5 years	1.73	1.66	1.56	**1.65**
5-10 years	1.54	1.62	1.55	**1.57**
10-15 years	1.53	1.58	1.63	**1.58**
Mean	**1.6**	**1.62**	**1.58**	**1.60**
SEM (±)	**0.65**	**0.23**	**0.25**	**0.25**
$LSD_{p = 0.05}$	**NS**	**NS**	**NS**	**NS**

Table 14. Pearson correlation matrix of stand, soil physiochemical properties TBD and TCD

	AC	pH	EC	N	P	K	SOC	TBD
AC	1							
pH	-0.266*	1						
EC	-0.120	0.616**	1					
N	0.060	-0.445**	-0.170	1				
P	-0.077	-0.072	-0.142	0.002	1			
K	0.253	-0.045	-0.018	0.063	0.020	1		
SOC	-0.051	0.043	0.382**	-0.121	-0.120	-0.043	1	
TBD	0.795**	-0.128	-0.009	0.025	-0.135	-0.107	-0.067	1

****Significant at 0.01 level; *Significant at 0.05 level (2 tailed); AC- age class; EC- electrical conductivity; N- nitrogen; P- phosphorus; K- potassium; SOC- soil organic carbon; TBD- Total Biomass Density**

Moreover, prior to establishment of the plantations the lands were unused or were agricultural fallow in and around crop lands. The plantations were not at all managed except during planting with FYM application or at the most once after one year of planting. The overall mean soil moisture, pH, EC and bulk density in the *Gmelina* farm forestry plantations 0-20, 20-40 and 40-60 cm depth was 28.25, 24.59, & 21.72 %; 5.42, 5.88 & 6.37; 0.28, 0.22 & 0.14 m mhos cm^{-1} and 1.6, 1.62 & 1.58 g cm^{-3}, respectively. All these soil physical parameters except bulk density were significantly influenced by the age of the plantations which however did not exhibit any discreet trend with increasing age of the plantations. The mean value estimated for soil moisture, pH, EC and bulk density for plantation of ≤ 5years age was 28.23, 24.56 & 21.22 %; 5.56, 6.19 & 6.59, 0.31, 0.29 & 0.17 m mhos cm^{-1}; 1.73, 1.66 & 1.56 g cm^{-3}, respectively at 0-20, 20-40 & 40-60 cm soil depth. The mean values estimated for these soil physical parameters

for 5-10 years age plantation at these soil depths were 26.94, 23.36 & 21.01 %; 5.28, 5.65 & 6.24; 0.25, 0.16 & 0.09 m mhos cm^{-1}; 1.54, 1.62 & 1.55g cm^{-3}, respectively; while for 10-15 years age plantation the mean value of soil moisture was 29.59, 25.84 & 22.93 %; pH was 5.39, 5.81 & 6.27; EC was 0.28, 0.20 & 0.17 m mhos cm^{-1} and bulk density was 1.53, 1.58 & 1.63 g cm^{-3} at 0-20, 20-40 and 40-60 cm soil depth, respectively.

Overhead pressure increases with increasing soil depth which increases the soil compactness in sub-surface layers thus increasing the bulk density (Brady and Weil, 2016). Soil water holding capacity in tree based land use systems is influenced by rainfall, humidity, amount of incident radiation on the soil floor, temperature, its aridity, structure and function of plant cover (Pande, 2001). Terai region of West Bengal located in the foothills of eastern Himalayas has tropical moist climate with high rainfall and acidic soil (Ghosh *et al*., 2019). High humidity and rainfall (fig. 1) increased the soil water retention by reducing evaporation rates and increasing the infiltration of water (Shukla and Chakravarty, 2012_a; Rai, 2017). Moreover, tree based land use systems were reported with higher soil organic matter on the surface soil layer due to litter input increasing the EC thus making the soil more acidic and these soils also can absorb and hold substantial quantities of water as compared to sub-surface layers (de Hann, 1977; Robertson and Vitousek, 1981; Adams and Sidle, 1987; Stevenson, 1994; Chavan *et al*., 1995; Contractor and Badnur, 1996; Chakravarty and Barthakur, 1997; Leskiw, 1998; Jha *et al*., 1999; Raina *et al*., 2001; Khera *et al*., 2001; Paudel and Sah, 2003; Koul, 2004; Chaudhuri *et al*., 2005, 2009; Bagherzadeh *et al*., 2008; Chandran *et al*., 2009; Sheikh and Kumar, 2010; Gairola *et al*., 2012; Shukla and Chakravarty, 2012_a). Higher acidity of surface soil is due to accumulation and subsequent slow decomposition of organic matter releasing acids (de Hann, 1977). Lower pH at soil surface inactivates the soil fauna resulting slower humus decomposition with more non-decomposed matter on the soil floor (Thuille and Schulze, 2006). The undisturbed *Gmelina* plantations increased the soil organic matter continuously without being removed which efficiently regulated the soil physical properties by increasing leaching of bases and weathering process due to decomposition of litter (Robertson and Vitousek, 1981; Adams and sidle, 1987; Woomer *et al*., 1994; Chakravarty and Barthakur, 1997; Leskiw, 1998; Khera *et al*., 2001; Paudel and Sah, 2003).

Soil physical parameters in the plantations of different age classes (AC I $\leq$ 5 years, AC II 5-10 years and AC III 10-15 years) varied significantly because of site quality factors at landscape level arising due to micro-landscape differences resulting

from differences in developing understorey vegetation and gap in the *Gmelina* canopy. There was mortality of *Gmelina* after its planting which resulted into its discontinuous canopy. Differences in development of understorey vegetation in the *Gmelina* plantations are indicated from the differences in its community parameters. The skewed variability in soil physical parameters observed in the plantations of different age classes was due to no silivicultural operations performed and thus was strongly influenced by socio-ecological conditions (Grimm *et al*., 2000; Pickett *et al*., 2001; Alberti, 2008) like vegetation structure of the plantations as well as inter culture operations performed on surrounding crop land (Wardle, 2002; Ponge, 2003; Cornwell *et al*., 2008; Holtkamp *et al*., 2008; Bardgett and Wardle, 2010).

4.3. Soil Available Organic Carbon, Nitrogen, Potassium and Phosphorus

The amount of available soil organic carbon (SOC), N, P and K decreased with increasing soil depth, highest at surface layer and lowest in the deepest layer analysed (table 15, 16, 17 and 18). The overall mean SOC estimated was 23.3, 16.35 and 11.94 Mg ha^{-1} at 0-20, 20-40 and 40-60 cm soil depth, respectively (table 15). Similarly, the overall mean amount of soil available N, P and K at 0-20, 20-40 and 40-60 cm soil depth was 156.93, 109.72 & 69.27 Kg ha^{-1} (table 16); 14.51, 15.02 & 13.5 Kg ha^{-1} (table 17) and 79.49, 69.2 and 65.95 Kg ha^{-1} (table 18), respectively. Regular litter input along with moderate temperature and humidity in the *Gmelina* based land use caused higher availability of organic carbon and nutrients on the surface than the sub-surface layers (Binkley and Giardina, 1998; Kaye *et al*., 2005; Golubiewski, 2006; Raciti *et al*., 2011; Bae and Ryu, 2015; Livesley *et al*., 2016; Deb *et al*., 2019).

The overall range of available SOC estimated for the plantations was 15.68-32.73, 8.14-21.1 and 9.01-14.35 Mg ha^{-1}at 0-20, 20-40 and 40-60 cm soil depth, while the estimated overall range of soil available nutrients was 111.9-244.6 Kg N ha^{-1}, 11.50-17.85 Kg P ha^{-1}& 41.81-108.71 Kg K ha^{-1} at 0-20 cm soil depth; 45.99-233.1 Kg N ha^{-1}, 10.85-35.44 Kg P ha^{-1}& 25.09-91.99 K ha^{-1} at 20-40 cm soil depth and 24.04-143.21 Kg N ha^{-1}, 6.87-19.53 Kg P ha^{-1}& 20.91-100.35 K ha^{-1} at 40-60 cm soil depth, respectively. The availability of soil primary nutrient in plantations was in the order N> K> P (Jha and Dimri, 1991; Pande, 2001; Rai, 2017; Shukla *et al*., 2014_b, 2017). The estimated available amount of these primary nutrients indicates that soil in the *Gmelina* farm forestry plantations was low-medium in available nitrogen, low-high in available phosphorus and low in available potassium (Tandon, 2005).

Table 15. SOC (Mg ha^{-1}) in *Gmelina* farm forestry plantations

Plantation in age classes	0-20 cm	20-40 cm	40-60 cm
AC I1	32.73_{c}	20.12_{cd}	12.45_{b}
AC I2	20.11_{a}	13.08_{a}	9.53_{a}
AC I3	31.19_{bc}	18.15_{b}	9.07_{a}
AC I4	25.06	21.10_{de}	12.45_{b}
AC I5	20.62_{a}	18.97_{bc}	9.53_{a}
AC I6	19.43_{a}	21.75_{e}	13.37_{b}
AC I7	30.34_{b}	17.99_{b}	13.06_{b}
Mean	**25.64**	**18.74**	**11.35**
AC II1	30.50_{c}	11.65_{b}	13.59_{b}
AC II2	27.31	18.20_{c}	9.16_{a}
AC II3	15.93_{ab}	11.97_{b}	12.67_{b}
AC II4	29.89_{c}	18.04_{c}	9.01_{a}
AC II5	18.06_{b}	18.83_{c}	9.62_{a}
AC II6	15.78_{a}	16.44	12.52_{b}
AC II7	17.60_{ab}	8.14_{a}	12.37_{b}
Mean	**22.15**	**14.75**	**11.28**
AC III1	30.60	17.43_{c}	12.69_{a}
AC III2	26.98_{b}	17.28_{c}	12.69_{a}
AC III3	22.46	18.84	13.33_{ab}
AC III4	26.08_{b}	13.85_{ab}	13.81_{ab}
AC III5	16.28_{a}	13.08_{a}	12.85_{a}
AC III6	16.73_{a}	13.54_{ab}	12.53_{a}
AC III7	15.68_{a}	14.98_{b}	14.35_{b}
Mean	**22.11**	**15.57**	**13.18**
Overall mean	**23.3**	**16.35**	**11.94**
SE	**1.87**	**1.46**	**0.58**
CD	**5.77**	**4.50**	**1.79**
CV	**19.69**	**21.88**	**11.95**

AC I (Age class I- ≤5 years); AC II (5-10 years); AC III (10-15 years)

Table 16. Soil available N (Kg ha^{-1}) in *Gmelina* farm forestry plantations

Plantation in age classes	0-20 cm	20-40 cm	40-60 cm
AC I1	113.90_{a}	89.90_{a}	28.22_{a}
AC I2	185.00	86.76_{a}	39.72
AC I3	140.10_{b}	114.99_{b}	28.22_{a}
AC I4	176.70	57.49	58.54
AC I5	168.30_{c}	136.94	139.03
AC I6	170.40_{c}	123.35_{b}	83.63
AC I7	145.30_{b}	45.99	48.09
Mean	**157.10**	**93.63**	**60.78**
AC II1	182.90	53.30_{a}	123.35
AC II2	111.90_{a}	82.60	59.58
AC II3	168.30	177.70_{b}	143.21
AC II4	146.30_{b}	118.10	30.31_{a}
AC II5	244.60	233.10	83.63
AC II6	143.20_{b}	48.10_{a}	48.09
AC II7	207.00	174.06_{b}	27.18_{a}
Mean	**172.03**	**126.79**	**73.62**
AC III1	182.90_{c}	90.90	75.26_{a}
AC III2	125.40_{ab}	120.20_{a}	82.58_{ab}
AC III3	128.60_{b}	121.30_{a}	24.04
AC III4	187.10_{c}	62.70	59.58
AC III5	123.30_{ab}	118.10_{a}	90.94_{c}
AC III6	119.20_{a}	123.30_{a}	90.94_{bc}
AC III7	125.10_{ab}	124.60_{a}	90.62_{c}
Mean	**141.66**	**108.73**	**73.42**
Overall mean	**156.93**	**109.72**	**69.27**
SE	**15.45**	**17.60**	**16.39**
CD	**47.59**	**54.22**	**50.50**
CV	**24.11**	**39.30**	**57.95**

AC I (Age class ≤ 5years); AC II (5-10 years); AC III (10-15 years)

Table 17. Soil available P (Kg ha^{-1}) in *Gmelina* farm forestry plantations

Plantation in age classes	0-20 cm	20-40 cm	40-60 cm
AC I1	13.02_{a}	16.63_{bc}	16.63_{ab}
AC I2	15.91_{a}	13.74_{ab}	14.46_{ab}
AC I3	12.29_{a}	16.63_{bc}	11.57_{a}
AC I4	13.02_{a}	11.57_{a}	17.36_{ab}
AC I5	17.85_{a}	11.57_{a}	11.57_{a}
AC I6	16.63_{a}	16.63_{bc}	13.02_{a}
AC I7	13.74_{a}	18.80_{c}	19.53_{b}
Mean	**14.63**	**15.08**	**14.88**
AC II1	13.02_{a}	13.74_{a}	10.85_{ab}
AC II2	12.29_{a}	10.85_{a}	15.19_{bc}
AC II3	13.74_{a}	13.02_{a}	6.87_{a}
AC II4	15.19_{a}	13.02_{a}	16.63_{c}
AC II5	13.02_{a}	10.85_{a}	12.37_{abc}
AC II6	15.91_{a}	13.02_{a}	10.85_{ab}
AC II7	15.91_{a}	18.08	10.12_{ab}
Mean	**14.15**	**13.23**	**11.84**
AC III1	13.74_{ab}	35.44_{a}	13.74_{a}
AC III2	17.30_{c}	10.85_{a}	13.74_{a}
AC III3	18.08_{c}	13.02_{a}	13.02_{a}
AC III4	11.50_{a}	12.51_{a}	15.69_{a}
AC III5	11.86_{a}	13.52_{a}	13.74_{a}
AC III6	15.19_{bc}	16.63_{a}	12.87_{a}
AC III 7	15.65_{bc}	15.38_{a}	13.51_{a}
Mean	**14.76**	**16.76**	**13.76**
Overall mean	**14.51**	**15.02**	**13.49**
SE	**0.92**	**1.93**	**0.89**
CD	**2.84**	**5.95**	**2.76**
CV	**15.58**	**31.47**	**16.23**

AC I (Age class I- ≤5 years); AC II (5-10 years); AC III (10-15 years)

Table 18. Soil available K (Kg ha^{-1}) in *Gmelina* farm forestry plantations

Plantation in age classes	0-20 cm	20-40 cm	40-60 cm
AC I1	62.72^{bc}	45.99	87.81^{d}
AC I2	45.99^{ab}	62.72	58.54^{c}
AC I3	79.45^{cd}	104.53^{c}	58.54^{c}
AC I4	87.81^{d}	25.09^{a}	20.91^{a}
AC I5	37.63^{a}	33.45^{ab}	41.81^{bc}
AC I6	41.81^{ab}	37.63^{ab}	29.27^{ab}
AC I7	100.35^{d}	91.99^{c}	83.63^{d}
Mean	**65.11**	**57.34**	**54.36**
AC II1	87.80_{a}	91.99_{c}	83.63_{c}
AC II2	79.40_{a}	71.08_{bc}	45.99_{a}
AC II3	50.18	33.50_{b}	25.09
AC II4	97.20_{a}	79.45_{bc}	96.17_{c}
AC II5	83.60_{a}	75.26_{bc}	79.45_{c}
AC II6	108.70_{c}	62.72_{b}	100.35_{c}
AC II7	100.40_{c}	87.81_{c}	75.26_{bc}
Mean	**86.37**	**71.68**	**72.28**
AC III1	100.35	91.99_{bc}	79.45_{b}
AC III2	50.18_{a}	91.99_{bc}	83.63_{b}
AC III3	108.71_{b}	96.17_{c}	66.90_{ab}
AC III4	100.35_{b}	75.26_{bc}	58.54_{a}
AC III5	41.81_{a}	41.81_{a}	83.63_{b}
AC III6	100.35_{b}	83.63_{bc}	58.54_{a}
AC III7	107.14_{b}	69.19	67.69_{ab}
Mean	**86.98**	**78.58**	**71.20**
Overall mean	**79.49**	**69.2**	**65.95**
SE	**8.30**	**10.14**	**9.79**
CD	**25.59**	**31.24**	**30.18**
CV	**25.55**	**35.89**	**36.38**

AC I (Age class I- ≤5 years); AC II (5-10 years); AC III (10-15 years)

Available soil nitrogen and potassium were synergistic to each other (Gairola *et al*., 2012). Forest and cultivated unmanaged land was estimated with highest available amount of nitrogen and organic carbon, while these are medium in well managed

cultivated soil and lowest in barren land (Gupta *et al*., 2001). Similar to the soil physical parameters in the plantations, the amount of available SOC and soil primary nutrients also differed significantly but without any visible trends with increasing age of the plantations indicating local differences (table 14). These differences were due to variations at micro-landscape level in site quality factors associated with socio-ecological conditions like vegetation parameters and management of surrounding crop fields (Grimm *et al*., 2000; Pickett *et al*., 2001; Wardle, 2002; Ponge, 2003; Alberti, 2008; Cornwell *et al*., 2008; Holtkamp *et al*., 2008; Bardgett and Wardle, 2010).

The mean available amount of SOC in the *Gmelina* farm forestry plantations at 0-20, 20-40 and 40-60 cm soil depth in age class I (≤ 5) was 25.64, 18.74 & 11.35 Mg ha^{-1}; 22.15, 14.75 & 11.28 Mg ha^{-1} in age class II (5-10 years) and 22.11, 15.57 & 13.18 55 Mg ha^{-1} in AC III (10-15 years), respectively. Similarly, the mean available soil primary nutrients estimated in age class I was 157.1, 93.63 & 60.78 Kg N ha^{-1}; 14.63, 15.08 & 14.88 Kg P ha^{-1} and 65.11, 57.34 & 54.36 Kg K ha^{-1} at 0-20, 20-40 and 40-60 cm soil depth, respectively. In age class II the mean available amount of these nutrients was 172.03, 126.79 & 73.62 Kg N ha^{-1}; 14.15, 13.23 & 11.84 Kg P ha^{-1} and 86.37, 71.68 & 72.28 Kg K ha^{-1}, respectively at 0-20, 20-40 and 40-60 cm soil depth. The amount of availability of available nitrogen 141.66, 108.73 & 73.41 Kg ha^{-1}; available phosphorus was 14.76, 16.76 & 13.76 Kg ha^{-1} and available potassium was 86.98, 78.58 & 71.20 Kg ha^{-1} at these three soil depths, respectively in plantations of 10-15 years.

The estimated amount of available SOC and primary nutrients was staggered at different soil depths with no discreet trend indicating highly inconsistent nature and unstable characteristics of soil in the *Gmelina* farm forestry plantations (Schleuss *et al*., 1998; Hope *et al*., 2005; Pouyat *et al*., 2007, 2010). Similar heterogeneity of soil physico-chemical properties with no discreet trend observed in the present study area was also reported from urban plantations (Ghosh *et al*., 2019). Adequate soil management is crucial for nutrient availability nutrients and organic carbon and build up (Mahendrappa *et al*., 1986; Ericsson, 1995; Alvarado *et al*., 2014; Fernández-Moya *et al*., 2014). Forests were converted to agricultural lands in terai region of West Bengal and generally were not adequately managed which resulted into inconsistent and unstable nature of soil indicated by unpredictable behaviour of soil physico-chemical properties including lesser amount of nutrient availability and organic carbon build up than the natural forests (Pal *et al*., 2015). The plantations were established in unused or fallow crop land and kept undisturbed except FYM application during planting and at the most once after one year

of planting. The growing plantation used nutrients from the soil with no or very less replenishment in the soil from litter input initially. Moreover there was also lesser understorey vegetation during initial years of plantation establishment adding less organic matter to the soil. With continuous growth of the trees and increase in understorey vegetation due to no management in the plantations there was nutrient build by organic matter (litter) input and thus the amount of soil available nutrients did not exhibited any discreet trend with increasing age of the plantations.

Topography, climate, weathering process, vegetation cover and microbial activities influences build-up of organic carbon and nutrients in the soil (Paudel and Sah, 2003). Differences in replenishment of nutrients back to the soil due to varied litter input, soil water content, aeration, temperature, microorganisms and efficiency of the root system to absorb nutrients caused variation of feedback mechanism of various ecosystem processes in the plantations (Raij, 1981; Pastor *et al*., 1984; Johnston, 1986; Singh *et al*., 1986; Woomer *et al*., 1994; Prescott, 2002; Jerabkova *et al*., 2006). *Gmelina* farm forestry plantations of different age group were thus vegetation of heterogeneous structure and composition that caused significant variation among their SOC build up and nutrient availability (Bhatnagar, 1965; Ruess and Innis, 1977; Binkly and Vitousek, 1989; Tans *et al*., 1990; Schnitzer, 1991; Woomer *et al*., 1994; Fenton *et al*., 1999; Bhattacharyya *et al*., 2001; Kimble *et al*., 2007; John, 2010; Koul *et al*., 2011; Gairola *et al*., 2012; Shukla and Chakravarty, 2012[a, c]; Scotti *et al*., 2015). Structure and composition of vegetation and soil properties are positively correlated with available soil organic carbon and nutrients (Binkely, 1995; Cote *et al*., 2000; Fisher and Binkley, 2000; Augusto *et al*., 2002; Sariyildiz and Anderson, 2003; Sariyildiz *et al*., 2005, 2015; Sariyildiz and Kuçuk, 2008).

There are abundant reports on negative influence of forest conversion to crop land or plantation (Houghton and Skole, 1990; Techienkoua and Zech, 2003; Jiang *et al.*, 2006; Hati *et al.*, 2007, 2008; Manna *et al*., 2007; Al-kaisi *et al.*, 2008; Sainju *et al.*, 2008; Chandra *et al.*, 2010; Verma *et al*., 2010; Zhu *et al*., 2010; Wang *et al*., 2011; Sidhu *et al*., 2014). Tree based land uses and management practices however positively change the soil physico-chemical properties including SOC build up (Mitchell and Chandler, 1939; Murphy, 1958; de Hann, 1977; Tomlinson and Tomlinson, 1990; Aber and Melillo, 1991; Clough, 1991; Sharpe *et al*., 1992; Brown *et al*., 1994; Ericsson, 1995; Khera *et al*., 2001; Pande *et al*., 2001; Abod and Siddiqui, 2002; Kumar *et al*., 2004; Soromessa *et al*., 2004; Srivastava *et al*., 2005; Dimri *et al*., 2006; Fenn *et al*., 2006;

Semwal, 2006; Koul and Panwar, 2008; Varnagirytė-Kabašinskienė, 2008; Gupta and Sharma, 2008; Ball *et al*., 2009; Liu and Yu, 2009; Nazir, 2009; Qazi *et al*., 2010; Sharma *et al*., 2010_{a-d}; Adeboye *et al*., 2011; Awotoye *et al*., 2011; Leite *et al*., 2011; Gairola *et al*., 2012; Imoro *et al*., 2012; Rahman *et al*., 2012; Sahu *et al*., 2013; Ekukinam *et al*., 2014; Hossain *et al*., 2014; Nazir and Netajini, 2014; Pal *et al*., 2015; Shukla *et al*., 2017).

Contrary to the reports of higher availability of soil primary nutrients due to higher soil organic matter in the tree based land uses (de Hann, 1977; Juo and Lal, 1977; Robertson and Vitousek, 1981; Jha *et al*., 1984; Adams and Sidle, 1987; Srinivasan and Caulfield, 1989; Chavan *et al*., 1995; Contractor and Badnur, 1996; Chakravarty and Barthakur, 1997; Kumar and Chaudhuri, 1997; Leskiw, 1998; Jha *et al*., 1999; Raina *et al*., 2001; Khera *et al*., 2001; Koul, 2004; Chaudhuri *et al*., 2005, 2009; Bagherzadeh *et al*., 2008; Gupta and Sharma, 2008; Koul and Panwar, 2008; Chandran *et al*., 2009; Sheikh and Kumar, 2010; Panwar *et al*., 2011; Gairola *et al*., 2012; Shukla and Chakravarty, $2012_{a, c}$, 2018; Shukla *et al*., 2014_{b}, 2017, 2018; Rai, 2017), the present study found no such trends with availability of soil primary nutrients with available carbon build up in the plantation soil. Application of FYM at early stage of plantation establishment might be the reason for no such trends in the plantations. Further, human activities in and around the plantations was also responsible for such unpredictable behaviour of soil properties in the plantations (Schindelbeck *et al*., 2008; Vrscaj *et al*., 2008). Trends or no trends, soils under *Gmelina* farm forestry plantations in terai region of West Bengal without any management also accumulated considerable amount of carbon and primary nutrients sometimes comparable to forest and well managed agricultural land uses Pouyat *et al*., 2007, 2010; Raciti *et al*., 2011; Edmondson *et al*., 2014; Livesley *et al*., 2016). However, the process of carbon accumulation in soils of *Gmelina* farm forestry plantations was still left largely unexplained like other studies (Stevenson, 1994; Golubiewski, 2006; Berthrong *et al*., 2009; Raciti *et al*., 2011; Livesley *et al*., 2016).

4.4. Biomass Production and Biomass Carbon Stock

The overall estimated mean above ground biomass, below ground biomass and total biomass with their corresponding carbon at the *Gmelina* farm forestry plantations was 104.72, 15.14, 119.86, 52.36, 7.55 and 59.91 Mg ha^{-1}, respectively (table 19).

Table 19. Biomass and carbon stock (Mg ha^{-1}) in *Gmelina* farm forestry plantations

Component	AGB	BGB	TB	AGC	BGC	TC
Age class I (≤ 5 years)						
G. arborea	**31.6**	**4.74**	**36.34**	**15.8**	**2.37**	**18.17**
B. ceiba	12.24	1.84	14.08	6.12	0.92	7.04
M. Azaderach	2.20	0.33	2.53	1.1	0.16	1.26
A. grandis	5.36	0.80	6.16	2.68	0.4	3.08
C. velutina	2.15	0.32	2.47	1.07	0.16	1.23
T. grandis	10.26	1.54	11.8	5.13	0.77	5.59
S. macrophylla	13.45	2.02	15.47	6.72	1.01	7.73
D. sissoo	2.72	0.41	3.13	1.36	0.20	1.56
A. lebbeck	12.42	1.86	14.28	6.21	0.93	7.14
Shrub	0.045	0.007	0.052	0.0225	0.0035	0.026
Herb	0.053	0.008	0.061	0.0265	0.004	0.031
Litter	2.65	-	2.65	1.32	-	1.32
Total	**95.15**	**13.88**	**109.03**	**47.57**	**6.94**	**54.51**
Age class II (5-10 years)						
G. arborea	**34.56**	**5.18**	**39.74**	**17.28**	**2.59**	**19.87**
M. Azaderach	2.68	0.4	3.08	1.34	0.2	1.36
C. velutina	9.1	1.36	10.46	4.55	0.68	5.23
B. ceiba	17.22	2.58	19.8	8.61	1.29	9.9
T. grandis	20.64	3.1	23.74	10.32	1.55	11.87
A. grandis	7.16	1.07	8.23	3.58	0.53	4.11
S. cumini	3.59	0.54	4.13	1.79	0.27	2.06
Shrub	0.054	0.008	0.062	0.027	0.004	0.031
Herb	0.062	0.009	0.071	0.031	0.004	0.035
Litter	3.95	-	3.95	1.97	-	1.97
Total	**99.02**	**14.25**	**113.27**	**49.51**	**7.12**	**56.63**
Age class III (10-15 years)						
G. arborea	**41.26**	**6.19**	**47.45**	**20.63**	**3.09**	**23.72**
M. Azaderach	7.21	1.08	8.29	3.6	0.54	4.14
C. velutina	6.32	0.95	7.27	3.16	0.47	3.63
B. ceiba	16.68	2.50	19.18	8.34	1.25	9.59
T. grandis	20.36	3.05	23.41	10.18	1.52	11.7
A. grandis	12.4	1.86	14.26	6.2	0.93	7.13
S. cumini	10.84	1.63	12.47	5.42	0.81	6.23
Shrub	0.057	0.008	0.065	0.028	0.004	0.032
Herb	0.073	0.011	0.084	0.036	0.0055	0.042
Litter	4.80	-	4.80	2.40		2.40
Total	**120.0**	**17.28**	**137.28**	**60.0**	**8.64**	**68.64**
Overall mean	**104.72**	**15.14**	**119.86**	**52.36**	**7.55**	**59.91**

AGB- above ground biomass; BGB- below ground biomass; TB- total biomass; AGC- above ground carbon; BGC- below ground carbon; TC- total carbon

The overall contribution of above ground biomass in the plantations was 87.37 % to the total biomass. Overall in the plantations, trees contributed 96.72 %, litter contributed 3.17 % and understorey shrubs and herbs contributed only 0.11% of the total biomass in the plantations, while overall in the plantations only *Gmelina* trees contributed 34.35 % and associated trees contributed 62.37 % of the total biomass. The biomass of the plantation increased gradually with its increasing age exhibiting strong positive correlation ($r = 0.795^{**}$; table 14) i.e. the biomass of the plantations increased with its increasing age. The mean above ground biomass, below ground biomass and total biomass with their corresponding carbon of *Gmelina* farm forestry plantations quantified was 95.15, 13.88, 109.03, 47.57, 6.94 & 54.51 Mg ha^{-1}, respectively for ≤ 5years age; 99.02, 14.25, 113.27, 49.51, 7.12 & 56.63 Mg ha^{-1}, respectively for 5-10 years age and for 10-15 years age plantations these values were 120.0, 17.28, 137.28, 60.0, 8.64 & 68.64 Mg ha^{-1}, respectively. The quantum of biomass increase was higher from AC II to AC III (21.19 % for above ground, 21.26 % for below ground and 21.20 % for total biomass) than from AC I to AC II (4.07 % for above ground, 2.66 % for below ground and 3.89 % for total biomass). *Gmelina* above ground, below ground and total biomass increased by 9.37 %, 9.28 % & 9.36 % from AC I to AC II, respectively; while the increase was 19.39 %, 19.5 % & 19.4 %. In age class I, mean contribution of total AGB, litter biomass and total shrubs + herbs biomass to mean total biomass of the plantations was 87.27 %, 2.43 % and 0.1%, respectively, while contribution of *Gmelina* and associated trees above ground, below ground and total biomass to mean total biomass of the plantations was 28.98 %,4.35 %, 33.33 %, 55.77 %, 8.34 % and 64.1 %, respectively.

Tree species associated with AC I were *Bombax ceiba*, *Melia azaderach*, *Ailanthus grandis*, *Chukrasia velutina*, *Tectona grandis*, *Swietenia macrophylla*, *Dalbergia sissoo* and *Albizia lebbeck* with their contribution of their total biomass to mean plantation total biomass was 12.88 %, 2.32 %, 5.65 %, 2.26 %, 10.82 %, 14.19 %, 2.87 % and 13.10 % respectively. Similarly in AC II contribution of mean total plantation AGB, litter biomass, total shrub + herb biomass, above ground, below ground and total biomass of *Gmelina* and associated trees to mean plantation total biomass was 87.42 %, and 3.49 %, 0.12 %, 30.51 %, 4.57 %, 35.08 %, 53.58 %, 8.04 % and 61.62 %, respectively, while in AC III the contributions were 87.41 %, 3.5 %, 0.11 %, 30.06 %, 4.51 %, 34.56 %, 53.80 %, 8.06 % and 61.83 %, respectively. *Melia azaderach*, *Chukrasia velutina*, *Bombax ceiba*, *Tectona grandis*, *Ailanthus grandis* and *Syzygium cumini* were associated with both AC II and AC III age group plantations and their

contribution of total biomass to the total plantation mean biomass was 2.72& 6.04 %, 9.23& 5.29 %, 17.48 & 13.97 %, 20.96 & 17.06 %, 7.26 & 10.39 % and 3.65 & 9.08 % respectively.

The amount of biomass estimated in the *Gmelina* farm forestry plantations was lesser than what was reported from plantation or stands in forest landscape from the same study area i.e. terai zone of West Bengal (Koul, 2004; Shukla and Chakravarty, 2012_a, 2018; Shukla *et al*., 2014_b, 2017, 2018; Rai, 2017; Subba *et al*., 2017, 2018). Negligible contribution of understorey vegetation and significant contribution by above ground parts to the total biomass of the tree based land uses was also reported by many earlier workers (Mac Lean and Wein, 1977; Negi, 1984; Pande *et al*., 1988; Rana and Singh, 1990; Rawat and Negi, 2004; Shukla and Chakravarty, 2012_a, 2018; Giri and Rawat, 2013; Shukla *et al*., 2014_b, 2017, 2018; Rai, 2017; Chakravarty *et al*., 2019; Meena *et al*., 2019; Pradhan, 2019; Tamang *et al*., 2019; Pala *et al*., 2020).

With increasing age biomass increased with no change in contribution of both AGB and BGB towards total biomass from AC I to AC II and AC II to AC III. The contributory trend of the different components of the *Gmelina* plantation towards total mean biomass with increasing age also remain unchanged with increasing age of the plantation. Litter production though increased with increasing age of the plantation but also exhibited the same contributory behaviour towards total mean biomass. *Bombax ceiba*, *Melia azaderach*, *Ailanthus grandis*, *Chukrasia velutina* and *Tectona grandis* were the five associated tree species found in all the age classes of *Gmelina* farm forestry plantations and their total biomass was 37.04, 65.31 and 72.41 Mg ha^{-1} which 33.97 %, 57.66 % and 52.74 % of the total plantation mean biomass in AC I, AC II and AC III, respectively. From AC I to AC II the contribution of these five associated species increased by 23.69 % but from AC II to AC III their contribution decreased by 4.92 %. The total biomass contribution of *Gmelina* was 33.33 %, 35.08 % and 34.56 % towards total plantation mean biomass in AC I, AC II and AC III, respectively. The trend of contribution of total biomass towards total plantation mean biomass to the next higher age class by the five common associated species and *Gmelina* was similar but the quantum of change was more for the five associated species considered together than the *Gmelina*.

The change and dynamics of contribution by the components of *Gmelina* farm forestry plantations towards total mean biomass can be explained by the increase and intensity of competition both inter and intra-specific. Carbon stocked in biomass is

generally considered as its half, so any factor that influences biomass also influence the carbon stock (Anon, 2000; Nowak and Crane, 2002; Chanan, 2011; Shukla *et al*., 2018) and thus exhibited the same trends as exhibited by the biomass with increasing age of the plantation. Biomass and biomass carbon varies with land use, climatic conditions, edaphic conditions, topography, site quality, age, species diversity, stem density, stem size distribution, density, structure, litter production, management practices and disturbance history along with variations in canopy height and wood density (Do *et al*., 2010; Chanan, 2012; Con *et al*., 2013; Kanime *et al*., 2013; Ngo *et al*., 2013; Slik *et al*., 2013; Goswami *et al*., 2014; Karthick and Pragasan, 2014; Mitra and Zaman, 2014; Churkina *et al.,* 2015; Mohandass *et al*., 2016; Mandari *et al*., 2016; Tang *et al*., 2016).

Similar attempts to quantify biomass accumulation and carbon storage in tree based land uses were abundantly reported (Negi and Sharma, 1984; Pandey *et al*., 1987; Raizada and Srivastava, 1989; Rana and Singh, 1990; Bargali *et al*., 1992; Lodhiyal *et al*., 1995; Lodhiyal and Lodhiyal, 1997; Nowak and Crane, 2002; Roshetko *et al*., $2002_{a, b}$; Swamy *et al*., $2003_{a, b}$, 2006, 2017; Rawat and Negi, 2004; Subedi, 2004; Singh, 2005; Jana *et al*., 2009; Liu and Yu, 2009; McHale *et al*., 2009; Singh and Lodhiyal, 2009; Sharma *et al*., 2010_{a}; Chanan, 2011; Davies *et al*., 2011; Chavan and Rasal, $2011_{a, b}$, 2012_{a-b}; Rizvi *et al*., 2011; Labata *et al*., 2012; Giri and Rawat, 2013; Kanime *et al*., 2013; Velasco *et al*., $2013_{a, b}$; Ali *et al*., 2014; Arora *et al*., 2014; Giri *et al*., 2014; Iqbal *et al*., 2014; Mangalassery *et al*., 2014; Behera and Mohapatra, 2015; Das and Mukherjee, 2015; Justine *et al*., 2015; Brahma *et al*., 2016; Morhart *et al*., 2016; Selvaraj *et al*., 2016; Singh and Singh, 2017; Sarangle *et al*., 2018; Chauhan *et al*., 2019; Gupta *et al*., 2019; Pradhan, 2019; Thakur and Verma, 2019; Kumar *et al*., 2020).

Quantification of biomass in forest tree plantations at agricultural landscape will aid in formulating sustainable management strategies for increasing carbon pool build up outside forest land use (Iverson *et al*., 1993; Mary *et al*., 2001; Mandal and Joshi, 2014; Shukla and Chakravarty, 2018). Present study was first attempt in the region to check potential of *Gmelina* farm forestry plantations which will be helpful to convert the unutilized land for carbon farming to create additional carbon sinks other than forests and to earn carbon credits as well.

4.5. Ecosystem Carbon Stock

Ecosystem carbonstock in *Gmelina* farm forestry plantations at terai region of West Bengal is illustrated in fig. 2.

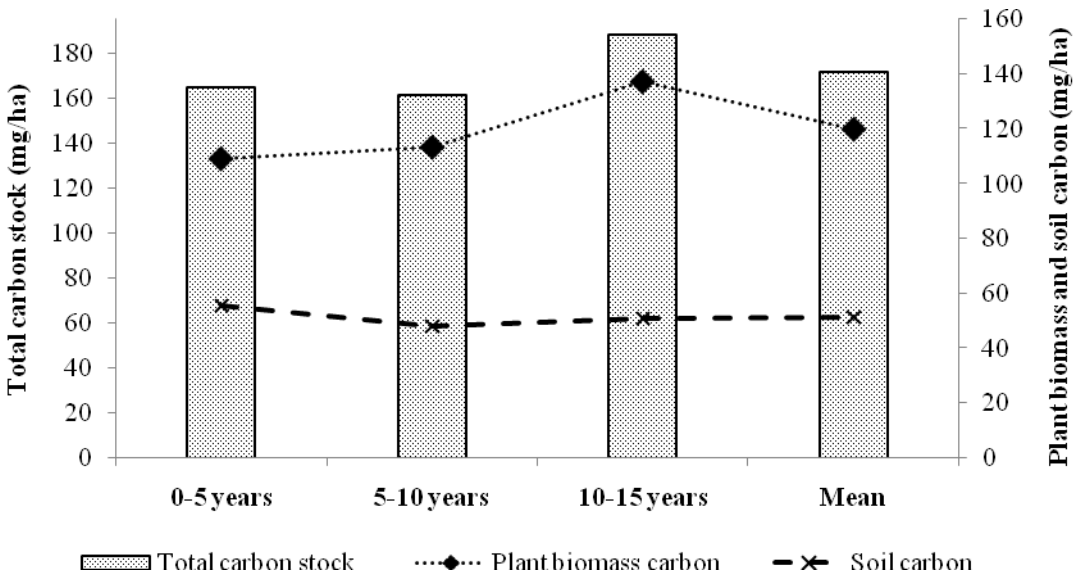

Fig. 2. Ecosystem carbon stock (Mg ha^{-1}) in *Gmelina* farm forestry plantations

The overall mean ecosystem carbon estimated in the plantations was 171.45 Mg ha^{-1}. Consistent increase in plant biomass carbon with increasing age of the plantation also resulted in consistent increase of ecosystem carbon with increasing plantation age. More the age of *Gmelina* plantation, more was the ecosystem carbon stock because of higher biomass production. Plantation with age class I, II and III was quantified with total carbon pool of 164.76, 161.45 and 188.14 Mg ha^{-1}, respectively. The present study was unable to make direct and accurate estimation of carbon uptake by the vegetation because of high variability in tree distribution and species causing uncertainties as was also earlier reported (Velasco *et al*., 2013$_{a, b}$).

Promoting plantations of suitable site specific tree species in less or unproductive and degraded agricultural lands is a recognized management action for offsetting terrestrial carbon emission because of longer duration carbon storage both in biomass and soil (Paustian *et al*., 1998, 2007, 2016; Metting *et al*., 2001; Maji *et al*., 2010; Powlson *et al*., 2011; Badgery *et al*., 2014; Whitmore *et al*., 2015; Lal, 2016; Sreenivas *et al*., 2016; Minasny *et al*., 2017). Forests are now net emitter due to degradation and deforestation and degradation (; Brown *et al*., 1996; Houghton, 2005). Changing the forests to net sink again from net emitter will need supplement of additional carbon emission offset by best available land management option through promoting afforestation/reforestation of available degraded and deforested lands (Lal *et al*., 1995, 1998, 2015; Van Noordwijk *et al*., 1997, 2014; Tarnocai, 1998; Lal and Singh, 2000; Lal, 2003, 2004, 2005, 2016; Sperow *et al*., 2003; Stolbovoi, 2003; Vanden Bygaart *et al*., 2003, 2008; Soussana *et al*.,

2004; Wang *et al*., 2004, 2009, 2010, 2015; Smith *et al*., 2005, 2008; Song *et al*., 2005; Tomlinson, 2005; Vanden Bygaart and Angers, 2006; Raji and Ogunwole, 2006; Baker *et al*., 2007; Mandal *et al*., 2007, 2008; Xie *et al*., 2007; Yu *et al*., 2007; Blanco-Canqui and Lal, 2008; Maji *et al*., 2010; Sanderman and Baldock, 2010; Sanderman *et al*., 2010; Sun *et al*., 2010; Tsai *et al*., 2010; Van Wesemael *et al*., 2010; Mandal, 2011; Pathak *et al*., 2011; Syswerda *et al*., 2011; Powlson *et al*., 2014; Lam *et al*., 2013; Tsui *et al*., 2013; Vågen and Winowiecki, 2013; Devine *et al*., 2014; Dimassi *et al*., 2014; Viscarra Rossel *et al*., 2014; Wheeler, 2014; Banger *et al*., 2015; Powlson and Johnston, 2015; Stockmann *et al*., 2015; Wei *et al*., $2015_{a,b}$; Van Straaten *et al*., 2015; Zhu *et al*., 2015; Piccoli *et al*., 2016; Sperow, 2016; Winowiecki *et al*., $2016_{a,b}$; Zuber and Villamil, 2016; Minasny *et al*., 2017; Rai, 2017). Managing soil and biomass carbon in an agricultural landscape by promoting *Gmelina arborea* or any other tree species plantation will both be an avoided emission and net addition of carbon to terrestrial pool thereby fulfilling the global 4 per mille initiative (Sanderman and Baldock, 2010; Powlson *et al*., 2011; Lal, 2016; Minasny *et al*., 2017). The studied *Gmelina* farm forestry plantations with only three age class series had considerable vegetation heterogeneity due to no disturbance or management which if allowed growing for full normal rotation period with selective logging, development of semi-natural secondary forest is expected (Martin *et al*., 2004).

Chapter 5

SUMMARY AND CONCLUSION

The present study entitled "**Floristic Diversity and Carbon Storage of *Gmelina arborea* (Roxb.) Plantation in Agricultural Landscape of Terai Zone of West Bengal**" was carried out in terai region of West Bengal from September 2018 to February 2020. The area around (within 10 kms) the university campus was surveyed for sampling of *Gmelina* based farm forestry plantations in farmer's fields. The randomly selected plantations were categorised into three age classes of ≤ 5 years, 5-10 years and 10-15 years. The plantation geometry of the *Gmelina* was 3 m x 3 m and was kept aside after planting i.e. not silviculturally managed. All the selected plantations were located in an around cropping area with rice based cropping system. The area of the selected plantations was at least one acre. In a plantation, 10 % of the *Gmelina* trees were selected randomly for sampling with dbh ≥ 10 cm for height and dbh. All the trees other than teak with dbh of ≥ 10 cm were also measured. Stratified random nested quadrate sampling method was adopted for analysing other vegetation forms. Composite soil samples were collected once separately from 0-20, 20-40, 40-60 cm depth. Litters were also collected once from three 1 x 1 m^2 sub-quadrates placed diagonally (two at opposite corners and one in centre) within the main quadrate. Soil samples were collected to analyze EC, pH, moisture, bulk density, available nitrogen, phosphorus & potassium and soil organic carbon. Non-destructive method was adopted to estimate tree biomass and destructive methods to estimate shrub and herb biomass. The vegetation of the plantations was analyzed with quantitative parameters like frequency, relative frequency, density, relative density, abundance, relative abundance and important value index. Height and diameter of the selected trees were also measured to estimate biomass and its carbon. Diversity of the plantations was also analyzed with various indices like species richness, species diversity index, concentration of dominance, Shannon-Wiener diversity index and species evenness index. The data were analyzed using software package Gen Stat along with one way analysis and Duncan multiple range test.

5.1. Diversity Indices and Species Composition

The overall richness of plant assemblages in the studied *Gmelina* farm forestry plantation was 51 species including *Gmelina,* of which four species remained unidentified. Identified species were represented by 51 genera and 33 families. The number of species in the plantations representing the tree, shrub, herb, climber, and fern

were 23, 7, 16, 2, and 3, respectively. Amongst the plant species found associated with *Gmelina* plantation, herbs dominated followed by trees, ferns and least by climbers in terms of their species richness. Highest age class (10-15 years) was associated with 15 tree species other than *Gmelina*, 15 herb species, seven shrub species, three fern species and two climber species, whereas in the lower two age classes (≤ 5 and 5-10 years) the species richness of the different life forms were equal.

The overall values estimated for species diversity or Menhinick's index, concentration of dominance, Shannon and Wiener index and evenness of the studied *Gmelina* farm forestry plantations are 1.18, 0.03, 1.29 and 8.69, respectively. These indices in the age class I (≤ 5 years), II (5-10 years) and III (10-15 years) estimated was 0.54, 0.62 & 0.59; 0.04, 0.05 & 0.04; 1.54, 1.59 & 2.0 and 3.35, 3.92 & 3.65, respectively. Shannon and Wiener index was found inversely proportional to concentration of dominance and the corresponding value estimated was highest (2.00 vs 0.04) in 10-15 year old *Gmelina* plantation followed by 5-10 year old plantation (1.59 vs 0.05) and lowest (1.54 vs 0.04) in ≤ 5 years old plantation. The evenness of different age group plantations estimated was 3.92 for 5-10 year old plantation, 3.65 for 10-15 year old plantation and 3.35 for ≤ 5 years year old plantation which indicate that the species were more or less evenly distributed in the plantations.

5.2. Vegetation Analysis

The overall frequency and relative frequency of the associated species plantations was in the range of 5.0-100.0 % and 0.25-4.95, whereas *Gmelina* was estimated with 100 % and 4.95, respectively. The overall frequency of trees (other than *Gmelina*), shrubs, herbs, climbers and ferns respectively was in the range of 5.0-80.0 %, 5.0-95.0 %, 30.0-100.0 %, 5.0-75.0 % and 45.0-85.0 %. *Acacia auriculiformis*, *Albizia lebbeck* and 15 other species had lowest representation in the sampled plots, while *Ageratum houstonianum* had highest representation. Correspondingly, these species were also observed with lowest and highest relative representation, respectively while sampling. Generally the representation of species and their relative representation during sampling increased initially i.e. from AC I to AC II but then decreased from AC II to AC III. The range of representation of associated species with their relative representation during sampling in the AC I, II and III was 14.29-100 % & 0.69-4.86; 14.29-100 % & 0.72-5.07 and 14.29-100 % & 0.82-4.92, respectively. In all the age classes *Ageratum houstonianum*, a herb was the most represented associated species during sampling in the *Gmelina* farm forestry plantations.

The overall density and relative density of the associated species in the plantation was 0.05-7.65 and 0.04-5.82, respectively, while the corresponding values estimated for *Gmelina* was 55.8 and 42.5, respectively. Among the life forms overall range of density for trees (other than *Gmelina*) was 0.05-2.0 (*Bombax ceiba* highest) shrubs was 0.20-7.65 (*Urena lobata-C. infortunatum*), herbs 1.30-5.20 (*Alternanthera bettzickiana-Ageratum houstonianum*), ferns 1.75-4.0 (*Phegopteris hexagonoptera-Diplazium esculentum* and climbers 0.1-2.70 (UN 1-*Mikania micrantha*). The range of density and relative density estimated in the plantations of AC I-III was 0.14-6.14 & 0.11-4.68; 0.14-7.57 & 0.11-5.82 and 0.33-9.5 & 0.25-7.14, respectively, while for *Gmelina* the values estimated were 58.43 & 44.5, 54.86 & 42.1 and 54.0 & 40.6, respectively.

The overall range of abundance and relative abundance of the associated species in the *Gmelina* plantations estimated was 1.0-8.05 % and 0.42-3.42, respectively; while for *Gmelina* the estimated values were 55.8 % and 23.7, respectively. The overall range of herbs, ferns and climbers was 2.82-5.81 %, 2.86-4.71 % and 2.0-3.6 %. The overall range of relative abundance estimated for associated trees, shrubs, herbs, ferns and climbers in the plantations was 0.42-3.4, 1.09-3.42, 1.2-2.47, 1.21-2.0 and 0.85-1.53, respectively. The range of abundance and relative abundance in ≤ 5, 5-10 and 10-15 years *Gmelina* farm forestry plantations estimated was 1.0-7.17 % & 0.58-4.12, 1.0-7.57 % & 0.55-4.19 and 1.0-9.5 % & 0.94-4.45, while values estimated for *Gmelina* was 58.4 % & 33.6; 54.9 % & 30.4 and 54.0 % and 25.31, respectively.

Overall IVI estimated for *Gmelina* in the plantations was 71.2 and in age class series I-III was 83.03, 77.59 and 70.83, respectively; while for the associated plant species the overall IVI was in the range of 0.71-13.95 and in age class series I-III was 1.38-12.97, 1.39-15.08 and 20.1-16.51, respectively. The most important of all the species associated with *Gmelina* plantations was *Clerodendron infortunatum*, a shrub and the least was *Acacia auriculiformis, Albizia lebbeck, Dalbergia sissoo, Lagerstroemia speciosa* and *Moringa oleifera*. The other important associated species in the plantations were *Clerodendron infortunatum* (shrub- 13.95), *Ageratum houstonianum* (herb- 11.12), *Cynodon dactylon* (herb- 9.97), *Ageratum conyzoides* (herb- 9.90), *Lantana camara* (shrub- 9.57), *Diplazium esculentum* (fern- 9.25), *Fragaria vesca* (herb- 8.16), *Lucas aspera* (herb- 7.99), *Tabernaemontana divaricata* (shrub- 7.51), *Mikania micrantha* (climber- 7.30), *Colocasia esculenta* (herb- 7.23), *Pouzolzia zeylanica* (herb- 7.16), *Bombax ceiba* (tree- 6.55), *Paspalum distichum* (herb- 6.42), *Matteuccia struthiopteris* (fern- 6.20) and *Oxalis corniculata* (herb- 6.06).

5.3. Soil Moisture, pH, Electrical Conductivity and Bulk Density

The overall mean soil moisture, pH, EC and bulk density in the *Gmelina* farm forestry plantations 0-20, 20-40 and 40-60 cm depth was 28.25, 24.59, & 21.72 %; 5.42, 5.88 & 6.37; 0.28, 0.22 & 0.14 m mhos cm^{-1} and 1.6, 1.62 & 1.58 g cm^{-3}, respectively. All these soil physical parameters except bulk density were significantly influenced by the age of the plantations which however did not exhibit any discreet trend with increasing age of the plantations. The mean value estimated for soil moisture, pH, EC and bulk density for plantation of ≤ 5years age was 28.23, 24.56 & 21.22 %; 5.56, 6.19 & 6.59, 0.31, 0.29 & 0.17 m mhos cm^{-1}; 1.73, 1.66 & 1.56 g cm^{-3}, respectively at 0-20, 20-40 & 40-60 cm soil depth. The mean values estimated for these soil physical parameters for 5-10 years age plantation at these soil depths were 26.94, 23.36 & 21.01 %; 5.28, 5.65 & 6.24; 0.25, 0.16 & 0.09 m mhos cm^{-1}; 1.54, 1.62 & 1.55 g cm^{-3}, respectively; while for 10-15 years age plantation the mean value of soil moisture was 29.59, 25.84 & 22.93 %; pH was 5.39, 5.81 & 6.27; EC was 0.28, 0.20 & 0.17 m mhos cm^{-1} and bulk density was 1.53, 1.58 & 1.63 g cm^{-3} at 0-20, 20-40 and 40-60 cm soil depth, respectively.

5.4. Soil Available Organic Carbon, Nitrogen, Potassium and Phosphorus

The amount of available soil organic carbon (SOC), nitrogen, phosphorus and potassium decreased with increasing soil depth, highest at surface layer and lowest in the deepest layer analysed. The overall mean SOC estimated was 23.3, 16.35 and 11.94 Mg ha^{-1} at 0-20, 20-40 and 40-60 cm soil depth, respectively. Similarly, the overall mean amount of soil available nitrogen, phosphorus and potassium at 0-20, 20-40 and 40-60 cm soil depth was 156.93, 109.72 & 69.27 Kg ha^{-1}; 14.51, 15.02 & 13.49 Kg ha^{-1} and 79.49, 69.2 and 65.95 Kg ha^{-1}. The overall range of available SOC estimated for the plantations was 15.68-32.73, 8.14-21.1and 9.01-14.35 Mg ha^{-1}at 0-20, 20-40 and 40-60 cm soil depth, while the estimated overall range of soil available nutrients was 111.9-244.6 Kg N ha^{-1}, 11.50-17.85 Kg P ha^{-1}& 41.81-108.71 Kg K ha^{-1} at 0-20 cm soil depth; 45.99-233.10 Kg N ha^{-1}, 10.85-35.44 Kg P ha^{-1} & 25.09-91.99 K ha^{-1} at 20-40 cm soil depth and 24.04-143.21 Kg N ha^{-1}, 6.87-19.53 Kg P ha^{-1} & 20.91-100.35 K ha^{-1} at 40-60 cm soil depth, respectively. The availability of soil primary nutrient in plantations was in the order N> K> P. The estimated available amount of these primary nutrients indicates that soil in the *Gmelina* farm forestry plantations was low-medium in available nitrogen, low-high in available phosphorusand low in available potassium.

The mean available amount of SOC in the *Gmelina* farm forestry plantations at 0-20, 20-40 and 40-60 cm soil depth in age class I (≤ 5) was 25.64, 18.74 & 11.35 Mg ha^{-1} ;

22.15, 14.75 & 11.28 Mg ha^{-1} in age class II (5-10 years) and 22.11, 15.57 & 13.18 55 Mg ha^{-1} in AC III (10-15 years), respectively. Similarly, the mean available soil primary nutrients estimated in age class I was 157.1, 93.63 & 60.78 Kg N ha^{-1}; 14.63, 15.08 & 14.88 Kg P ha^{-1} and 65.11, 57.34 & 54.36 Kg K ha^{-1} at 0-20, 20-40 and 40-60 cm soil depth, respectively. In age class II, the mean available amount of these nutrients was 172.03, 126.79 & 73.62 Kg N ha^{-1}; 14.15, 13.23 & 11.84 Kg P ha^{-1} and 86.37, 71.68 & 72.28 Kg K ha^{-1}, respectively at 0-20, 20-40 and 40-60 cm soil depth. The amount of availability of available nitrogen 141.66, 108.73 & 73.41 Kg ha^{-1}; available phosphorus was 14.76, 16.76 & 13.76 Kg ha^{-1} and available potassium was86.98, 78.58 & 71.20 Kg ha^{-1} at these three soil depths, respectively in plantations of 10-15 years.

5.5. Biomass Production and Biomass Carbon Stock

The overall estimated mean above ground biomass, below ground biomass and total biomass with their corresponding carbon at the *Gmelina* farm forestry plantations was 104.72, 15.14, 119.86, 52.36, 7.55 and 59.91 Mg ha^{-1}, respectively. The overall contribution of above ground biomass in the plantations was 87.37 % to the total biomass. Overall in the plantations, trees contributed 96.72 %, litter contributed 3.17 % and understorey shrubs and herbs contributed only 0.11 % of the total biomass in the plantations, while overall in the plantations only *Gmelina* trees contributed 34.35 % and associated trees contributed 62.37 % of the total biomass. The biomass of the plantation increased gradually with its increasing age.

The mean above ground biomass density, below ground biomass density and total biomass density with their corresponding carbon density of *Gmelina* farm forestry plantations, 5-10 and 10-15 years of age quantified was 95.15, 13.88, 109.03, 47.57, 6.94 & 54.51 Mg ha^{-1}, respectively for ≤ 5years age; 99.02, 14.25, 113.27, 49.51, 7.12 & 56.63 Mg ha^{-1}, respectively for 5-10 years age and for 10-15 years age plantations these values were 120.0, 17.28, 137.28, 60.0, 8.64 & 68.64 Mg ha^{-1}, respectively. The quantum of biomass increase was higher from AC II to AC III (21.19 % for above ground, 21.26 % for below ground and 21.20 % for total biomass) than from AC I to AC II (4.07 % for above ground, 2.66 % for below ground and 3.89 % for total biomass).

5.6. Ecosystem Carbon Stock

The overall mean ecosystem carbon estimated in the plantations was 171.45 Mg ha^{-1}. Consistent increase in plant biomass carbon with increasing age of the plantation also resulted in consistent increase of ecosystem carbon with increasing plantation age. More the age of *Gmelina* plantation, more was the ecosystem carbon stock because of

higher biomass production. Plantation with age class I, II and III was quantified with total carbon pool of 164.76, 161.45and 188.14 Mgha^{-1}, respectively.

5.7. Conclusion

Farm forestry plantations are now globally recognised as low cost viable option to supplement forest for offsetting carbon emission. Left aside younger *Gmelina* farm forestry plantations (up to 15 years of age) after planting with no silvicultural management in terai region of West Bengal has the potential to become a source of both avoided emission and additional carbon sink to supplement the remaining forests for their capability of longer duration carbon storage in their biomass and soil. The average ecosystem carbon of these plantations was 171.45 Mg ha^{-1}, of which average biomass carbon and soil carbon was 119.86 and 51.59 Mg ha^{-1}, respectively. This much amount of carbon stored by a small aged plantation indicates its much higher capacity to become efficient carbon pool if allowed to complete normal rotation cycle of 60-80 years. The plantations if continued for their full rotation without any disturbance but with selective logging, considerable vegetation heterogeneity will lead to conversion of homogenous plantations into semi-natural secondary forest. These micro-landscapes within the agricultural or human dominated landscapes will act as oasis for biodiversity conservation and if prioritized with incentives to the growers through popular policy decisions will increase heterogeneity of these forest deficient landscapes improving connectivity of the habitat as corridors with multiple benefits of soil restoration, satisfying human needs and overall supplement the natural forest to offset carbon emission.

5.8. Recommendations and Future Research

The study recommends popular plantation programs through mission mode with these high value timber speciesas carbon farming initiative either in the unproductive and degraded non-forested or agricultural landscape. Popularizing such plantation programs needs policy decision and action with suitable site specific tree species participatory mode with intensive to the growers. Plantations were generally alleged to limit biodiversity and are developed for economic benefits by the owners (Manhas *et al*., 2011). These allegations can be cleared off by adopting site specific different management strategies by removing disturbance factors to allow heterogeneity of the landscape so that semi-natural forest vegetation within the agricultural or any other non-forested landscape is developed without compromising the timber demands, while accommodating social and ecological benefits (Ito *et al*., 2003). This needs more studies

to understand the plantations at various successional stages throughout the age classes of natural rotation of species. The effect of plant community composition on ecosystem functioning and services is yet to be understood (Udayana *et al*., 2019).

Establishing plantations with higher diversity of indigenous tree species is required for studying this relationship. In farm tree plantations plant life history strategies requires clear understanding to analyse patterns of biomass allocation and partitioningin various tree species for sustainable tree based land management and identifying the most productive tree species for carbon sequestration (Silvertown and Doust, 1993; Bazzaz and Grace, 1997; Westoby *et al*., 2002; Chhabra and Dadhwal, 2004; Wright *et al*., 2004; Pickup *et al*., 2005; Niinemets *et al*., 2007; Devi and Yadava, 2009). Driving mechanisms of terrestrial carbon sinks and sources with their regional pattern and magnitude still remain are unclear (Zhao *et al*., 2013) which need to be studied for success of these plantations to avoid emission. Even now uncertainties prevail over quantifying carbon fluxes in and out of a system due to absence of information on land use and land cover change i.e. LUCC (Canadell *et al*., 2007; Strassmann *et al*., 2008; Stone, 2009; Zhao *et al*., 2009, $2010_{a.\ b}$; Zhu *et al*., 2011). Information on carbon exchange between these plantations and the atmosphere needs to be generated for efficient carbon budgeting for viable policy support and management decisions as the present study was also unable to generate such information for the region.

REFERENCES

Aber J D and Melillo J M (1991) *Terrestrial Ecosystems*. Saunders College Publishing, Philadelphia.

Abod S A and Siddiqui M T (2002) Growth response of teak (*Tectona grandis* L. f.) seedlings to nitrogen, phosphorus and potassium fertilizers. *Pertanika Journal of Tropical Agriculture Science* **25:** 107-113.

Adaaja B O, Tanko D, Bako S P and Oloyede O E (2017) Diversity and distribution of trees and shrubs in Gurara Forest, Kaduna State. *International Journal of Applied Biological Research* **8:** 133-141.

Adams P W and Sidle R C (1987) Soil conditions in three recent landslides in southeast Alaska. *Forest Ecology and Management* **18:** 93-102.

Adeboye M K A, Bala A, Osunde A O, Uzoma A O, Odofin A J and Lawal B (2011) Assessment of soil quality using soil organic carbon and total nitrogen and microbial properties in tropical agroecosystems. *Agricultural Sciences* **2:** 34-40.

Aerts R and Honnay O (2011) Forest restoration, biodiversity and ecosystem functioning. *BMC Ecology* **11:** 29, Doi: 10.1186/1472-6785-11-29.

Aggangan R T (2001) Tree farming in the Philippines: Some issues and recommendations. In: *Socio-economic evaluation of the potential for Australian tree species in the Philippines*, eds. Harrison S and Herbohn J. ACIAR Monograph, 75, pp. 33-44.

Agus C, Karyanto O, Kita S, Haibara K, Toda H, Hardiwinoto S, Supriyo H, Na'iem M, Wardana W, Sipayung M S, Khomsatun and Wijoyo S (2004) Sustainable site productivity and nutrient management in a short rotation plantation of *Gmelina arborea* in East Kalimantan, Indonesia. *New Forest* **28:** 277-285.

Agus C (2003) Nutrient dynamics in short-rotation *Gmelina arborea* plantations in East Kalimantan, Indonesia. Ph. D. Thesis, Tokyo University of Agriculture and Technology, Tokyo.

Ajit, Dhyani S K, Handa A K, Newaj R, Chavan S B, Alam B, Prasad R, Ram A, Rizvi R H, Jain A K, Tripathi D, Shakhela R R, Patel A G, Dalvi V V, Saxena A K, Parihar A K S, Backiyavathy M R, Sudhagar R J, Bandeswaran C and Gunasekaran S (2016) Estimating carbon sequestration potential of agroforestry systems in India. *Agroforestry Systems* DOI 10.1007/s10457-016-9986-z.

Akinrinde E A and Obigbesan G O (2000) Evaluation of fertility status of selected soils for crop production in five ecological areas of Nigeria. *Proc. 26th Annual Conference of the Soil Science Society of Nigeria*, 30 October-3 November 2000, University ofIbadan, Ibadan, Oyo State, Nigeria, Pp. 279-288.

Alberti M (2008) *Advances in Urban Ecology: Integrating Humans and Ecological Processes in Urban Ecosystems*. Springer US. 366p.

Albrecht A and Kandji S T (2003) Carbon sequestration in tropical agroforestry system.*Agriculture Ecosystems and Environment* **99:** 15-27.

Ali A, Ma W J, Yang X D, Sun B W, Shi Q R and Xu M S (2014) Biomass and carbon stocks in *Schima superba* dominated subtropical forests of eastern china. *Journal of Forest Science* **60:** 198-207.

Ali A, Lin S-L, He J-K, Kong F-M, Yu J-H and Jiang H-S (2019_a) Climate and soils determine above ground biomass indirectly via species diversity and stand structural complexity in tropical forests. *Forest Ecology and Management* **432:** 823-831.

Ali A, Lin S-L, He J-K, Kong F-M, Yu J-H and Jiang H-S (2019_b) Tree crown complementarity links positive functional diversity and aboveground biomass along large-scale ecological gradients in tropical forests. *Science of the Total Environment* **656:**45-54.

Ali S, Begum F, Hayat R and Bohannam B J M (2017) Variation in soil organic carbon stock in different land uses and altitudes in Bagrot Valley, Northern Karakoram. *Acta Agriculturae Scandinavica, Section B- Soil and Plant Science* **67:** 551-561.

Al-kaisi M M, Kruse M L and Sawyer J E (2008) Effect of nitrogen fertilizer application on growing season carbon dioxide emission in a corn-soybean rotation. *Journal of Environmental Quality* **37:** 325-332.

Alonso I, Weston K, Gregg R and Morecroft M (2012) Carbon storage by habitat - Review of the evidence of the impacts of management decisions and condition on carbon stores and sources. *Natural England Research Reports, Number NERR043*.

Alvarado A, Fernández-Moya J, Segura J M, Vaides E E, Camacho M, Avellán M J and Ávila C E (2014) Nutrient Management Improvements in Forestry Species. *Better Crops* **98:** 16-18.

Alves R R N and Rosa I L (2007) Biodiversity, traditional medicine and public health: where do they meet? *Journal of Ethnobiology and Ethnomedicine* **3:** 1-9.

Anonymous (1995) Summary for policymakers. In: *Contribution of Working Group II of the Intergovernmental Panel on Climate Change,forming part of the IPCC Second Assessment Report*, eds. Watson T, Zinyowera M C and Moss R H. Cambridge University Press. Cambridge. Pp. 3-32. IPCC, Rome, Italy.

Anonymous (2000) Chapter 3: *Afforestation, reforestation and deforestation activities.* In: *IPCC 2000: Land use, land use change and forestry*, eds. Watson R T, Noble I R, Bolin B, Rabindranath N H, Verardo D J and Dokken D J. Cambridge University Press, UK.

Anonymous (2001) *4th Working Plan for the Forests of Cooch Behar district and Jalpaiguri district (Part) Comprising Cooch Behar Forest Division and Cooch Behar S. F.* Division Volume – I, 2000-01 to 2009-10. Divisional Forest Officer, Working Plans (North) Division, Darjeeling.

Anonymous (2003) *IPCC good practice guidance for LULUCF sector*. Intergovernmental Panal on Climate Change. Cambridge University Press.

Anonymous (2005) Millennium Ecosystem Assessment. World Resources Institute. Washington. DC.

Anonymous (2006) *Guidelines for National Greenhouse Gas Inventories, Prepared by the National Green house Gas Inventories Programme*. IPCC, Rome, Italy.

Anonymous (2008) *Report on the workshop on methodological issues relating to reducing emissions from deforestation and forest degradation in developing countries*. 29th session. UNFCC, Tokyo, Japan. Pp. 89-96.

Anonymous (2013) Summary for policymakers. In: *Climate change 2013: the physical science basis. Contribution of working group I to the Fifth assessment Report of the Intergovernmental Panel on Climate Change*, eds. Stoker T F, Qin D, Planter G K, Tignor M, Allen S K, Boschung J, Nauels A, Xia Y, Bex V and Midgley P M. Cambridge University Press. Cambridge. Pp. 3-32. IPCC, Rome, Italy.

Anonymous (2019) *India State of Forest Report*. Forest Survey of India, Dehra Dun. Government of India.

Arora G S, Chaturvedi R, Kaushal A, Nain S, Tewari N, Alam M and Chaturvedi O P (2014) Growth, biomass, carbon stocks, and sequestration in an age series of *Populus deltoides* plantations in Tarai region of central Himalaya. *Turkish Journal of Agriculture and Forestry* **38:** 550-560.

Ashton M, Gunatilleke C, Singhakumara B and Gunatilleke I (2001) Restoration pathways for rain forest in southwest Sri Lanka: a review of concepts and models. *Forest Ecology and Management* **525:** 1-23.

Augusto L, Ranger J, Binkely D and Rothe A (2002) Impact of several common tree species of European temperate forests on soil fertility. *Annals of forestry Science* **59:** 233-253.

Awotoye O O, Ogunkunle C O and Adeniyi, S A (2011) Assessment of soil quality under various land use practices in a humid agro-ecological zone of Nigeria. *African Journal of Plant Science* **5:** 565-569.

Babweteera F and Brown N (2010) Spatial patterns of tree recruitment in East African tropical forests that have lost their vertebrate seed dispersers. *Journal of Tropical Ecology* **26:** 193-203.

Badgery W B, Simmons AT, Murphy B W, Rawson A, Andersson K O and Lonergan V E (2014) The influence of land use and management on soil carbon levels for crop-pasture systems in Central New South Wales, Australia. *Agricculture, Ecosystem and Environment* **196:** 147-157.

Bae J and Ryu Y (2015) Land use and land cover changes explain spatial and temporal variations of the soil organic carbon stocks in a constructed urban park. *Landscape and Urban Planning* **136:** 57-67, Doi: http://dx.doi.org/10.1016/j.landurbplan.2014.11.015

Bagherzadeh A, Brumme R and Beese F (2008) Temperature dependence of carbon mineralization and nitrous oxide emission in a temperate forest ecosystem. *Journal of Forestry Research* **19:** 107-112.

Baishya R and Barik S K (2011) Estimation of tree biomass, carbon pool and net primary production of an old-growth *Pinus kesiya* Royle ex. Gordon forest in North-Eastern India. *Annals of Forest Science* **68:** 727-736.

Baishya R, Barik SK and Upadhaya K (2009) Distribution pattern of aboveground biomass in natural and plantation forests of humid tropics in northeast India. *Tropical Ecology* **50:** 295-304.

Bajracharya R M, Sitaula B K, Shrestha B M, Awasthi K D, Balla M K and Singh B R (2004) Soil organic carbon status and dynamics in the central Nepal Middle Mountains. *Journal of Institute of Forestry* **12:** 28-44.

Baker J M, Ochsner T E, Venterea R T and Griffis T J (2007) Tillage and soil carbon sequestration-what do we really know? *Agriculture, Ecosystem and Environment* **118:** 1-5

Bakker M A, Carreño-Rocabado G and Poorter L (2011) Leaf economics traits predict litter decomposition of tropical plants and differ among land use types. *Functional Ecology* **25:** 473-483.

Ball B A, Bradford M A and Hunter M D (2009) Nitrogen and phosphorus release from mixed litter layers in lower than predicted from single species decay. *Ecosystems* **12:** 87-100.

Balu A, Rajarishi R, Thangapandian K, Senthilkumar P and Murugesan S (2015) Management of important insect pests of *Gmelina arborea* under agroforestry system. *Advances in Tree Seed Science and Silviculture*, 360.

Banday M, Gangoo S A, Raja R, Pala N A and Gatoo A A (2019) Soil organic carbon distribution, mitigation and management practices. *Indian Forester* **145:** 246-254.

Banger K, Tian H, Tao B, Lu C, Ren W and Yang J (2015) Magnitude, spatio-temporal patterns and controls for soil organic carbon stocks in India during 1901-2010. *Soil Science Society of America Journal* **79:** 864-875.

Bardgett R D and Wardle D A (2010) Above ground-below ground linkages. Biotic Interactions, Ecosystem Processes and Global Change. Oxford University Press, New York. 301p.

Bargali S S, Singh S P and Singh R P (1992) Structure and function of an age series of eucalyptus plantations in central Himalaya. I. Dry matter dynamics. *Annals of Botany* **69:** 405-411.

Batjes N H (1996) Total carbon and nitrogen in the soils of the world. *European Journal of Soil Science* **47:** 151-163.

Batjes N H and Dijkshoorn J A (1999) Carbon nitrogen stocks in the soil of Amazon Region. *Geoderma* **89:** 273-286.

Bazzaz F A and Grace J (1997) *Plant resources allocation*. Academic Press, London.

Becknell J M, Kucek L K and Powers J S (2012) Above ground biomass in mature and secondary seasonally dry tropical forests: A literature review and global synthesis. *Forest Ecology and Management* **276:** 88-95.

Behera M K and Mohapatra N P (2015) Biomass accumulation and carbon stocks in 13 different clones of teak (*Tectona grandis* Linn. F.) in Odisha, India. *Current World Environment* **10:** 1011-1016.

Bellamy P H, Loveland P J, Bradley R I, Lark R M and Kirk G J (2005) Carbon losses from all soils across England and Wales 1978-2003. *Nature* **437:** 245-248.

Berthrong S T Jobbagy E G and Jackson R B (2009) A global meta-analysis of soil exchangeable cations, pH, carbon, and nitrogen with afforestation. *Ecological Applications* **19:** 2228-2241.

Bhatnagar H P (1965) Soils from different quality Sal (*Shorea robusta*) forests of Uttar Pradesh. *Tropical Ecology* **6:** 56-62.

Bhattacharyya T, Pal D K, Velayutham M, Chandran P and Mandal C (2001) Total Carbon Stock in Indian Soils: Issues, Priorities and Management. In: *Land Resource Management for Food and Environmental Security*. Soil Conservation Society of India New Delhi, India. Pp.1-46.

Binkely D (1995) The influence of tree species on forest soils: processes and patterns. In: *Proceedings of the trees and soil workshop*, Mead D J and Cornforth I S eds., Lincoln University, agronomy society of New Zealand special publications number 10. Lincoln University Press, Canterbury. Pp. 1-33.

Binkley D and Giardina C (1998) Why do tree species affect soils? The warp and woof of tree-soil interactions. *Biogeochemistry* **42:** 89-196

Binkley D and Valentine D (1991) Fifty-year biogeochemical effects of green ash, white pine and Norway spruce in a replicated experiment. *Forest Ecology and Management* **40:** 13-25.

Binkly D and Vitousek P M (1989) Soil Nutrient Availability. In: *Plant Physiological, Field Methods and Instrumentation*, eds. Pearey R W, Ehleringer J, Mooney N A and Rundel P W. Champan and Hall, London. Pp. 75-96.

Biswas K and Das A (2016) Allelopathic effects of Teak (*Tectona grandis* Lf) on germination and seedling growth of *Plumbago zeylanica* L. *Pleione* **10:** 262-268.

Blair G, Lefroy R and Lisle L (1995) Soil carbon fractions based on their degree of oxidation, and the development of a carbon management index for agricultural systems. *Australian Journal of Soil Research* **46:** 1459-1466.

Blanco-Canqui H and Lal R (2008) No-tillage and soil-profile carbon sequestration: an on-farm assessment. *Soil Science Society of American Journal* **72:** 693-701.

Blanco-Canqui H and Ruis S J (2018) No-tillage and soil physical environment. *Geoderma* **326:** 164-200.

Bohre P, Chaubey O P and Singhal P K (2013) Biomass accumulation and carbon sequestration in *Tectona grandis* Linn.f. and *Gmelina arborea* Roxb. *International Journal of Bio-Science and Bio-Technology* **5:** 153-174.

Bombelli A, Henry M, Castaldi S, Adu-Bredu S, Arneth A, Grandcourt A D, Grieco E, Kutsch W L, Lehsten V and Rasile A (2009) An outlook on the sub-Saharan Africa carbon balance. *Biogeosciences* **6:** 2193-2205.

Brady N C and Weil R R (2016) *The Nature and Properties of Soil*. 15th ed. Pearson Education, USA.

Brahma B, Nath A J and Das AK (2016) Managing rubber plantations for advancing climate change mitigation strategy. *Current Science* **110:** 2015-2019.

Bray R H and Kurtz L T (1945) Determination of total, organic and available form of phosphorus in soils. *Soil Science* **59:** 39-45.

Brovin V, Stich S, von Bloh W, Clausen M, Bauer E and Cramer W (2004) Role of land cover changes for atmospheric CO_2 increase and climate change during the last 150 years. *Global Change Biology* **10:** 1253-1266.

Brown N, Van Staden J, Daws M, Johnson T and Van Wyk A (2003) Patterns in the seed germination response to smoke in plants from the Cape Floristic Region, South Africa. *South African Journal of Botany* **69:** 514-525.

Brown S, Anderson J M, Woomer P L, Swift M J and Barrios E (1994) Soil biological processes in tropical ecosystems. In: *The biological management of tropical soil fertility*, eds. Woomer P L and Swift M J. Wiley Chichester. Pp. 15-46.

Brown S, Sathaye J, Cannell M and Kauppi P E (1996) Mitigation of carbon emissions to the atmosphere by forest management. *Commercial Forestry Review* **75:** 80-91.

Brown S L, Schrooder P and Kern J S (1999) Spatial distribution of biomass in forests of the eastern USA. *Forest Ecology and Management* **123:** 81-90.

Brunet J (2007) Plant colonization in heterogeneous landscapes: an 80- year perspective on restoration of broadleaved forest vegetation. *Journal of Applied Ecology* **44:** 563-572.

Bulluck L R, Brosius M, Evanylo G K and Ristaino J B (2002) Organic and synthetic fertility amendments influence soil microbial, physical and chemical properties in organic and conventional farms. *Applied Soil Ecology* **19:** 147-160.

Cairns M A, Brown S, Helmer E H and Baumgardner G A (1997) Root biomass allocation in the world's upland forests. *Oecologia* **111:** 1-11.

Cairns M A, Olmsted L, Gradanos J and Argaeg J (2003) Composition and aboveground tree biomass of dry semi-evergreen forest on Mexico's Yucatan Peninsula. *Forest Ecology and Management* **186:** 125-132.

Cameron D R, Marvin D C, Remucal J M and Passero M C (2017) Ecosystem management and land conservation can substantially contribute to California's climate mitigation goals. *Proceeding of National Academic of Science* **114:** 12833-12838.

Campos-Arceiz A and Blake S (2011) Megagardeners of the forest- the role of elephants in seed dispersal. *Acta Oecologia* **37:** 542-553.

Canadell J G, Le Quéré C, Raupach M R, Field C B, Buitenhuis E T, Ciais P, Conway T J, Gillett N P, Houghton R A and Marland G (2007) Contributions to accelerating atmospheric CO_2 growth from economic activity, carbon intensity, and efficiency of natural sinks. *Proceedings of National Academy of Science USA* **104:** 18866-18870.

Carnevale N J and Montagnini F (2002) Facilitating regeneration of secondary forests with the use of mixed and pure plantations of indigenous tree species. *Forest Ecology and Management* **163:** 217-227.

Chakravarty D N and Barthakur B C (1997) Acid Soils of Assam Area and Extent of Acidity. In: *Acid Soils of India*, eds. Mahapatra I C, Mandal S C, Misra C, Mitra G N and Panda N. ICAR, New Delhi.

Chakravarty S, Ghosh S K, Suresh C P, Dey A N and Shukla G (2012) Deforestation: Causes, Effects and Control Strategies. In: *Global Perspectives on Sustainable Forest Management*, ed. Okia, C. A. Intech Publishers Croatia. Pp 3-28.

Chakravarty S, Pala N A, Tamang B, Sarkar B C, K Manohar A, Rai P, Puri A, Vineeta and Shukla G (2019) Ecosystem Services of Trees Outside Forest. In: *Sustainable Agriculture, Forest and Environmental Management*, eds. Jhariya M K, Banerjee A, Meena R S and Yadav D K. Springer Nature Singapore Pte Ltd., Singapore. Pp. 327-352.

Chakravarty S, Puri A, Abha A M, Rai P, Lepcha U, Vineeta, Pala N A and Shukla G (2020) Linking Social Dimensions of Climate Change: Transforming Vulnerable Smallholder Producers for Empowering and Resiliency. In: Climate Change and Agroforestry Systems, eds. Raj A, Jhariya M K, Yadav M K and Banerjee A. Apple Academy Press, Doi: 10.1201/9780429286759-7.

Chanan M (2011) Potensikarbon di ataspermu kaantanah di blokper lindungan Taman Wisata Alam Gunung Baung Pasuruan –Jawa Timur. *Journal Gamma* **6:**101-12.

Chanan M (2012) Pendugaan cadangan karbon (C) tersim pan di ataspermu kaantanah padavegeta sihutantana manjati (*Tectona Grandis* Linn. F) (Di RPH Sengguruh BKPH Sengguruh KPH Malang PerumPerhutani II Jawa Timur). *Journal Gamma* **7:** 61-73.

Chandra S, Nautiyal P, Chauhan S and Bhatia C R (2010) Changes in soil physico-chemical properties and microbial functional diversity due to 14 years of conversion of grams land to organic agriculture in semiarid agro-ecosystem. *Soil and Tillage Research* **109:** 55-60.

Chandran P, Ray S K, Durge S L, Raja P, Nimkar A M, Bhattacharyya T and Pal D K (2009) Scope of horticulture land-use system in enhancing carbon sequestration ferruginous soils of the semi-arid tropics. *Current Science* **97:** 1039-1046.

Chapin F S, Oswood M W, Van Cleve K, Viereck L A and Verbyla D L (2006) *Alaska's changing boreal forest*. Oxford University Press, New York, USA.

Chapin F S, Walker B H III, Hobbs R J, Hooper D U, Lawton J H, Sala O E, and Tilman D (1997) Biotic control over the functioning of ecosystems. *Science* **277:** 500-504.

Chaturvedi O P, Handa A K, Kaushal R, Uthappa A R, Sarvade S and Panwar P (2016) Biomass production and carbon sequestration through agroforestry. *Range Management and Agroforestry* **37:** 116-127.

Chaudhuri S G, Dinesh R, Raja R, Kumar S and Ravishankar N (2005) Physico-chemical, biochemical and microbial characteristics of soil of mangroves of south Andaman: impacts of anthropogenic disturbances. *Indian Forester* **131:** 660-666.

Chaudhuri S G, Dinesh R, Sheeja T E, Raja R, Jey Kumar V and Srivastava R C (2009) Physico-chemical, biochemical and microbial characteristics of soils of mangroves of Andaman: a post-tsunami analysis. *Current Science* **97:** 98-102.

Chauhan S K, Ritu and Chauhan R (2016) Carbon Sequestration in Plantations. In: *Agroforestry for Increased Production and Livelihood Security* eds. Gupta S K, Panwar P and Kaushal R. NIPA, New Delhi. Pp. 215-234.

Chauhan S K, Singh S, Sharma S, Sharma R, Saralch H S (2019) Tree biomass and carbon sequestration in four short rotation tree plantations. *Range management and Agroforestry* **40:** 77-82.

Chauhan S K, Gupta N, Ritu, Yadav S and Chauhan R (2009) Biomass and carbon allocation in different parts of agroforestry tree species. *Indian Forester* **135:** 981-992.

Chauhan SK, Sharma R, Singh B and Sharma SC (2015) Biomass production, carbon sequestration and economics in on-farm poplar plantations in Punjab, India. *Journal of Applied and Natural Science* **7:** 452-458.

Chavan B L and Rasal G B (2011_a) Potential of carbon sequestration in six year ages young plant from university campus of Aurangabad. *Global Journal of Energy Science Research* **11:** 15-20.

Chavan B L and Rasal G B (2011_b) Sequestered carbon potential and status of *Eucalyptus* tree. *International Journal of Applied Engineering and Technology* **1:** 41-47.

Chavan B L and Rasal G B **(**2012_a) Carbon Sequestration potential and status of *Peltophorum pterocarpum* (DC.) K. Heyne. *Science Research Reporter* **2:** 51-55.

Chavan B L and Rasal G B (2012_b) Carbon sequestration potential of young *Annona Reticulate* and *Annona Squamosa* from University Campus of Aurangabad. *International Journal of Physical and Social Sciences* **2:** 193-198.

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

Chavan K N, Kenjale R Y and Chavan A S (1995) Effect of Forest Tree Species on Properties of Lateritic Soil.*Journal Indian Society of Soil Science* **43:** 43-46.

Chhabra A and Dadhwal V K (2004) Assessment of major pools and fluxes of carbon in Indian forests. *Climate Change* **64:** 341-360.

Chidumayo E N (2012) *Assessment of existing models for biomass and volume calculations for Zambia. Report prepared for FAO-Zambia and the Integrated Land Use Assessment (ILUA) Phase 2 Project*. FAO, Rome.

Chijioke E O (1980) *Impacts on soils of fast growing species in lowland tropics*. FAO Forestry Paper No. 21. Rome.

Chowdhury M S H, Halim M A, Biswas S, Haque S M S, Muhammed N and Koike M (2007) Comparative evaluation of physical properties in soils of orange orchard and bushy forest in Chittagong hill tracts, Banglandesh. *Journal of Forestry Research*, Doi: 10.1007/s11676-007-0050-8.

Churkina G, Grote R, Butler T M and Lawrencea M (2015) Natural selection? Picking the right trees for urban greening. *Environmental Science Policy* **47:** 12-17.

Cilliers S S, Cilliers J, Lubbe R and Siebert S J (2013) Ecosystem services of urban green spaces in African countries – perspectives and challenges. *Urban Ecosystems* **16:** 681-702, Doi: 10.1007/s11252-012-0254-3.

Cintron G and Novelli Y S (1984) Methods for studying mangrove structure, In: The mangrove ecosystem: research methods, eds. Snedaker S C and Snedaker J G. United Nations Educational Scientific and Cultural Organization, Paris. Pp. 91-113.

Clemmensen K, Bahr A, Ovaskainen O, Dahlberg A, Ekblad A, Wallander H, Stenlid J, Finlay R, Wardle D and Lindahl B (2013) Roots and associated fungi drive long-term carbon sequestration in boreal forest. *Science* **339:** 1615-1618.

Clough M E (1991) Comparison of aluminium, basic cations and acidity in the soil of indigenous forests and pine stands in the southern Cape. *South African Journal of Plant and Soil* **8:** 177-183, Doi: 10.1080/02571862.1991.10634830

Con T V, Thang N T, Ha D T T, Khiem C C, Quy T H, Lam V T, Do T V and Tamotsu S (2013) Relationship between aboveground biomass and measures of structure and species diversity in tropical forests of Vietnam. *Forest Ecology and Management* **310:** 213-218.

Conti G and Díaz S (2013) Plant functional diversity and carbon storage - an empirical test in semi-arid forest ecosystems. *Journal of Ecology* **101:** 18-28.

Contractor R M and Badnur V P (1996) Effect of Forest Vegetation on Properties of a Vertisols.*Journal Indian Society of Soil Science* **44:** 510-511.

Cornelis J and Herny M (2004) Biodiversity relationships in urban and suburban parks in Flanders. *Landscape and Urban Planning* **69:** 285-401.

Cornwell W K, Cornelissen J H C, Amatangelo K, Dorrepaal E, Eviner V T and Godoy O (2008) Plant species traits are the predominant control on litter decomposition rates within biomes worldwide. *Ecological Applications* **11:** 1065-1071.

Cote L, Brown S, Pare D, Fyles J and Bauhus J (2000) Dynamics of carbon and nitrogen mineralization in relation to stand type stand age and soil texture in the boreal mixed wood. *Soil Biology and Biochemistry* **32:** 1079-1090.

Curtis J T (1959) *The Vegetation of Wisconsin. An Ordination of Plant Communities*. University Wisconsin Press, Madison Wisconsin, 657.

Dachung G, Verinumbe I and Ayuba S A (2014) Effect of agroforestry trees on chemical properties of vertisols of the Sahel region of Borno state, Nigeria. *Journal of Research in Forestry, Wildlife and Environment* **6:** 1-7.

Dadhwal V K, Pandhya N and Vora A B (1998) Carbon cycle for Indian forest ecosystem; a preliminary estimate In: Global change studies: Scientific results from ISRO, eds. Subbraya B H, Rao D P, Desai P S and Manikaram R. GBP ISRO, Bangaluru. Pp. 411-430.

Das B, Sarkar P K, Kumari N, Dey P, Singh A K and Bhatt B P (2019) Biophysical performance of different multipurpose trees species in Jharkhand, India. *Current Science* **116:** 82-88.

Das M and Mukherjee A (2015) Carbon sequestration potential, its correlation with height and girth of selected trees in the golapbag campus, Burdwan, West Bengal (India). *Indian Journal of Science Research* **10:** 53-57.

Dash P K, Mohapatra P P and Rao Y G (2009) Diversity and distribution pattern of tree species in Niyamgiri hill ranges, Orissa, India. *Indian Forester* **135:** 927-942.

Davidson E A and Ackerman I L (1993) Changes in soil carbon inventories following cultivation of previously untilled soils. *Biogeochemistry* **20:** 161-193.

Davies Z G, Edmondson J L, Heinemeyer A, Leake J R and Gaston K J (2011) Mapping an urban ecosystem service: quantifying above-ground carbon storage at a citywide scale. *Journal of Applied Ecology* **48:** 1125-1234.

Dawson J J C and Smith P (2007) Carbon losses from soil and its consequences for land-use management. *Science of the Total Environment* **382:** 165-190.

de Hann S (1977) Humus, its formation, its relation with the mineral part of the soil and its significance for soil productivity. In: *Organic matter studies*, vol 1. International Atomic Energy Agency, Vienna. Pp. 21-30.

Deb S, Kumar D, Chakraborty S, Weindorf D C, Choudhury A, Banik P, Deb D, De P, Saha S, Patra A K, Majhi M, Naskar P, Panda P and Hoque A (2019) Comparative carbon stability in surface soils and sub soils under submerged rice and upland non-rice crop ecologies: a physical fractionation study. *Catena* **7:** 400-410.

Deka J, Tripathi P O and Khan L M (2012) High dominance of *Shorea robusta* Gaertn. in alluvial plain Kamrup Sal forest of Assam, N. E. India. *International Journal of Ecosystem* **2:** 67-73.

Denslow J S and Guzman G S (2000) Variation in stand structure, light and seedling abundance across a tropical moist forest chronosequence, Panama. *Journal of Vegetation Science* **11:** 201-212.

Devi L S and Yadava P S (2009) Above ground biomass and net primary production of semi-evergreen tropical forest of Manipur, north-eastern India. *Journal of Forestry Research* **20:** 151-55.

Devine S, Markewitz D, Hendrix P and Coleman D (2014) Soil Aggregates and Associated Organic Matter under Conventional Tillage, No-Tillage, and Forest Succession after Three Decades. *PLoS ONE* **9:** e84988, Doi: 10.1371/journal.pone.0084988

Dewar R C and Cannell M G R (1991) *Carbon Sequestration in the Trees, Products and Soils of Forest Plantations: An Analysis using UK Examples*. Institute of Terrestrial Ecology, Bush Estate, Peniquik, Midlothian EH 26 OQB, Scotland. Pp. 47-67.

Dhakal S, Koirala M, Sharma E, and Subedi NR (2010) *Effect of Land Use Change on Soil Organic Carbon Stock in Balkhu Khola Watershed Southwestern Part of Kathmandu Valley, Central Nepal*. Conference Paper: World Academy of Science, Engineering and Technology, June 2010.

Diekow J, Mielniczuk J, Knicker H, Bayer C, Dick D P and Kögel-Knabner I (2005) Carbon and nitrogen stocks in physical fractions of a subtropical Acrisol as influenced by long-term no-till cropping systems and N fertilisation. *Plant and Soil* **268:** 319-328.

Dimassi B, Mary B, Wylleman R, Labreuche J, Couture D, Piraux F and Cohan J P (2014) Long-term effect of contrasted tillage and crop management on soil carbon dynamics during 41 years. *Agriculture Ecosystem and Environment* **188:** 134-146.

Dimri B M, Jha M N and Gupta M K (2006) Soil potassium changes at different altitudes and seasons in upper Yamuna Forests of Garhwal Himalayas. *Indian Forester* **132:** 609-614.

Do T V, Osawa A and Thang N T (2010) Recovery process of a mountain forest after shifting cultivation in Northwestern Vietnam. *Forest Ecology and Management* **259:** 1650-1659.

Dudley N S and Fownes J H (1992) Preliminary biomass equations for eight species of fast-growing tropical trees. *Journal of Tropical Forest Science* **5:** 68-73.

Dunnett N and Qasim M (2000) Perceived benefits to human well-being of urban gardens. *Hort Technology* **10:** 40-45.

Edmondson J L, Davies Z G, McCormack S A, Gaston K J and Leake J R (2014) Land-cover effects on soil organic carbon stocks in a European city.*Science of Total Environment* **472:** 444-453.

Ekukinam E U, Iwara A I and Gani B S (2014) Evaluation of phosphorus and exchangeable bases status of soil under rubber plantation of different ages in south-eastern Nigeria.*Open Science Journal of Bioscience and Bioengineering* **1:** 19-22.

Epron D, Marsden C, M'Bou AT, Saint-André L, D'Annunzio R and Nouvellon Y (2009) Soil carbon dynamics following afforestation of a tropical savannah with *Eucalyptus* in Congo. *Plant and Soil* **323:** 309-322.

Ericsson T (1995) Nutrient dynamics and requirements of forest crops.*New Zealand Journal of Forestry Science* **24:** 133-168.

Eswaran H, Reich P F, Kimble J, Beinroth F H, Padmanabhan E and Moncharoen P (2000) Global Carbon Stocks. In: *Global Climate Change and Pedogenic Carbonates*, ed. Lal R. Lewis Publishers, Boca Raton, Fl. Pp. 15-26.

Farrell M, Prendergast-Miller M, Jones D L, Hill P W and Condron L M (2014) Soil microbial organic nitrogen uptake is regulated by carbon availability. *Soil Biology and Biochemistry* **77:** 261-267.

Fayolle A, Doucet J L, Gillet J F, Bourland N and Lejeune P (2013) Tree allometry in Central Africa: testing the validity of pantropical multispecies allometric equations for estimating biomass and carbon stocks. *Forest Ecology and Management* **305:** 29-37.

Feller C, Albrecht A, Blanchard E, Cabidoche Y M, Chevalier T, Hartmann C, Eschenbrenner V, LarreLarrouy M C and Ndandou J F (2001) Soil organic carbon sequestration in tropical areas.General considerations and analysis of some edaphic determinants for Lesser Antilles soils. *Nutrient Cycling in Agroecosystems* **61:** 19-31.

Fenn M E, Perea-Estrada V M, de Bauer L I, Pe´rez-Suárez M, Parker D R and Centina-Alcala V M (2006) Nutrient status and plant growth effects of forest soils in the Basin of Mexico. *Environmental Pollution* **140:** 187-199.

Fenton T E, Brown J R and Maubach M J (1999) Effects of long-term cropping on organic matter content of soils: Implication for soil quality. *Soil and Water Consevation Journal* 95-124.

Fernandez-Juricic E and Jokimaki J (2001) A habit island approach to conserving birds in urban landscapes: case studies from southern and northern Europe. *Biodiversity Conservation* **10:** 2023-2043.

Fernández-Moya J, Alvarado A, Miguel-Ayanz A S and Marchamalo-Sacristán M (2014) Forest nutrition and fertilization in teak (*Tectona grandis* L. f.) plantations in Central America. *New Zealand Journal of Forestry Science* **44:** 1-8.

Fisher R F and Binkley D (2000) *Ecology and management of forest soils*, 3rd edn.Wiley, New York. 489p.

Flinn K M and Vellend M (2005) Recovery of forest plant communities in post-agricultural landscapes. *Frontiers in Ecology and the Environment* **3:** 243-250.

Freschet G T, Aerts R and Cornelissen J H C (2012) A plant economics spectrum of litter decomposability. *Functional Ecology* **26:** 56-65.

Gairola S, Sharma C M, Ghildiyal S K and Suyal S (2011) Live tree biomass and carbon variation along an altitudinal gradient in moist temperate valley slopes of the Garhwal Himalaya (India). *Current Science* **100:** 1862-1870.

Gairola S, Sharma C M, Ghildiyal S K and Suyal S (2012) Chemical properties of soils in relation to forest composition in moist temperate valley slopes of Garhwal Himalaya, India. *Environmentalist*, Doi: 10.1007/s10669-012-9420-7.

George S, Kumar B M and Rajiv G R (1993) Nature of secondary succession in the abandoned Eucalyptus plantations of Neyyar (Kerala) in peninsular India. *Journal of Tropical Forest Science* **5:** 372-386.

Ghimire P, Bhatta B, Pokhrel B, Kafle G and Paudel P (2018) Soil organic carbon stocks under different land uses in Chure region of Makawanpur District, Nepal. *SAARC Journal of Agriculture* **16:** 13-23.

Ghosh S, Scharenbroch B and Ow LF (2019) Soil organic carbon distribution in roadside soils of Singapore. *Chemosphere* **165:** 163-172.

Gideon I K, Ogbonna A N and Nzegbule E C (2016) Soil physico-chemical properties in three land use systems (*Theobroma cacao*, *Gmelina arborea* and Secondary Forest) in Umuahia North of Abia State, Nigeria. *World Journal of Agricultural Sciences* **12:** 236-244.

Giri N and Rawat L (2013) Assessment of biomass carbon stock in an *Ailanthus excelsa* Roxb. plantation Uttarakhand, India. *Journal of Ecology and the Natural Environment* **5:** 352-359.

Giri N, Rawat L and Kumar P (2014) Assessment of biomass carbon stock in *Tectona grandis* Linn F. plantation ecosystem of Uttarakhand, India. *International Journal of Engineering Science and Invention* **3:** 46-53.

Githae E W, Gachene C K K and Njoka J T (2011) Soil physicochemical properties under *Acacia senegal* varieties in the dry land areas of Kenya. *African Journal of Plant Science* **5:** 475-482.

Goddard M A, Dougill A J and Benton T G (2010) Scaling up from gardens: biodiversity conservation in urban environments. *Trends in Ecology and Evolution* **25:** 90-98, Doi: 10.1016/j.tree.2009.07.016.

Golubiewski N E (2006) Urbanization increases grassland carbon pools: effects of landscaping in Colorado's Front Range. *Ecological Application* **16:** 555-571.

Gosain B G, Negi G C S, Dhyani P P, Bargali S S and Saxena R (2015) Ecosystem services of forests: carbon stock in vegetation and soil components in a watershed of Kumaun Himalaya, India. *International Journal of Ecology and Environment Science* **41:** 177-188.

Goswami S, Verma K S and Kaushal R (2014) Biomass and carbon sequestration in different agroforestry systems of a Western Himalayan watershed. *Biological Agriculture and Horticulture* 30: 88-96, Doi: 10.1080/01448765.2013.855990.

Gower S T (2003) Patterns and mechanisms of the forest carbon cycle. *Annual Review of Environment and Resources* **28:** 169-204.

Grdovic S and Stevanonvic V (2006) The moss flora in the central urban area of Belgrade. *Archives of Biological Science Belgrade* **58:** 55-59.

Grimm N B, Grove M J, Pickett S T A and Redman C L (2000) Integrated approaches to long-term studies of urban ecological systems. *Bioscience* **50:** 571-584.

Guariguata M R and Ostertag R (2001) Neotropical secondary forest succession: changes in structural and functional characteristics. *Forest Ecology and Management* **148:** 185-206.

Guevara S, Purata S E and Van der Maarel E (1986) The role of remnant forest trees in tropical secondary succession. *Vegetation* **66:** 77-84.

Guo X, Meng M, Zhang J and Chen H Y H(2016) Vegetation change impacts on soil organic carbon chemical composition in subtropical forests. *Scientific Reports* **6:** 29607, Doi: https://doi.org/10.1038/srep29607.

Gupta D K, Bhatt R K, Keerthika A, Noor Mohamed M B, Shukla A K and Jangid B L (2019) Carbon sequestration potential of *Hardwickia binata* Roxb. based

agroforestry in hot semi-arid environment of India: an assessment of tree density impact. *Research Communications, D*oi: 10.18520/cs/v116/i1/112-116.

Gupta J P, Sharma M P and Gupta G D (2001) Characterization of Kandi belt soils of Jammu region as affected by different land use patterns. *Journal Indian Society Soil Science* **49:** 770-773.

Gupta M K and Sharma S D (2008) Effect of tree plantation on soil properties, profile morphology and productivity index I. Poplar in Uttarakhand. *Annals of Forestry* **16:** 209-224.

Gupta M K and Pandey R (2008) Soil organic carbon pool under different plantations insome districts of Uttarakhand and Haryana. *Indian Journal of Forestry* **31:** 369-374.

Hamilton P C, Chandler L R, Brodie A W and Cornelius J P (1998) A financial analysis of a small scale *Gmelina arborea* Roxb.improvement program in Costa Rica. *New Forests* **16:** 89-99.

Haque S M S (1997) Afforestation effects on former agricultural soils. Ph. D. Thesis. University of Aberdeen.

Harmer R, Peterken G, Kerr G and Poulton P (2001) Vegetation changes during 100 years of development of two secondary woodlands on abandoned arable land. *Biological Conservation* **101:** 291-304.

Harmon M E, Ferrell W K and Franklin J F (1990) Effects on carbon storage of conversion of old-growth forests to young forests. *Science* **247:** 699-702.

Harrington R A and Ewel J J (1997) Invasibility of tree plantations by native and non-indigenous species in Hawaii. *Forest Ecology and Management* **99:** 153-162.

Hartley M J (2002) Rationale and methods for conserving biodiversity in plantation forests. *Forest Ecology and Management* **155:** 81-95.

Hati K M, Mishra B, Manna M C, Wanjari R H, Mandal K G and Mishra A K (2008) Impact of long-term application of manure, fertilizer and lime under intensive cropping on physical properties and organic carbon content of an Alfisols. *Geoderma* **148:** 173-179.

Hati K M, Swarup A, Dwivedi A K, Misra A K and Bandyopadhyay K K (2007) Changes in soil physical properties and organic carbon status at the topsoil horizon of a *vertisol* of central India after 28 years of continuous cropping, fertilization and manuring. *Agriculture Ecosystem and Environment* **119:** 127-134.

He M, Dijkstra F A, Zhang K, Li X, Tan H, Gao Y and Li G (2014) Leaf nitrogen andphosphorus of temperate desert plants in response to climate and soil nutrientavailability. *Science Reporter* **4:** 1-7.

Higgins K F, Oldemeyer J L, Jenkins K J, Clambery G K and Harlow R F (1994) Vegetation sampling and measurement. In: *Research and Management Techniques for Wildlife and Habitats*. The Wildlife Society, Bethesda, MD. Pp. 567-591.

Hingane LS (1991) Some aspects of carbon dioxide exchange between atmosphere and Indian plant biota. *Climate Change* **18:** 425-435.

Holtkamp R, Kardol P, vander Val A, Dekker S C vander Putten W H and de Ruiter P C (2008) Soil food web structure during ecosystem development after land abandonment. *Applied Soil Ecology* **39:** 23-34.

Hooper D U, Chapin F S, Ewel J J, Hector A, Inchausti P, Lavorel S, Lawton J H, Lodge D M, Loreau M, Naeem S, Schmid B, Setälä H, Symstad A J, Vandermeer J and Wardle D A (2005) Effects of biodiversity on ecosystem functioning: A consensus of current knowledge. *Ecological Monographs* **75:** 3-35.

Hope D, Zhu W, Gries C, Oleson J, Kaye J, Grimm N and Baker L (2005) Spatial variation in soil inorganic nitrogen across an arid urban ecosystem. *Urban Ecosystem* **8:** 251-273.

Hossain M I, Kashem M A and Osman K T (2014) Fertility status of some forested soils of Chittagong hill tracts, Bangladesh. *International Journal of Latest Research in Science and Technology* **3:** 82-87.

Houghton R A and Skole D L (1990) Carbon. In: *The earth as transformed by human action*, eds. Turner B L, Clark W C, Kates R W, Richards J F, Matthews J T and Meyer W B. Cambridge University Press, New York USA. Pp. 393-408.

Houghton RA (2005) Tropical deforestation as a source of greenhouse gas emissions. In: *Tropical Deforestation and Climate Change*, eds. Moutinho P and Schwartzman S. Instituto de Pesquisa Ambiental da Amazonia, Belem, and Environmental Defence, Washington DC. Pp 13–21.

Houghton R A, Hall F and Goetz S J (2009) Importance of biomass in the global carbon cycle. *Journal of Geophysical Research* **114:** G00E03, Doi: 10.1029/2009JG000935

Idiege D A, Ijomah J U, Amadi D C A, Agba O A and Lifu M (2014) Nutrient distribution of *Gmelina arborea* L. plantation on the slopes of Ukpon river forest

reserve of cross river state, Nigeria. *IOSR Journal of Environmental Science, Toxicology and Food Technology* **8:** 1-8.

Igwe C A and Obalum SE (2013) Microaggregate stability of tropical soils and its roles on soil erosion hazard prediction. In: *Advances in Agrophysical Research*, eds. Grundas S and Stępniewski A. Intech Publishers. Pp. 175-192.

Imani G, Boyemba F, Lewis S, Nabahungu NL, Calders K, Zapfack L, Riera B, Balegamire C and Cuni-Sanchez A (2017) Height-diameter allometry and above ground biomass in tropical montane forests: insights from the Albertine Rift in Africa. *PLoS ONE* **12:** 0179653.

Imoro Z A, Tom-Dery D and Kwadwo K A (2012) Assessment of soil quality improvement under Teak and Albizia. *Journal of Soil Science and Environmental Management* **3:** 91-96.

Ingle N R (2003) Seed dispersal by wind, birds, and bats between Philippine montane rainforest and successional vegetation.*Oecologia* **134:** 251-261.

Iqbal K, Bhat J A, Pala N A, Hussain A and Negi A K (2014) Carbon and biomass density of trees in Duggada area of Garhwal Himalaya. *Indian Forester* **140:** 18-22.

Iqbal K, Bhat J A, Pala N A and Negi A K (2012) Structure and composition estimation of plant species around Khoh river of Garhwal Himalaya, India. *Journal of Biodiversity and Environmental Sciences* **2:** 1-11.

Islam K R and Weil R R (2000) Land use effect on soil quality in a tropical forest ecosystem of Bangladesh. *Agriculture, Ecosystem and Environment* **79:** 9-16.

Ito S, Nakagawa M, Buckley G P and Nogami K (2003) Species richness in sugi (*Cryptomeria japonica* D. DON) plantations in southeastern Kyushu, Japan: the effects of stand type and age on understorey trees and shrubs. *Journal of Forestry Research* **8:** 49-57.

Iverson L R, Brown S, Grainger A, Prasad A and Liu D (1993) Carbon sequestration in tropical Asia: an assessment of technically suitable forest lands using geographic information systems analysis. *Climate Research* **3:** 23-38.

Jackson M L (1967) *Soil chemistry analysis*.Prentice Hall of India Pvt. Ltd., New Delhi.

Jana B K, Biswas S, Majumdar M, Roy P K, Mazumdar A (2009) Carbon superstation rate and above ground biomass, carbon potential of four young species. *Journal of Ecology and Natural Environment* **1:** 15-24.

Jasmin S K S and Birundha VD (2011) Adaptation to climate change through forest carbon sequestration in Tamil Nadu, India. *International Journal of Research in Commerce & Management* **1:** 36-40.

Jeddi K and Chaieb M (2012) Restoring degraded arid Mediterranean areas with exotic tree species: influence of an age sequence of *Acacia salicina* on soil and vegetation dynamics. *Flora* **207:** 693-700.

Jensen M (1995). *Trees commonly cultivated in south East Asia: Illustrated field guide*. RAP publication: 1995/38, FAO, Bangkok, Thailand.93p.

Jerabkova L, Prescott C E and Kishchuk B E (2006) Nitrogen availability in soil and forest floor of contrasting types of boreal mixed wood forests. *Canadian Journal of Forestry Research* **36:** 112-122.

Jha M N and Dimri B M (1991) Soil nutrient and forest productivity in four stands.*Journal of Indian Society Soil Science* **39:** 735-738.

Jha M N, Gupta M K and Dimri B M (1999) Soil organic matter status under different social forestry plantations. *Indian Forester* **125:** 883-890.

Jha M N, Rathore R K and Pande P (1984) Soil factor affecting the natural regeneration of silver fir and spruce in Himachal Pradesh. *Indian Forester* **110:** 293-298.

Jhariya M K (2017) Vegetation ecology and carbon sequestration potential of shrubs in tropics of Chhattisgarh, India. *Environmental Monitoring and Assessment* **189:** 518, Doi: 10.1007/s10661-017-6246-2.

Jhariya M K and Yadav D K (2018) Biomass and carbon storage pattern in natural and plantation forest ecosystem of Chhattisgarh, India. *Journal of Forestry and Environment Science* **34:** 1-11, Doi: 10.7747/JFES.2018.34.1.1

Jhariya M K, Banerjee A, Yadav D K and Raj A (2018) Leguminous trees an innovative tool for soil sustainability. In: *Legumes for soil health and sustainable management*, eds. Meena R S, Das A, Yadav G S and Lal R. Springer. Pp. 315-345.

Jiang Y J, Yuan D X and Zhang C (2006) Impact of land use change on soil properties in a typical karst agricultural region of southwest China: a case study of Xiaojiang watershed, Yunan. *Environmental Geography* **50:** 911-918.

Joao Carlos de M, Sa C, Cerri Carlos, Warren A D, Lal R, Solismar P, Venske F, Marisa C, Piccolo and Brigitte F (2001) Organic matter dynamics and carbon sequestration rates for a tillage chronosequence in Brazilian Oxisol . *Soil Science Society of America Journal* **65:** 1486-1499.

John P (2010) Carbon Farming. *Acres Australia* **18:** 28.

Johnson J F, Allmaras R R and Reicosky D C (2006) Estimating source carbon from crop residues, roots and rhizo deposits using the national grain-yield database. *Agronomy Journal* **98:** 622-636.

Johnston A E (1986) Soil organic matter; effects on soil and crops. *Soil Use and Management* **2:** 97-105.

Johnston DJ and Alongi DM (1995) Comparative study of soil properties in Mekong delta and Cao Mao Hill forest, Vietnam. *Canopy International* **25:** 6-7.

Jones J M and Richards B N (1977) Effect of reforestation on turnover of 15N-labeled nitrate and ammonia in relation to changes in soil microflora. *Soil Biology and Biochemistry* **9:** 383-392.

Juo A S R and Lal R (1977) The effects of fallow land continuous cultivation on the chemical and physical properties of Alfisols in western Nigeria. *Plant and Soil* **47:** 517-589.

Justine M F, Yang W, Wu F, Tan B, Khan M N and Zhao Y (2015) Biomass stock and carbon sequestration in a chronosequence of *Pinus massoniana* plantations in the upper reaches of the Yangtze River. *Forests* **6:** 3665-3682.

Kanime N, Kaushal R, Tewari S K, Rivera K P, Chaturvedi S and Chaturvedi O P (2013) Biomass production and carbon sequestration in different tree-based systems of central Himalayan tarai region. *Forest Trees and Livelihoods* **22:** 38-50.

Kaonga M L and Bayliss-Smith T P (2009) Carbon pools in tree biomass and the soil in improved fallows in eastern Zambia. *Agroforestry Systems* **76:** 37-51.

Karizumi N (1974) The mechanism and function of tree root in the process of forest production II – root biomass and distribution in stands. *Bulletin of the Imperial Forest Experiment Station* **267:** 1-88.

Karthick A and Pragasan L A (2014) Stand structure and above-ground biomass of two tree plantations at Bharathiar University, Coimbatore.*Indian Forester* **140:** 29-33.

Kaswala R, Patel V, Chakraborty M and Kamath A V (2012) Phytochemical and pharmacological profile *Gmelina arborea*: an overview. *International Research Journal of Pharmacy* **3:** 21-64.

Kaye J P McCulley R L and Burke I C (2005) Carbon fluxes, nitrogen cycling and soil microbial communities in adjacent urban, native and agricultural ecosystems. *Global Change Biology* **11:** 575-587.

Kenzo T, Ichie T, Hattori D, Itioka T, Handa C, Ohkubo T, Kendawang J J, Nakamura M, Sakaguchi M, Takahashi N, Okamoto M, Tanaka-Oda A, Sakurai Kand Ninomiya I (2009) Development of allometric relationships for accurate estimation of above- and below-ground biomass in tropical secondary forests in Sarawak, Malaysia. *Journal of Tropical Ecology* **25:** 371-386.

Kershaw K A (1973) *Quantitative and Dynamic Plant Ecology*. 3rd edition. ELBS and Edward Arnold Ltd, London. 308p.

Ketterings Q N, Coe R, Noordwijk M V, Amvagau Y and Palmca C A (2001) Reducing uncertainty in the use of allometric biomass equation for predicting above ground tree biomass in mixed secondary forests. *Forest Ecology and Management* **146:** 199-209.

Khera N, Mehta V and Sabata B (2009) Interrelationship of birds and habitat features in urban green spaces in Delhi, India. *Urban Forestry Urban Greening* **8:**187-196.

Khera N, Kumar A, Ram J and Tewari A (2001) Plant biodiversity assessment in relation to disturbances in mid-elevational forest of Central Himalaya, India. *Tropical Ecology* **42:** 83-95.

Khlifa R, Paquette A, Messier C, Reich PB and Munson A D (2017) Do temperate treespecies diversity and identity influence soil microbial community function andcomposition? *Ecology and Evolution* **7:** 7965-7974.

Kim J H, Jobbagy E G and Jackson R B (2016) Trade-offs in water and carbon ecosystem services with land-use changes in grasslands. *Ecological Application* **26:** 1633-1644.

Kim S-G, Kwon B, Son Y and Yi M J (2018) Carbon Storage in an Age-Sequence of Temperate *Quercus mongolica* Stands in Central Korea. *Journal of Forest and Environment Science* **34:** 472-480.

Kimble J M, Rice C W, Reed D, Mooney S, Follett R F and Lal R (2007) *Soil Carbon Management: Economic, Environmental and Societal Benefits*. CRC Press, Boca Raton, F L, USA. 280p.

Kimmins JP (2004) *Forest Ecology: A Foundation for Sustainable Forest Management and Environmental Ethics in Forestry*, third ed. Pearson Prentice Hall, Inc., New Jersey, 700p.

Kongmeesup I and Boonyanuphap J (2019) Estimation of carbon offset for teak plantationin lower northern Thailand. *Songklanakarin Journal of Science and Technology* **41:** 580-586.

Koul D N (2004) *Carbon sequestration estimates of various land uses in Terai Zone of West Bengal.* M. Sc. Thesis. Uttar Banga Krishi Viswavidyalaya, Pundibari, West Bengal.Unpubl.

Koul D N, Shukla G, Panwar P and Chakravarty S (2011) Status of soil carbon sequestration under different land use system in Terai Zone of West Bengal. *Environment & We International Journal of Science and Technology* **6:** 95-100.

Koul DN and Panwar P (2008) Prioritizing land management options for carbon sequestration potential. *Current Science* **95:** 658-663.

Krischbaum M U F (2000) Will changes in soil organic carbon act as a positive or negative feed-back on global warming? *Biogeochemistry* **48:** 21-51.

Krishnaswamy V S and Puri G S (1954) Results of an experiment to study the succession of ground flora species under forest plantations raised on old agricultural land in the new forest, Dehradun, India. *Indian Forester* **80:** 522-530.

Kumar A (2007) Growth performance and variability in different clones of *Gmelina arborea* (Roxb). *Silvae Genetica* **56:** 32-35.

Kumar B M and Nair P K R (2011) *Carbon sequestration potential of agroforestry systems: opportunity and challenges*. Springer, Dordrecht/Heidelberg/London. 307p.

Kumar K (2017) *Developing Prediction Models for Biomass Components of Gmelina arborea (Roxb.).* Master Thesis. Punjab Agricultural University, Ludhiana. Unpubl.

Kumar K and Chaudhuri M R (1997) Phosphorus fractions as affected by different land uses in acid hill soils of Monupur. *Journal of the Indian Society of Soil Science* **45:** 574-577.

Kumar M, Rajwar G S and Sharma C M (2004) Physico-Chemical properties of forest soils along altitudinal gradient in the Garhwal Himalayas. *Journal of Hill Research* **17:** 60-64.

Kumar P, Mishra A K, Chaudhari S K, Sharma D K, Rai A K, Singh K, Rai P and Singh R (2020) Carbon sequestration and soil carbon build-up under Eucalyptus plantation in semi-arid regions of north west India. *Journal of Sustainable Forestry*, http://doi.org/10.1080/10549811.2020.1749856

Kumar S and Satapathy M K (2011) Medicinal plants in an urban environment; herbaceous medicinal flora from the campus of regional Institute of Education,

Bhubaneswar, Odisha. *International Journal of Pharmacy and Life Sciences* **2:** 1206-1210.

Kumar S, Das G, Han-Seung S, Kumar P and Patra J K (2018) Diversity of plant species in the steel city of Odisha, India: ethnobotany and implications for conservation of urban bio-resources. *Brazilian Archives of Biolog and Technology* **61:** e18160650.

Kumar A, Marcot B G and Saxena A (2006) Tree species diversity and distribution patterns in tropical forests of Garo hills. *Current Science* **91:** 1370-1381.

Kumar L and Mutanga O (2017) Remote sensing of above-ground biomass. *Remote Sensing* **9:** 935, Doi: 10.3390/rs9090935

Kumar M and Pandey R (2017) Carbon stock loss of Chir pine forest through tree felling in Lower Himalaya. *Environmental Risk Assessment Remediation* **1:** 19-21.

Labata M M, Aranico E C, Tabaranza A C E, Patricio J H P and Amparado Jr. R F (2012) Carbon stock assessment of three selected agroforestry systems in Bukidnon, Philippines. *Advances in Environmental Sciences* **4:** 5-11.

Lal C, Singh L, Attri V and Sarvade S (2015) Tree species diversity, distribution and population structure in tropical dry deciduous forests of Chhattisgarh, India. *Journal of Applied and Natural Science* **7:** 681-685.

Lal M and Singh R (2000) Carbon sequestration potential of Indian forests. *Environment Monitoring and Assessment* **60:** 315-327.

Lal R (2003) Global potential of soil carbon sequestration to mitigate the greenhouse effect.*Critical Review on Plant Science* **22:** 151-184.

Lal R (2004) Soil carbon sequestration impacts on global climate change and food security. *Science* **304:** 1623-1627.

Lal R (2005) Forest soils and carbon sequestration.*Forest Ecology and Management* **220:** 242-258.

Lal R (2016) Beyond COP 21: potential and challenges of the "4 per Thousand" initiative. *Journal of Soil Water Conservation* **71:** 20A-25A.

Lal R, Kimble J M, Follett R and Cole C V (1998) *The Potential of US Cropland to Sequester Carbon and Mitigate the Greenhouse Effect*. Sleeping Bear Press, Chelsea, MI. 144p.

Lal R, Kimble J M, Levines E and Whiteman C (1995) World soil and greenhouse effect: an overview In: *Soil and Global Change*, eds. Lal R, Kimble J M, Levines E and Stewart B A. CRC Press, Boca Raton FL. Pp. 1-25.

Lal S H, Bajracharya R M and Sitaula B K (2012) Forest and Soil Carbon Stocks, Pools and Dynamics and Potential Climate Change Mitigation in Nepal. *Journal of Environmental Science and Engineering B* **1:** 800-811.

Lam S K, Chen D, Mosier A R and Roush R (2013) The potential for carbon sequestration in Australian agricultural soils is technically and economically limited. *Scientific Reports* **3:** 2179, Doi: 10.1038/srep02179

Lamb D (2018) Undertaking large-scale forest restoration to generate ecosystem services. *Restoration Ecology* **26:** 657-666.

Lamb D, Erskine P D and Parrotta J A (2005) Restoration of degraded tropical forest landscapes. *Science* **310:** 1628-1632.

Lehmann J and Kleber M (2015) The contentious nature of soil organic matter. *Nature* **528:** 60-68.

Leite F R, Silva I R, Novais R F, Barros N F de, Neves J C L and Villani E M de A (2011) Nutrient relations during an eucalyptus cycle at different population densities. *Revista Brasileira de Ciência do Solo* **35:** 949-959.

Leskiw L A (1998) *Land capability classification for forest ecosystem in the oil stands region*. Alberia Environmental Protection, Edmonton.

Lewis S L, Sonke´ B, Sunderland T, Begne S K, Lopez-Gonzalez G, van der Heijden G M F, Phillips O L, Affum-Baffoe K, Baker T R, Banin L, Bastin J-F, Beeckman H, Boeckx P, Bogaert J, De Cannière C, Chezeaux E, Clark C J, Collins M, Djagbletey G, Djuikouo M N K, Droissart V, Doucet J-L, Ewango C E N, Fauset S, Feldpausch T R, Foli E G, Gillet J-F, Hamilton A C, Harris D J, Hart T B, de Haulleville T, Hladik A, Hufkens K, Huygens D, Jeanmart P, Jeffery K J, Kearsley E, Leal M E, Lloyd J, Lovett J C, Makana J-R, Malhi Y, Marshall A R, Ojo L, Peh K S-H, Pickavance G, Poulsen J R, Reitsma J M, Sheil D, Simo M, Steppe K, Taedoumg H E, Talbot J, Taplin J R D, Taylor D, Thomas S C, Toirambe B, Verbeeck H, Vleminckx J, White L J T, Willcock S, Woell H and Zemagho L (2013) Above-ground biomass and structure of 260 African tropical forests. *Philosophical Transactions of the Royal Society B* **368:** 20120295, Doi: 10.1098/rstb.2012.0295

Lin D, Anderson-Teixeira K J, Lai J, Mi X, Ren H and Ma K (2016) Traits of dominanttree species predict local scale variation in forest aboveground and topsoil carbonstocks. *Plant and Soil* **409:** 435-446.

Liu S and Yu X (2009) Nutrient cycling of planted forest of *Pinus tabulaeformis* in the Miyun Reservoir Watershed, Beijing. *Frontiers of Forestry in China* **4:** 46-52.

Livesley S J, Ossola A, Threlfall C G, Hahs A K and Williams NSG (2016) Soil carbon and carbon/nitrogen ratio change under tree canopy, tall grass, and turf grass areas of urban green space. *Journal of Environmental Quality* **45:** 215-223.

Lodhiyal L S and Lodhiyal N (1997) Variation in biomass and net primary productivity in short rotation high density central Himalayan poplar plantations. *Forest Ecological and Management* **98:** 167-179.

Lodhiyal L S, Singh R P and Singh S P (1995) Structure and function of an age series of poplar plantation in central Himalaya. I. Dry matter dynamics. *Annals of Botany* **76:** 191-199.

Ludwig F, de Kroon H, Berendse F and Prins H H T (2004) The influence of savanna trees on nutrient, water and light availability and the understorey vegetation. *Plant Ecology* **170:** 93-105.

Lugo A E (1997) The apparent paradox of re-establishing species richness on degraded lands with tree monocultures. *Forest Ecology and Management* **99:** 9-19.

Luyssaert S, Schulze E D, Börner A, Knohl A, Hessenmöller D, Law B E, Ciais P and Grace J (2008) Old-growth forests as global carbon sinks. *Nature* **455:** 213.

Ma J and Liu Q (2003) Flora of Beijing: an overview and suggestion for future research. *Urban Habitats* **3:** 30-44.

Mac Lean D A and Wein RW (1977) Nutrient accumulation for post fire jack pine and hardwood succession patterns in New Brunswick. *Canadian Journal of Forestry Research* **7:** 562-578.

Mace G M, Norris K and Fitter A H (2012) Biodiversity and ecosystem services: a multilayered relationship. *Trends in Ecology and Evolution* **27:** 19-26.

MacDicken K G (1997) *A guide to monitoring carbon storage in forestry and agroforestry project*. USA, Winrock International Institute for Agricultural Development.

Maeght J-L, Rewald B and Pierret A (2013) How to study deep roots – and why it matters. *Frontiers in Plant Science* **4:** 299, Doi: 10.3389/fpls.2013.00299.

Magar L B, Khadka S, Pokharel U, Rana N, Thapa P, Khadka U, Joshi J R, Sharma R K, Thapa G, Marasini B P and Parajuli N (2018) Total Biomass Carbon Sequestration Ability under the Changing Climatic Condition by *Paulownia*

tomentosa Steud. *International Journal of Applied Science and Biotechnology* **6:** 220-226.

Mahendrappa M K, Foster N W, Weetman G F and Krause H H (1986) Nutrient cycling and availability in forest soils. *Canadian Journal of Soil Science* **66:** 547-572.

Maity D, Pardhan N and Chauhan A S (2004) Folk uses of some medicinal plants from North Sikkim. *Indian Journal of Traditional Knowledge* **3:** 66-71.

Maji A K, Obi Reddy G P and Sarkar D (2010) *Degraded and Wastelands of India Status and Spatial Distribution*. Indian Council of Agricultural Research New Delhi.

Malhi Y, Danielwoodw W, Baker T R, Wright J, Phillips O L, Cochranek T, MEIR P, Chave J, Almeida S, Arroyo L, Higuchi N, Killeen T J, Laurancekk S G, Laurancekk W F, Lewis S L, Monteagudo A, Neillzzz D A, Vargas P N, Pitman C A N, Quesada C A, Saloma R, Silvakkk J N M, Lezama A T, Terborgh J, Martinez, R V and Vincetizz B (2006) The regional variation of aboveground live biomass in old-growth Amazonian forests.*Global Change Biology* **12:** 1107-1138.

Mandal B (2011) The 29th Professor JN Mukherjee-ISSS Foundation lecture-soil organic carbon research in India- a way forward. *Journal of Indian Society of Soil Science* **59:** S9.

Mandal B, Majumder B Adhya T K, Bandyopadhyay P K, Gangopadhyay A, Sarkar D, Kundu M C, Choudhury S G, Hazra G C, Kundu S, Samantaray R N and Misra A K (2008) Potential of double-cropped rice ecology to conserve organic carbon under sub-tropical climate. *Global Change and Biology***14:** 2139-2151.

Mandal B, Majumder B, Bandyopadhyay P K, Hazra G C, Gangopadhyay A, Samantaray R N, Mishra A K, Chaudhury J, Saha M N and Kundu S (2007) The potential of cropping systems and soil amendments for carbon sequestration in soils under long-term experiments in subtropical India. *Global Change and Biology* **13:** 357-369.

Mandal G and Joshi S P (2014) Biomass accumulation and carbon sequestration potential of *Shorea robusta* and *Lantana camara* from the dry deciduous forests of Doon Valley, western Himalaya, India. *International Journal of Environmental Biology* **4:** 157-169.

Mandari D Z, Gunawan H and dan Isda M N (2016) Penaksiran biomass adankar bontersim panpadae kosistemhutan mangrove di kawasan Bandar Bakau Dumai. *Jurnal Riau Biologia* **1:** 17-23.

Mangalassery S Dayal D, Meena S L and Ram B (2014) Carbon sequestration in agroforestry and pasture systems in arid north western India. *Current Science* **107:** 1290-1293.

Manhas R K, Chauhan P S, Singh M L and Negi J D S (2011) Structure and diversity of 80-yr-old plantations after successional colonization of the natives. *Current Science* **100:** 714-725.

Manimegalai A (2012) Allelopathic effect of *Tectona grandis* leaves on protein content changes of black gram and green gram. *International Journal of Current Sciences* **4:** 30-34.

Manna M C, Swarup A, Wanjari R H and Ravankar H N (2007) Long-term effect of NPK fertilizer and manure on soil fertility and a sorghum-wheat farming system. *Australian Journal of Experimental Agriculture* **47:** 700-711.

Martin P H, Sherman R E and Fahey T J (2004) Forty years of tropical forest recovery from agriculture: structure and floristics of secondary and old-growth riparian forests in the Dominican Republic. *Biotropica* **36:** 297-317.

Mary A A, Steven P H and Siccama T (2001) Validating allometric estimates of aboveground living biomass and nutrient contents of a northern hardwood forest. *Canadian Journal of Forest Research* **31:** 11-17.

Mathur H N and Soni P (1983) Comparative account of undergrowth under eucalyptus and sal in three different localities in Doon Valley. *Indian Forester* **109:** 882-890.

McCarl B A and Schneider U A (2001) Greenhouse gas mitigation in U.S. agriculture and forestry. *Science* **294:** 2481-2482.

McHale M R, Burke I C, Lefsky M A, Peper P J and McPherson E G (2009) Urban forest biomass estimates: is it important to use allometric relationships developed specifically for urban trees? *Urban Ecosystem* **12:** 95-113.

McNicol I M, Berry N J, Bruun T B, Hergoualch K, Mertz O, de Neergaard A, Ryan C M (2015) Development of allometric models for above and belowground biomass in swidden cultivation fallows of Northern Laos. *Forest Ecology and Management* **357:** 104-116.

Meena A, Bidalia A, Hanirf M, Dinakaran J and Rao KS (2019) Assessment of above- and belowground carbon pools in a semi-arid forest ecosystem of Delhi, India. *Ecological Process* **8:** 8, Doi: 10.1186/s13717-019-0163-y

Menhinick E F (1964) A comparison of some species diversity indices applied to samples of field insects. *Ecology* **45:** 858-861.

Metting F B, Smith J L, Amthor J S and Izaurralde R C (2001) Science needs and new technology for increasing soil carbon sequestration. *Climatic Change* **51:** 11-34.

Milcu A, Roscher C, Gessler A, Bachmann D, Gockele A, Guderle M, Landais D, Piel C, Escape C, Devidal S and Ravel O (2014) Functional diversity of leaf nitrogen concentrations drives grassland carbon fluxes. *Ecology Letters* **17:** 435-444.

Minasny B, Malone B P, McBratney A B, Angers D A, Arrouays D, Chambers A, Chaplot V, Chen Z.-S, Cheng K, Das B S, Field D, Gimona A, Hedley C B, Hong SY, Mandal B, Marchant B P, Martin M, McConkey B G, Mulder V L, O'Rourke S, Richer-de-Forges A C, Odeh I, Padarian J, Paustian K, Pan G, Poggio L, Savin I, Stolbovoy V, Stockmann U, Sulaeman Y, Tsui C C, Vågen T-G, van Wesemael B and Winowiecki L (2017) Soil carbon 4 per mile. *Geoderma* **292:** 59-86.

Mishra R (1968) *Ecology Work Book*. Oxford and IBH Publishing Co., New Delhi.

Mishra A, Sharma S D, Khan GH (2003) Improvement in physical and chemical properties of sodic soil by 3, 6- and 9-years old plantation of Eucalyptus tereticornis bio rejuvenation of sodic soil. *Forest Ecology and Management* **184:** 115-124.

Mishra G, Jangir A and Francaviglia R (2019) Modelling soil organic carbon dynamics under shifting cultivation and forests using Rothc model. *Ecological Modelling* **396:** 33-41.

Mitchell H L and Chandler R F (1939) *The nitrogen nutrition and growth of certain deciduous trees of Northeastern United States*. The Blackrock Forest Bulletin no. 11. Cornwall-on-the-Hudson, NY.

Mitra A and Zaman S (2014) *Carbon Sequestration by Coastal Floral Community*. TERI, New Delhi.

Mohandass D, Hughes A C, Mackay B, Davidar P and Chhabra T (2016) Floristic species composition and structure of a mid-elevation tropical montane evergreen forests (sholas) of the western Ghats, southern India. *Tropical Ecology* **57:** 533-543.

Mokany K, Raison R J and Prokushkin A S (2006) Critical analysis of root: shoot ratios in terrestrial biomes. *Global Change Biology* **12:** 84–96.

Mongia A D and Bandyopadhyay A K (1994) Soil nutrients under natural and planted forest in island ecosystem.*Journal of Indian Society of Soil Science* **42:** 43-46.

Morhart C, Sheppard J P, Schuler J K and Spiecker H (2016) Above-ground woody biomass allocation and within tree carbon and nutrient distribution of wild cherry

(*Prunus avium L.*)- a case study. *Forest Ecosystems* **3:** 4, Doi: 10.1186/s40663-016-0063-x.

Müller N, Werner P and Kelcey J G (2010) *Urban biodiversity and design*. Conservation Science and Practices Series No. 7. Blackwell Publishing Ltd. Oxford, England.

Muratet A, Porcher E, Devictor V, Arnal G, Moret J, Wright S and Machon N (2008) Evaluation of floristic diversity in urban areas as a basis for habitat management. *Applied Vegetation Science* **11:** 451-460.

Murphy H P (1958) *The fertility status of some soils of Ethiopia*. College of Agriculture, Jimma.

Muscarella R and Fleming T H (2007) The role of frugivorous bats in tropical forest succession. *Biological Reviews* **82:** 573-590.

Naeem S (2009) Biodiversity ecosystem functioning and human wellbeing: An ecological and economic perspective. *Ecological and Economic Perspective* **281:** 102-112.

Nagebdra H and Gopal D (2010) Tree diversity distribution history and change in urban parks: studies in Bangalore, India. *Urban ecosystem* **2:** 88-102.

Nath A J, Tiwari B K, Sileshi G W, Sahoo U K, Brahma B, Deb S, Devi N B, Das A K, Reang D, Chaturvedi S S, Tripathi O P, Das D J and Gupta A (2019) Allometric models for estimation of forest biomass in north east India. *Forests*, Doi: 10.3390/f10020103.

Nazir T (2009) *Estimation of site quality of important temperate forest cover on the basis of soil nutrient and growing stock in Garhwal Himalaya*. D. Phil. Thesis, HNB Garhwal University, Srinagar (Garhwal), Uttarakhand, India.

Nazir T and Netajini N (2014) Economic valuation of NPK and soil vegetation interrelationship in three forest types of Dehradun. *Nature and Science* **12:** 80-87.

Negi J D S (1984) *Biological productivity and cycling of nutrients in managed and man-made ecosystems*.Ph. D Dissertation, Garhwal University, Srinagar.Unpubl.

Negi J D S and Sharma S C (1984) Biomass and nutrient distribution in an age series of *Eucalyptus* hybrid plantation and *Acacia auriculiformis* in Bihar. *Indian Forester* **111:** 1111-1112.

Negi S C and Nautiyal S (2005) Phyto-sociological studies of a traditional reserve forest – Thal Ke Dhar, Pithoragarh, Central Himalayas.*Indian Forester* **131**: 519-34.

Ngo K M, Turner B L, Muller-Landau H C, Davies S J, Larjavaara M, Hassan N, Fbin N and Lum S (2013) Carbon stocks in primary and secondary tropical forests in Singapore. *Forest Ecology and Management* **296:** 81-89.

Nicholson S A and Monk C D (1974) Plant diversity in old field succession on the Georgia piedmont. *Ecology* **55:** 1075-1085.

Niinemets U, Portsumuth A and Tobias M (2007) Leaf shape and venation pattern alter the support investments within leaf lamina in temperate species: neglected sources of leaf physiological differentiation. *Functional Ecology* **21:** 28-40.

Niiyama K, Kajimoto T, Matsuura Y, Yamashita T, Matsuo N, Yashiro Y, Ripin A, Kassim A R and Noor N S (2010) Estimation of root biomass based on excavation of individual root systems in a primary dipterocarp forest in Pasoh Forest Reserve, Peninsular Malaysia. *Journal of Tropical Ecology* **26:** 271-284.

Nowak D J and Crane D E (2002) Carbon storage and sequestration by urban trees in the USA, *Environment Pollution* **116:** 381-389.

Nowak D J, Noble M H, Sisinni S M and Dwyer J F (2001) Assessing the US urban forest resource. *Journal of Forestry* **99:** 37-42.

Nyambane D O Njoroge J B and Watako A O (2016) Assessment of tree species distribution and diversity in the major urban green spaces of Nairobi city, Kenya. Journal of Horticulture and Forestry **8:** 12-23.

O'Neill K P, Richter D D and Kasischke E S (2006) Succession-driven changes in soil respiration following fire in black spruce stands of interior Alaska. *Biogeochemistry* **80:** 1-20.

Odum E P (1971) *Fundamentals of Ecology* (3rd edn.). W. B. Saunders Co., Philadelphia.

Oelbermann M, Voroney R P and Gordon A M (2004) Carbon sequestration in tropical and temperate agroforestry systems: a review with examples from Costa Rica and Southern Canada. *Agriculture Ecosystems and Environment* **104:** 359-377.

Oelbermann M M (2002) *Linking carbon inputs to sustainable agriculture in Canadian and Costa Rican*. Agroforestry systems. Ph. D. Thesis. University of Guelph.

Ogidiolu A (1997) *Productivity of cultivated indigenous tropical tree species (Terminalia ivorensis and Triplochiton scleroxylon in relation to site characteristics in a part of Southwestern Nigeria*. Ph. D. Thesis, University of Ibadan. Unpubl.

Okagbare G O, Akpodiete O J, Esiekpe O and Onagbesan O M (2004) Evaluation of *Gmelina arborea* leaves supplemented with grasses (*Panicum maximum* and *Pennisetum purpureum*) as feed for West Africa dwarf Goats. *Tropical Animal Health and Production* **36:** 593-598.

Onyekwelu J C (2004) Above-ground biomass production and biomass equations for even-aged *Gmelina arborea* (Roxb) plantations in south-western Nigeria. *Biomass and Bioenergy* **26:** 39-46.

Onyekwelu J C (2002) *Growth characteristics and management scenarios for plantation-grown Gmelina and Nauclea in SW Nigeria*. Hieronymus Verlag, Munich, Germany. 196p.

Orwa C, Mutua A, Kindt R, Jamnadass R and Simons A (2009) *Agroforestree Database: a tree reference and selection guide version 4.0*. Available at http://www.worldagroforestry.org/af/treedb/.

Osman K T, Rahman M M and Sikder S (2002) Growth and nutrition of some forest tree species in Bangladesh, *Annals of Forestry* **10:** 214-227.

Osuntogun CA (2001) *Challenges for environment and sustainable Development in Nigeria in the 21st Century*. Public lectures, Institute of Ecology and Environmental Studies, Obafemi Awolowo University, Ile-Ife.

Ota H O, Daniel A, Christopher O C, Obianuju O C and Nte N J (2018). Influence of tree plantation *Gmelina* arborea And Gliricidia sepium on soil physico-chemical properties in Abakaliki, Southeast, Nigeria. *Acta Chemica Malaysia* **2:** 23-28.

Owen J (2010) *Wildlife of a garden: a thirty-year study*. Royal Horticultural Society. Peterborough, Cambridgeshire, UK.

Pal D K, Wani S P and Sahrawat K L (2015) Carbon Sequestration in Indian Soils: Present Status and the Potential. *Proceedings of the National Academy of Sciences, India - Section B: Biological Sciences* **85:** 337-358.

Pala N A, Sarkar B C, Gokhale Y, Manohar A K, Shukla G and Chakravarty S (2020) Potential of homestead gardens to gain from global carbon markets to mitigate climate change in Cooch Behar, West Bengal. *Indian Forester* **146:** 159-164.

Pande P K (2001) Litter nutrient dynamics of *Shorea robusta* Gaertn. plantation at Doon Valley (Uttaranchal), India. *Indian Forester* **127:** 980-994.

Pande P K, Bisht A P S and Sharma S C (1988) Comparative vegetation analysis of some plantation ecosystems. *Indian Forester* **114:** 379-389.

Pande P K, Negi J D S and Sharma S C (2001) Plant species diversity and vegetation analysis in moist temperate Himalayan forest. *Indian Journal of Forestry* **24:** 456-470.

Pandey M C, Tandon V N and Rawat H S (1987) Organic matter production and distribution of nutrient in eucalyptus hybrid plantation ecosystem in Karnataka. *Indian Forester* **114:** 713-724.

Pandey R (2000). Forestry and sustainable livelihoods: What part can forests and forestry play in reducing poverty? *Unasylva* **202:** 3-12.

Pandey U, Kushwaha S P S, Kachhwaha T S, Kunwar P and Dadhwal V K (2010) Potential of Envisat ASAR data for woody biomass assessment. *Tropical Ecology* **51:** 117-124.

Pandey R, Rawat G S and Kishwan J (2011) Changes in distributions of carbon in various forest types of India from 1995-2005. *Silva Lusitana* **19:** 41-54.

Panskus A B, Breckling B and Hamberger S (2013) Cultivation-independent establishment of genetically engineered plants in natural populations: current evidence and implications for EU regulation. *Environmental Sciences Europe* **25:** 34-35.

Panwar P, Pal S, Reza S K and Sharma B (2011) Soil fertility index, soil evaluation factor and microbial indices under different land use in acidic soil of humid subtropical India. *Communication in soil Science and Plant Analysis* **42:** 2724-2737.

Paquette A and Messier C (2011) The effect of biodiversity on tree productivity: from temperate to boreal forests. *Global Ecology and Biogeography* **20:** 170-180.

Parrotta J A (1992) The role of plantation forests in rehabilitating degraded tropical ecosystems. *Agriculture, Ecosystem and Environment* **41:** 115-133.

Parrotta J A (1995) Influence of overstorey composition on understory colonization by native species in plantations on a degraded tropical site.*Journal of Vegetation Science* **6:** 627-636.

Parrotta J, Turnbull J and Jones N (1997) Catalyzing native forest regeneration on degraded tropical lands. *Forest Ecology and Management* **99:** 1-7.

Pastor J, Aber J D, Mc Clangherty C A and Melillo J M (1984) Above ground production and N and P cycling along a nitrogen mineralization gradient on black hank island. *Wisconsin Ecology* **65:** 256-268.

Pathak H, Byjesh K, Chakrabarti B and Aggarwal P K (2011) Potential and cost of carbon sequestration in Indian agriculture: estimates from long-term field experiments. *Field Crop Research* **120:** 102-111.

Pathala D, Harini A and Hegde P L (2015) A Review on Gambhari (*Gmelina arborea* Roxb.). *Journal of Pharmacognosy and Phytochemistry* **4:** 127-132.

Paudel S and Sah J P (2003) Physiochemical characteristic of soil in Sal (*Shorea robusta*) forests in eastern Nepal. *Himalayan Journal of Sciences* **1:** 107-110.

Paustian K, Andren O, Janzen H H, Lal R and Smith P, Tian G, Tiessen H, Van Noordwijk M and Woomer P L (2007) Agricultural soils as a sink to mitigate CO_2 emissions. *Soil Use and Management* **13:** 230-244.

Paustian K, Cole C V, Sauerbeck D and Sampson N (1998) CO_2 mitigation by agriculture: An overview. *Climate Change* **40:** 135-162.

Paustian K, Lehmann J, Ogle S, Reay D, Robertson G P and Smith P (2016) Climate-smart soils. *Nature* **532:** 49-57.

Peichl M and Arain M A (2006) Above- and below ground ecosystem biomass and carbon pools in an age-sequence of temperate pine plantation forests. *Agriculture and Forest Meteorology* **140:** 51-63.

Peichl M and Arain M A (2007) Allometry and partitioning of above and belowground tree biomass in an age-sequence of white pine forests. *Forest Ecology and Management* **253:** 68-80.

Pérez CA, Carmona MR, Aravena J C and Armesto J J(2004) Successional changes in soil nitrogen availability, non-symbiotic nitrogen fixation and carbon/nitrogen ratios in southern Chilean forest ecosystems. *Oecologia* **140:** 617-625.

Phillips E A (1959) *Methods of Vegetation Study*. Henry Holt and Co. Inc., New York.

Phillips R, Brzostek E and Midgley M (2013) The mycorrhizal-associated nutrient economy: a new framework for predicting carbon–nutrient couplings in temperate forests. *New Phytologist* **199:** 41-51.

Piccoli I Chiarini F, Carletti P, Furlan L, Lazzaro B, Nardi S, Berti A, Sartori L, Dalconi M C and Morari F (2016) Disentangling the effects of conservation agriculture practices on the vertical distribution of soil organic carbon. Evidence of poor carbon sequestration in North-Eastern Italy.*Agriculture Ecosystem and Environment* **230:** 68-78.

Pickett S T A, Cadenasso M L, Grove J M, Nilon C H, Pouyat R V, Zipperer W C and Costanza R (2001) Urban ecological systems: linking terrestrial ecological, physical, and socioeconomic components of metropolitan areas. *Annual Review of Ecology and Systematics* **32:** 127-157.

Pickup M, Westoby M and Basden A (2005) Dry mass costs of developing leaf area in relation to leaf size. *Functional Ecology* **19:** 88-97.

Pielou E C (1966) The measurement of diversity in different types of biological collections. *Journal of Theoretical Biology* **13:** 131-144.

Pieniak B F and Chylinski K (2012) Diversity of spontaneous flora of unused industrial buildings in Warsaw, Poland. *Ekológia (Bratislava)* **31:** 379-389.

Piper C (1950) *Soil and Plant Analysis*. International Public Inc., New York.

Piper C S (1966) *Soil and plant analysis*. Maver Publisher, Bombay, India.

Poeplau C and Don A (2013) Sensitivity of soil organic carbon stocks and fractions to different land-use changes across Europe. *Geoderma* **192:** 189-201.

Ponge J F (2003) Humus forms in terrestrial ecosystems: a framework to biodiversity. *Soil Biology and Biochemistry* **35:** 935-945.

Pooja V, Arvind B, Anil S and Monmohan J R D (2017) Scaling up an indigenous tree based agroforestry system India. *International Journal of Science and Qualitative Analysis* **3:** 73-77.

Poorter L, van der Sande M T, Aret, E J M M, Ascarrunz N, Enquist B, Finegan B, Licona J C, Martínez-Ramos M, Mazzei L, Meave J A, Munoz R, Nytch C J, de Oliveira A A, Perez-García E A, Prado-Junior J, Rodríguez-Velazques J, Ruschel A R, Salgado-Negret B, Schiavini I, Swenson N G, Tenorio E A, Thompson J, Toledo M, Uriarte M, van der Hout P, Zimmerman J K and Pena-Claros M (2017) Biodiversity and climate determine the functioning of Neotropical forests. *Global Ecology and Biogeography* **26:** 1423-1434.

Post W M and Kwon K C (2000) Soil carbon sequestration and land-use change: processes and potential. *Global Change Biology* **6:** 317-327.

Post W M, Izaurralde R C, Mann L K, Bliss N (2001) Monitoring and verifying changes of organic carbon in soil. *Climate Change* **51:** 73-99.

Post W M, Emanuel W R, Zinke P J and Stangenberger A G (1982) Soil pools and world life zone. *Nature* **298:** 156-59.

Poudel G S and Thapa G B (2001) Changing farmer's land management practices in the hills of Nepal. *Environmental Managegement* **28:** 789-803.

Pouyat R V, Yesilonis I D, Russell-Anelli J and Neerchal K N (2007) Soil chemical and physical properties that differentiate urban land-use and cover types. *Soil Science* **71:** 1010-1019.

Pouyat R V, Szlavecz K, Yesilonis I D, Groffman P M and Schwarz K (2010) Chemical, physical, and biological characteristics of urban soils. In: Agronomy Monograph 55. *Urban Ecosystem Ecology*eds. Aitkenhead-Peterson J and Volder A. Pp. 119-152.

Powers J S, Haggar J P and Fisher R F (1997) The effect of overstorey composition on understory woody regeneration and species richness in seven year old plantations in Costa Rica. *Forest Ecology and Management* **99:** 43-54.

Powlson D and Johnston J (2015) Potential soil organic matter benefits from mixed farming: evidence from long-term experiments. *From Sustainable Food Trust Meeting: What Role for Grazing*. Available at http://www.slideshare.net/Sustainablefoodtrust/david-powlson

Powlson D S, Stirling C M, Jat M L, Gerard B G, Palm C A, Sanchez P A and Cassman K G (2014) Limited potential of no-till agriculture for climate change mitigation. *National Climate Change* **4:** 678-683.

Powlson D S, Whitmore A P and Goulding K W (2011) Soil carbon sequestration to mitigate climate change: a critical re-examination to identify the true and the false. *European Journal of Soil Science* **62:** 42-55.

Prabha A C S, Senthivelu M and Paramasivam A (2014) Carbon sequestration potential in different land uses: a review. *International Journal of Environmental Research and Development* **15:** 727-736.

Prabha S J, Kumar S, Shrinidhi T M and Megha M (2017) Quantitative analysis of carbon storage capacity in the standing biomass of semi-arid regions of Ramdurga Taluk, Belagavi district, Karnataka. *Asian Journal of Science and Technology* **8:** 6510-6515.

Pradhan R (2019) *Documentation and Quantification of Phytodiversity and Carbon stock of Public Park and Institutional Land Vegetation of Cooch Behar Town, West Bengal*. M. Sc. Thesis. Uttar Banga Krishi Viswavidyalaya, Pundibari-736165, West Bengal.

Pregitzer K S and Euskirchen E S (2004) Carbon cycling and storage in world forests: Biome patterns related to forest age. *Global Change Biology* **10:** 2052-2077.

Prescott C E (2002) The influence of the forest canopy on nutrient cycling. *Tree Physiology* **22:** 1193-1200.

Puri S and Nair P K R (2004) Agroforestry research for development in India. *Agroforestry Systems* **61-62:** 437-452.

Purswani E, Pathak B and Salvi H (2019) Allocation of biomass and carbon stocks in seven woody species of tropical deciduous forests, Dang, Gujarat. *Current Science* **116:** 472-478.

Qazi G, Kumar J I N and Bhoi R (2010) Nutrient dynamics of teak (*Tectona grandis)* in a dry tropical teak forest of Rajasthan. *International Journal of Forestry and Crop Improvement* **1:** 134-138.

Raciti S M, Groffman P M, Jenkins J C, Pouyat R V, Fahey T J and Pickett S T A (2011) Accumulation of carbon and nitrogen in residential soils with different land use histories. *Ecosystems* **14:** 287-297.

Rahman M H, Bahauddin M, Khan M A S A, Islam M J and Uddin M B (2012) Assessment of soil physical properties under plantation and deforested sites in a biodiversity conservation area of north-eastern Bangladesh. *International Journal of Environmental Sciences* **3:** 1079-1088.

Rai P (2017) *Nutrient Status and Carbon Stock of Different Stands in a Foothill Humid Tropical Forest of Indian Eastern Himalaya*. Ph. D. Thesis. Uttar Banga Krishi Viswavidyalaya, Pundibari. Unpubl.

Raij B (1981) *Avaliacao da fertilidade do solo*. Instituto da Potassa and Fosfato, Piracicaba. 142p.

Raina A K, Jha M N and Pharasi S C (2001) Forest soil: vegetation relationship in Mussoorie forest division (Uttaranchal). *Indian Forester* **127:** 883-890.

Raizada A and Srivastava M M (1989) Biomass yield and biomass equations for *Populus deltoides* Marsh.*Indian Journal of Forestry* **12:** 56-61.

Raj A, Jhariya M K and Bargali S S (2018_b) Climate smart agriculture and carbon sequestration. In: *Climate change and agroforestry: adaptation mitigation and livelihood security*, eds. Pandey C B, Gaur M K and Goyal R K. New India Publishing Agency (NIPA), New Delhi. Pp 1-19.

Raj A, Jhariya M K and Harne S S (2018_a) Threats to biodiversity and conservation strategies. In: *Forests, climate change and biodiversity*, eds. Sood K K and Mahajan V. Kalyani Publisher, New Delhi. Pp. 304-320.

Raji B A and Ogunwole J O (2006) Potential of soil carbon sequestration under various land use in the sub-humid and semi-arid savanna of Nigeria: lessons from long-term experiments. *International Journal Soil Science* **1:** 33-43.

Rajput B S, Bhardwaj D R and Pala N A (2015) Carbon dioxide mitigation potential and carbon density of different land use systems along an altitudinal gradient in North-Western Himalayas. *AgroforestrySystems* **89:** 525-536.

Rajvanshi A, Soni S, Kukreti U D and Srivastava M M (1983) A comparative study of undergrowth of Sal forest and Eucalyptus plantation at Golatappar, Dehra Dun during rainy season. *Indian Journal of Forestry* **6:** 107-119.

Rana B S and Singh R P (1990) Plant biomass and productivity estimates for central Himalayan mixed Banj oak (*Quercus leucotrichophora* A. camus)- chir pine (*Pinus roxburghii*). *Indian Forester* **116:** 220-226.

Ratcliffe S, Wirth C, Jucker T, van der Plas F, Scherer-Lorenzen M, Verheyen K, Allan E, Benavides R, Bruelheide H, Ohse B, Paquette A, Ampoorter E, Bastias CC, Bauhus J and Joly F (2017) Biodiversity and ecosystem functioning relations in European forests depend on environmental context. *Ecology Letters* **20:** 1414-1426.

Rathore S S, Karunakaran K and Prakash B (2010) Alber based farming system a traditional farming practices in Nagaland for amelioration of jhum land. *Indian Journal of Traditional Knowledge* **9:** 677-680.

Ravindranath N H, Somasekhar B S and Gadgil M (1997) Carbon flows in Indian forest. *Climate Change* **35:** 297-320.

Rawat M, Arunachalama K, Arunachalam A, Alatalo J and Pandey R (2019) Associations of plant functional diversity with carbon accumulation in a temperate forest ecosystem in the Indian Himalayas. *Ecological Indicators* **98:** 861-868.

Rawat V and Negi J D S (2004) Biomass production of *E. terticornis* in different agroecological regions of India. *Indian Forester* **130:** 762-770.

Redondo-Brenes A and Montagnini F (2006) Growth, productivity, aboveground biomass, and carbon sequestration of pure and mixed native tree plantations in the Caribbean lowlands of Costa Rica. *Forest Ecology and Management* **232:** 168-178.

Ren Y, Yan J, Wei X, Wang Y, Yang Y, Hua L, Xiong Y, Niu X and Song X (2012) Effects of rapid urban sprawl on urban forest carbon stocks: integrating remotely sensed, GIS and forest inventory data. *Journal of Environmental Management* **113:** 447-455.

Rizvi R H, Dhyani S K, Yadav R S and Singh R (2011) Biomass production and carbon stock of popular agroforestry systems in Yamunanagar and Saharanpur districts of northwestern India. *Current Science* **100:** 736-742.

Robertson G P and Vitousek P M (1981) Nitrification in primary and secondary succession. *Ecology* **62:** 376-386.

Rocheleau D, Weber F and Field–Juma A (1988) *Agroforestry in dryland: 3 Science and Practice of Agroforestry*. ICRAF, Nairobi, Kenya. 320p.

Roshetko J M, Delaney M, Hairiah K and Purnomosidhi P (2002_b) Carbon stocks in Indonesian homegarden systems: Can smallholder systems be targeted for increased carbon storage? *American Journal of Alternative Agriculture* **17:** 138-148.

Roshetko J M, delos Angeles M S and Warner K (2002_a) Smallholder Agroforestry Systems as a Strategy for Carbon Storage. In: *Proceedings of International Symposium on Forest Carbon Sequestration and Monitoring*. November 11-15, 2002, Taipei, Taiwan.

Roshetko J M, Lasco R D and Angeles M D (2007) Small holder agroforestry systems for carbon storage. *Mitigation, Adaptation Strategies for Global Change* **12:** 219-242.

Roshetko J M, Mulawarman, Sasongko S M and Irianto D (2003) *Tree seed management seed sources, seed collection and seed handling: A field manual for field workers and farmers*. International centre for research in agroforestry (ICRAF) and Winrock International Bogor, Indonesia.

Roshetko J M, Mulawarman and Purnomosidhi P (2004) *Gmelina arborea*: a viable species for smallholder tree farming in Indonesia? *New Forests* **28:** 207-215.

Rothstein D E, Yermakov Z and Buell A L (2004) Loss and recovery of ecosystem carbon pools following stand-replacing wildfire in Michigan jack pine forests. *Canadian Journal of Forestry Research* **34:** 1908-1918.

Ruess J O and Innis G S (1977) A grassland nitrogen flow simulation mode. *Ecology* **58:** 348-429.

Ruiz-Benito P, Gómez-Aparicio L, Paquette A, Messier C, Kattge J and Zavala M A (2014) Diversity increases carbon storage and tree productivity in Spanish forests. *Global Ecology and Biogeography* **23:** 311-322.

Ruiz-Jaén M C and Aide T M (2005) Vegetation structure, species diversity, and ecosystem processes as measures of restoration success. *Forest Ecology and Management* **218:** 159-173.

Saatchi S S, Harris N L, Brown S, Lefsky M, Mitchard E T A, Salas W, Zutta B R, Buermannb W, Lewisg S L, Hagen S, Petrova S, Whiteh L, Silmani M and Morel A (2011) Benchmark map of forest carbon stocks in tropical regions across three continents. *Proceedings of the National Academy of Sciences (USA)* **108:** 9899-9904.

Saha S K, Nair P K R, Nair V D and Kumar B M (2010) Carbon storage in relation to soil size fractions under tropical tree based land use systems. *Plant and Soil* **328:** 433-446.

Sahoo U K, Singh S L, Gogoi A, Kenye A and Sahoo S S (2019) Active and passive soil organic carbon pools as affected by different land use types in Mizoram, Northeast India. *PLoS ONE* **14:** e0219969, Doi: 10.1371/journal.pone.0219969.

Sahu K P, Singh L and Jhariya M K (2013) Fine root biomass, forest floor and nutrient status of soil in an age series of teak plantation in dry tropics. *Journal of Life Science* **8:** 1149-1152.

Sainepo B M, Gachene C K and Karuma A (2018) Assessment of soil organic carbon fractions and carbon management index under different land use types in Olesharo Catchment, Narok County, Kenya. *Carbon Balance Management* **13**, Doi: 10.1186/s13021-018-0091-7.

Sainju U M, Jabro J D and Stevans W B (2008) Soil carbon dioxide emission and carbon sequestration as influenced by irrigation, tillage, cropping system, and nitrogen fertilization.*Journal of Environmental Quality* **37:** 98-106.

Saint-André L, Rouspard O, Marsden C, M'Bou A T, D'Annunzio R, Grandcourt A D, Jourdan C, Derrier D, Picard N and Zeller B (2007) *Quantification, understanding and prediction of carbon cycle and other GHG gases in Sub-Saharan Africa.* Carbo Africa project no. 037132. Sixth Framework Programme of the European Commission.

Saldarriaga J G, West D C, Tharp M and Uhl C (1988) Long-term chronosequence of forest succession in the upper Rio Negro of Colombia and Venezuela. *The Journal of Ecology* **76:** 938-958.

Salunkhe O and Khare P K (2016) Above ground biomass and carbon stock of tropical deciduous forest ecosystems of Madhya Pradesh, India. *International Journal of Ecology and Environmental Science* **42(S):** 75-81.

Salunkhe O, Khare P K, Sahu T R and Singh S (2014) Aboveground biomass and carbon stocking in tropical deciduous forests of state of Madhya Pradesh, India. *Taiwania* **59:** 353-359.

Salunkhe O, Khare P K, Sahu T R and Singh S (2016) Estimation of tree biomass reserve in tropical deciduous forests of Central India by non-destructive approach. *Tropical Ecology* **57:** 153-161.

Sanderman J and Baldock J A (2010) Accounting for soil carbon sequestration in national inventories: a soil scientist's perspective. *Environment Research Letter* **5:** 034003.

Sanderman J, Farquharson R and Baldock J (2010) *Soil carbon sequestration potential: a review for Australian agriculture*. A report prepared for the Department of Climate Change and Energy Efficiency CSIRO National Research Flagships.

Sanginga N, Mulongoy Kand Swift M J (1992) Contribution of soil microorganisms to the sustainability and productivity of cropping systems in tropics. *Agriculture, Ecosystem and Environment* **41:** 135-152.

Santantonio D, Hermann R K and Overton W S (1977) Root biomass studies in forest ecosystems. *Pedobiologia* **17:** 1-31.

Santoso H (2012) *Management of forest, land, and water resources based on watershed*. Bunga Rampai Pemikiran Mendukung Pembangunan Hutan Berkelanjutan. Wana Aksara, Banten, Indonesia.

Sarangle S, Rajasekaran A, Benbi D K and Chauhan S K (2018) Biomass and carbon stock, carbon sequestration potential under selected land use systems in Punjab. *Forest Research Engineering: International Journal* **9:** 75-80.

Sariyildiz T and Anderson J M (2003) Interactions between litter quality, decomposition and soil fertility: a laboratory study. *Soil Biology and Biochemistry* **35:** 391-399

Sariyildiz T and Kuçuk M (2008) Litter mass loss rates in deciduous and coniferous trees in Artvin, northeast Turkey: relationships with litter quality, microclimate and soil characteristics. *Turkish Journal of Agriculture and Forestry* **32:** 547-559.

Sariyildiz T, Anderson J M and Kucuk M (2005) Effects of tree species and topography on soil chemistry, litter quality and decomposition in Northeast Turkey. *Soil Biology and Biochemistry* **37:** 1695-1706.

Sariyildiz T, Savaci G and Kravkaz I S (2015) Effects of tree species, stand age and land-use change on soil carbon and nitrogen stock rates in northwestern Turkey. *iForest* **9:** 165-170.

Schindelbeck R R, van Abawi E S H M, Wolfe G S, Whitlow D W, Gugino B K, Idowu O J and Moebius-Clune B N (2008) Comprehensive assessment of soil quality for landscape and urban management. *Landscape and Urban Planning* **88:** 73-80.

Schleuss U, Wu Q L and Blume P H (1998) Variability of soils in urban and per urban areas in Northern Germany. *Catena* **33:** 255-270.

Schnitzer M (1991) Soil organic matter-the next 75 years. *Soil Science* **151:** 41-58.

Schroth G, Sammya A D A, Teixeira W G, Haag D and Lieberei R (2002) Conversion of secondary forest into agroforestry and monoculture plantation in Amazonia: consequences for biomass, litter and soil carbon stocks after 7 years. *Forest Ecology and Management* **163:** 131-150.

Scotti R, Bonanomi G, Scelza R, Zoina A and Rao M A (2015) Organic amendments as sustainable tool to recovery fertility in intensive agricultural systems. *Journal of Soil Science and Plant Nutrition* **15:** 333-352.

Sedelnikov V P, Lapshina E I, Korolyuk A Y Valutskii V I, Ermakov N B, Ershova E A, Makunina N I and Maltseva T V (2008) Medium-scale mapping of vegetation in mountains of southern Siberia. *Contemporary Problems of Ecology* **1:** 153-167.

Selvaraj A, Jayachandran S, Thirunavukkarasu D P, Jayaraman A and Karuppan P (2016) Carbon sequestration potential physicochemical and microbiological properties of selected trees *Mangifera indica* L., *Manikara zapota* L., *Cocus nucifera* L. and *Tectona grandis* L. *Bioscience Discovery* **7:** 131-139.

Semwal S (2006) *Studies on phytosociology, diversity patterns and competition along an altitudinal gradient in a part of lesser Himalaya in Garhwal, Uttaranchal*. D. Phil. Thesis, HNB Garhwal University, Srinagar (Garhwal), Uttarakhand, India.

Shaifullah K, Mohammad M, Mohammad S, Sirajul H S (2008) Effects of coastal afforestation on some soil properties in Lakshmipur coast of Bangladesh. *Journal of Forestry Research* **19:** 32-36.

Shannon C E and Weaver (1949) *The Mathematical Theory of Communication*. University of Illinois Press, Urbana, USA.117p.

Shannon C E and Wiener W (1963) *The Mathematical Theory of Communication*. University of Illinois Press, Urbana.

Sharma C M, Baduni N P, Gairola S, Ghildiyal S K and Suyal S (2010_a) Tree diversity and carbon stocks of some major forest types of Garhwal Himalaya, India.*Forest Ecology Management* **260:** 2170-2179.

Sharma C M, Baduni N P, Gairola S, Ghildiyal S K and Suyal S (2010_c) The effect of slope aspects on forest compositions, community structures and soil properties in natural temperate forests in Garhwal Himalaya. *Journal of Forest Research* **21:** 331-337

Sharma C M, Gairola S, Ghildiyal S K and Suyal S (2010_d) Physical properties of soils in relation to forest composition in moist temperate valley slopes of the Central Western Himalaya. *Journal of Forest Science* **26:** 117-129.

Sharma C M, Suyal S, Ghildiyal S K and Gairola S (2010_b) Role of Physiographic factors in distribution of *Abies pindrow* (Silver Fir) along an altitudinal gradient in Himalayan temperate Forests. *Environmentalist* **30:** 76-84.

Sharma R K, Sankhayan P L and Ole Hotstad (2008) Forest biomass density, utilization and production dynamic in a western Himalayan watershed. *Journal of Forestry Research* **19:** 171-80.

Sharpe W E, Swistock B R and Dewalle D R (1992) A greenhouse study of northern red oak seedling growth of two forest soils at different stages of acidification. *Water Air and Soil Pollution* **66:** 121-133.

Sheikh M A and Kumar M (2010) Nutrient status and economic analysis of soils in oak and pine forests in Garhwal Himalaya. *Journal of American Science* **6:** 117-122.

Sheikh M A, Kumar M, Todaria N P and Pandey R (2020) Biomass and soil carbon along altitudinal gradients in temperate *Cedrus deodara* forests in Central Himalaya, India: Implications for climate change mitigation. *Ecological Indicators* 111: 106025, Doi: 10.1016/j.ecolind.2019.106025.

Sherman E R, Fahey J T and Martinez P (2003) Spatial Patterns of Biomass and Aboveground Net Primary Productivity in a Mangrove Ecosystem in the Dominican Republic. *Ecosystems* **6:** 384-398.

Shrestha B M and Singh B R (2008) Soil and vegetation carbon pools in a mountain watershed of Nepal. *Nutrient Cycling in Agro-Ecosystems* **81:** 179-191.

Shukla G and Chakravarty S (2012_a) *Biodiversity Cause and Pattern (in the foot hills of Eastern Himalaya)*. Lambert Academic Publishing, German. 200p.

Shukla G and Chakravarty S (2012_b) Ethnobotanical plant use of Chilapatta Reserved Forest in West Bengal. *Indian Forester* **138:** 1116-1124.

Shukla G and Chakravarty S (2012_c) Soil Carbon sequestration vis-à-vis soil management. *Environment & We International Journal of Science and Technology* **7:** 107-122.

Shukla G and Chakravarty S (2014) Cause, pattern and consequences of understorey herbaceous vegetation at a foothill forest in Indian eastern Himalayas. *Indian Forester* **140:** 354-362.

Shukla G and Chakravarty S (2018) Biomass, primary nutrient and carbon stock in a sub Himalayan forest of West Bengal, India. *Journal of Forest and Environmental Science* **34:** 12-23.

Shukla G, Biswas R, Das A P and Chakravarty S (2016) Floristic diversity of Chilapatta Reserve Forest of West Bengal India. *International Journal of Forest Usufructs Management* **17:** 46-57.

Shukla G, Biswas R, Das A P and Chakravarty S (2014_a) Plant diversity at Chilapatta Reserve Forest of Terai Duars in sub-humid tropical foothills of Indian Eastern Himalayas. *Journal of Forestry Research* doi: 10.1007/s11676-014-0452-3.

Shukla G, K Manohar A, Rai P and Chakravarty S (2019) Diversity, biomass accumulation and carbon storage of shrub community in a foothill forest of Indian Eastern Himalayas. *Indian Forester* **146:** 309-314.

Shukla G, Pala N A and Chakravarty S (2014_b) Carbon, litter and nutrient status in teak stands of a foothill forest in Indian Eastern Himalayas. *Journal of Tree Science,* **33:**24-32.

Shukla G, Pala N A, Moonis M and Chakravarty S (2018) Carbon accumulation and partitioning in sub-humid forest stands of West Bengal India. *Indian Forester***144:** 229-233.

Shukla G, Pala N A and Chakravarty S (2017) Quantification of organic carbon and primary nutrients in litter and soil at foothill forest stands of Eastern Himalaya. *Journal of Forestry Research*, Doi: 10.1007/s11676-017-0394-7.

Shukla G, Subba M, Dey T, Rai P, Puri A and Chakravarty S (2014_c) Tree diversity pattern in sub-humid tropical foothill forest of Indian eastern Himalayas. *Journal of Tree Sciences* **33:** 69-77.

Sidhu G S, Bhattacharyya T, Sarkar D, Ray S K, Chandran P, Mandal D K, Prasad J, Mandal C, Srivastava R, Sen T K, Chatterji S, Patil N G, Obireddy G P, Tiwary P, Karthikeyan K, Durge S L, Kamble G K, Gaikwad M S, Nimkar A M, Bobade SV, Anantwar S G, Patil S, Sahu VT, Gaikwad K M, Bhondwe H, Dohtre S S, Gharami S, Khapekar S G, Parhad V N, Wadhai K, Lokhande M, Dongare VT, Hukare A, Bansod N, Kolhe A, Khuspure J, Kuchankar H, Balbuddhe D, Sheikh S, Gautam N, Telpande B A, Nimje A M, Likhar C, Thakre S, Pal D K,

Mahapatra S K, Mohanty B, Nair K M, Anil Kumar K S, Srinivas S, Koyal A, Sujatha Reddy, B M N Sreekumar, Sunitha P, Sahoo B P, Das A K, DasT H, Dutta K, Halder D, Basu A S, Majumdar R, Singh S, Singh R S, Singh A K, Jat R, Oad B L, Ola D L, Garhwal N R, Reza R S, Dutta S K, D.P., Gogoi, L., Hazarika D, Venugopalan M V, Velmourougane K, Sahu A, Srivastava A, Kumar A, Raychaudhuri M, Kundu D K, Mandal K G, Kar Mahapatra S and Puspamitra S (2014) Impact of management levels and land-use changes on soil properties in rice-wheat cropping system of the Indo-Gangetic plains. *Current Science* **107:** 1487-1501.

Silvertown J W and Doust J L (1993) *Introduction to plant population biology*. Blackwell, London.

Simpson E H (1949) Measurement of diversity. *Nature* **163:** 688.

Singh A K, Parsad A and Singh B (1986) Availability of phosphorus and potassium and its relationship with physicochemical properties of some forest soils of Pali-range (Shahodol, M.P.). *Indian Forester* **112:** 1094-1104.

Singh A (2013) Vascular floristic wealth of Banaras Hindu University main campus, India. *International Journal of Plant Science* **2:** 124-149.

Singh G (2005) Carbon sequestration under an agri-silvicultural system in the arid region. *Indian Forester* **131:** 543-552.

Singh G and Singh B (2017) Biomass equations and assessment of carbon stock of *Calligonum polygonoides* L., a shrub of Indian arid zone. *Current Science* **112:** 2456-2462.

Singh G, Singh B, Kuppusamy V and Bala N (2002) Variations in foliage and soil nutrient composition in *Acacia tortilis* plantation of different ages in North-Western Rajasthan. *Indian Forester* **128:** 514-521.

Singh P and Lodhiyal L S (2009) Biomass and carbon allocation in 8-year-old poplar *Populus deltoides* Marsh) plantation in Tarai agroforestry systems of central Himalaya, India. *New York Science Journal* **2:** 49-53.

Singh K P, Mandal T N and Tripathi S K (2001) Patterns of restoration of soil physico chemical properties and microbial biomass in different landslide sites in the sal forest ecosystem of Nepal Himalaya. *Ecological Engineering* **17:** 385-401.

Slik J W F, Gary P, Krista M and Shin-Ichiro A (2013) Large trees drive forest aboveground biomass variation in moist lowland forests across the tropics. *Global Ecology and Biogeography* **22:** 1261-1271.

Smith P, Andrén O, Karlsson T, Perälä P, Regina K, Rounsevell M and Van Wesemael B V (2005) Carbon sequestration potential in European croplands has been overestimated. *Global Change Biology* **11:** 2153-2163.

Smith P, Martino D, Cai Z, Gwary D, Janzen H, Kumar P, McCarl B, Ogle S, O'Mara F, Rice C and Scholes B (2008) Greenhouse gas mitigation in agriculture. *Philosophical Transactions of Royal Society B* **363:** 789-813.

Smith P G R (2007) Characteristics of urban natural area influencing winter bird use in Southern Ontario, Canada. *Environmental Management* **39:** 338-352.

Smith R M, Thompson K, Hodgson G J, Warren P H and Gaston K J (2006_a) Urban domestic gardens: composition and richness of vascular plant flora and implications for native biodiversity. *Biological Conservation* **19:** 7-22.

Smith R M, Warren P J, Thompson K and Gaston K J (2006_b) Urban domestic gardens (VI): environmental correlates of invertebrate species richness . *Biodiversity and Conservation***15:** 2415-2438.

Smith J E and Heath L S (2002) *A model of forest floor carbon mass of United States type*. Research paper NE-722, USDA Forest Service, Newton Square, PA.

Sobuj N and Rahman M (2011) Comparison of Plant Diversity of Natural Forest and Plantations of Rema-Kalenga Wildlife Sanctuary of Bangladesh.*Journal of Forest and Environmental Science* **27:** 127-134.

Song G H, Li L Q and Pan G X (2005) Topsoil organic carbon storage of China and its loss by cultivation. *Biogeochemistry* **74:** 47-62.

Soromessa T, Teketay D and Demissew S (2004) Ecological study of the vegetation in Gamo Gofa zone, southern Ethiopia. *Tropical Ecology* **45:** 209-221.

Soto-Pinto L, Anzueto M, Mendoza J, Ferrer G J and de Jong B (2010) Carbon sequestration through agroforestry in indigenous communities of Chiapas, Mexico. *Agroforestry Systems* **78:** 39-51.

Soussana J F, Loiseau P, Vuichard N, Ceschia E, Balesdent J, Chevallier T and Arrouays D (2004) Carbon cycling and sequestration opportunities in temperate grasslands. *Soil Use Management* **20:** 219-230.

Sperow M (2016) Estimating carbon sequestration potential on US agricultural top soils. *Soil Tillage Research* **155:** 390-400.

Sperow M, Eve M and Paustian K (2003) Potential soil C sequestration on US agricultural soils.*Climate Change* **57:** 319-339.

Sreenivas K, Dadhwal V K, Kumar S, Harsha G S, Mitran T, Sujatha G, Suresh G J R, Fyzee M A and Ravisankar T (2016) Digital mapping of soil organic and inorganic carbon status in India. *Geoderma* **269:** 160-173.

Srinivas K and Sundarapandian S (2018) Biomass and carbon stocks of trees in tropical dry forest of East Godavari region, Andhra Pradesh, India. *Geology, Ecology, and Landscapes* Doi: 10.1080/24749508.2018.1522837.

Srinivasan U M and Caulfield I (1989) Agroforestry land management system in developing countries: An overview. *Indian Forester* **115:** 57-68.

Srivastava R K, Khanduri V P, Sharma C M and Kumar P (2005) Structure, diversity and regeneration potential of oak-dominant conifer mixed forest along an altitudinal gradient in Garhwal Himalaya. *Indian Forester* **131:** 1537-1553.

Stanturf J A, Palik B J and Dumroese R K (2014) Contemporary forest restoration: a review emphasizing function. *Forest Ecology and Management* **331:** 292-323.

Stas M S (2011) *Above ground biomass and carbon stocks in a secondary forest in comparison with adjacent primary forest on limestone in Seram, the Moluccas, Indonesia*. Postgraduate thesis, Utrecht University, The Netherlands. Unpubl.

Stevenson F J (1994) *Humus chemistry*, 2nd edition.Wiley, New York.

Stockmann U, Padarian J, McBratney A, Minasny B, de Brogniez D, Montanarella L, Hong S Y, Rawlins B G and Field D J (2015) Global soil organic carbon assessment. *Global Food Security* **6:** 9-16.

Stolbovoi V (2003) Carbon in agricultural soils of Russia. In: *Soil Organic Carbon and Agriculture: Developing Indicators for Policy Analyses*, ed. Smith C A S. Proceedings of an OECD expert meeting, Ottawa Canada. Agriculture and Agriculture Food Canada, Ottawa and Organization for Economic Co-operation and Development, Paris. Pp. 301-307.

Stone B Jr (2009) Land use as climate change mitigation.*Environmental Science and Technology***4 3:** 9052-9056.

Strassmann K M, Joos F and Fischer G (2008) Simulating effects of land use changes on carbon fluxes: past contributions to atmospheric CO_2 increases and future commitments due to losses of terrestrial sink capacity. *Tellus, Series B: Chemical and Physical Meteorology* **60:** 583-603.

Su Y Z and Zhao L H (2003) Soil properties and plant species in an age sequence of *Caragana microphylla* plantations in the Horqin Sandy Land, north China. *Ecological Engineering* **20:** 223-235.

Subba M, Pala N A, Shukla G, Pradhan K and Chakravarty S (2017) Refocusing the correlates of carbon sequestration through maintaining the carbon stock in home gardens of West Bengal, India. In: *Natural Resources Management for Sustainable Development and Rural Livelihoods*, Vol. 3., eds. Sati V P and Lalmalsawmzauva K C. Today & Tomorrow's Printers and Publishers, New Delhi. Pp. 1139-1151.

Subba M, Pala A N, Shukla G and Chakravarty S (2018) Study of the variability of home gardens influencing carbon stock under sub-humid tropical zone of West Bengal, India. *Indian Forester* **144:** 66-72.

Subedi M N (2004) Above ground biomass of *Quercus semicarpifolia* Sm. Forest surveyed on natural and semi-natural stands in Nepal. *Indian Forester* **130:** 858-866.

Sun W J, Huang Y, Zhang W and Yu Y Q (2010) Carbon sequestration and its potential in agricultural soils of China. *Global Biogeochemical Cycles* **24:** 1302-1307.

Sundriyal R C and Shrama E (1996) Anthropogenic pressure on tree structure and biomass in the temperate forest of Mamlay watershed in Sikkim. *Forest Ecology and Management* **81:** 113-134.

Swamy S L and Mishra A (2014) Comparison of Biomass and C Storage in Three Promising Fast Growing Tree Plantations under Agroforestry System in Sub-humid Tropics of Chhattisgarh, India, *Universal Journal of Agricultural Research* **2:** 284-296.

Swamy K R, Shivaprasad D, Bammanahalli S, Lamani N and Shivanna H (2017) Carbon storage potential of shelter belt agroforestry system in northern transitional zone of Karnataka, India. *Journal of Applied and Natural Science* **9:** 1390-1396.

Swamy S L, Mishra A and Puri S (2006) Comparison of growth, biomass and nutrient distribution in five promising clones of *Populus deltoides* under an agrisilviculture system.*Bioresource Technology* **97:** 57-68.

Swamy S L, Mishra A, Puri S (2003_b) Biomass production and root distribution of *Gmelina arborea* under an agrisilvicultre system in sub-humid tropics of central India. *New Forests* **26:** 167-186.

Swamy S L, Puri S and Singh A K (2003_a) Growth, biomass, carbon storage and nutrient distribution in *Gmelina arborea* Roxb. stands on red lateritic soils in central India. *Bioresource Technology* **90:** 109-126.

Swamy S L and Puri S (2005) Biomass production andC-sequestration of *Gmelina arborea* in plantation andagroforestry system in India. *Agroforestry Systems* **64:** 181-195.

Swamy S L, Bharitya J K and Alka M (2008) Growth, biomass, nutrient storage and crop productivity under differenttree spacing's of *Gmelina arborea* in agrisilviculture system. *Indian Journal of Agroforestry* **10:** 3-9.

Swamy S L, Kushwaha S K and Puri S (2004) Tree growth, biomass, allometry and nutrient distribution in *Gmelina arborea* stands grown in red lateritic soils of Central India. *Biomass and Bioenergy* **26:** 305-317.

Syswerda S P, Corbin A T, Mokma D L, Kravchenko A N and Robertson G P (2011) Agricultural management and soil carbon storage in surface vs. deep layers. *Soil Science Society of American Journal* **75:** 92-101.

Tahmasebi P, Moradi M and Omidipour R (2017) Plant functional identity as the predictor of carbon storage in semi-arid ecosystems. *Plant Ecology and Diversity* **10:** 139-151.

Takimoto A, Nair P K R and Nair V D (2008) Carbon stock and sequestration potential of traditional and improved agroforestry systems in the West African Sahel. *Agriculture, Ecosystems and Environment* **125:** 159-166.

Tamang B, Sarkar B C, Pala N A, Shukla G, Vineeta, Patra P S, Bhat J A, Dey A N and Chakravarty S (2019) Uses and ecosystem services of trees outside forest (TOF)-A case study from Uttar Banga Krishi Viswavidyalaya, West Bengal, India. *Acta Ecologica Sinica*, Doi: 10.1016.chnaes.2018.09.017

Tandon H L S (2005) *Methods of analysis of soils, plants, waters, fertilizers and organic manures*. Fertilizer Development and Consultation Organization, New Delhi. India. 204p.

Tang Y J, Chen A P and Zhao S Q (2016) Carbon Storage and Sequestration of Urban Street Trees in Beijing, China. *Frontiers in Ecology and Evolution* **4:** 53-61.

Tanji K K (1990) *Agriculture salinity assessment and management*. American Society of Civil Engineers, New York.

Tanko D, Ezealor A U and Bako S P (2013) Current status of the woody vegetation of Dumbi inselbergs and its surroundings, Zaria, Northern Guinea Savanna Nigeria. *Nigeria Journal of Scientific Research* **13:** 1-9.

Tans P P, Fung I F and Takahashi T (1990) Observational constraints on the global atmospheric CO_2 budget. *Science* **247:** 1431-1438.

Tarnocai C (1998) The amount of organic carbon in various soil orders and eco-provinces in Canada. In: *Soil Processes and the Carbon Cycle*, eds. Lal R, Kimble J, Follett R F and Stewart B A. CRC Press, Boca Raton, FL. Pp. 81-92.

Techienkoua M and Zech W (2003) Chemical and spectral characterization of soil phosphorus under three land uses from an andic palehumult in west Cameroon.*Agriculture, Ecosystem and Environment* **100:** 193-200.

Tecimen H B, Sevgi O, Akkaya M, Sevgi E, Hançer C K and Çakır E A (2018) Some soil physical and chemical properties of natural stands and plantations at different ages of stone pine in Biga (Çanakkale-Turkey). *Eurasian Journal of Forest Science* **6:** 42-47.

Tecimen H B, Sevgi O, Akkaya M, Sevgi E, Hançer C K and Çakır E A (2017) Comparison of species richness and diversity at natural stands and plantations of stone pine (*Pinus pinea* L.). *Pakistan Journal of Botany* **49:** 1743-1748.

ter Steege H, Pitman N C, Sabatier D, Baraloto C, Salomão R P, Guevara J E and Monteagudo A (2013) Hyperdominance in the Amazonian tree flora. *Science* **342:** 1243-1292.

Tewari D N (1995) *A Monograph on Gmelina (Gmelina arborea Roxb.).* International Book distributors, Dehra Dun.

Thakur M and Verma R K (2019) Biomass and soil organic carbon stocks under *Cedrus deodara* forests in Mandi district of Himachal Pradesh. *Nature Environment and Pollution Technology* **18:** 879-887.

Thapa G B and Yila O M (2012) Farmers' land management practices and status of agricultural land in the Jos Plateau, Nigeria. *Land Degradation & Development* **23:** 263-277.

Thompson K and McCarthy M A (2008) Traits of British alien and native urban plants. *Journal of Ecology* **96:** 853-859.

Thompson K K, Austin K C, Smith R M, Warren P H, Arnold P G and Gaston K J (2003) Urban domestic gardens (I): putting small scale plant diversity in context. *Journal of Vegetation Science* **14:** 71-78.

Thuille A and Schulze E D (2006) Carbon dynamics in succession and afforested spruce stands in Thuringia and the Alps. *Global Change Biology* **12:** 325-342.

Tilman D, Reich P B, Knops J, Wedin D, Mielke T and Lehman C (2001) Diversity and productivity in a long-term grassland experiment. *Science* **294:** 843-845.

Tomlinson G H and Tomlinson F L (1990) *Effects of acid deposition on the forests of Europe and North America*. CRC Press, Boca Raton, FL. 281p.

Tomlinson R W (2005) Soil carbon stocks and changes in the Republic of Ireland. *Journal of Environment Management* **76:** 77-93.

Trexler M C and Haugen C (1994) *Keeping it Green: Evaluating Tropical Forestry Strategies to Mitigate Global Warming*. World Resources Institute, Washington DC.

Troup R S (1975)The silviculture of Indian trees. ed. 2, vol. 2.Government of India.

Trouve C, Mariott A, Schwartz D and Guillet B (1994) Soil organic carbon dynamics under Eucalyptus and Pinus planted on savannas in the Congo. *Soil Biology and Biochemistry* **26:** 287-295.

Tsai C C, Chen Z S, Hseu Z Y, Duh C T and Guo H Y (2010) Organic Carbon Storage and Management Strategies of the Forest Soils on the Forest Soil Survey Database in Taiwan. In: *Proceedings of International Workshop on Evaluation and sustainable management of soil carbon sequestration in Asian countries,* eds. Chen Z S and Agus F. Bogor, Indonesia, Sep 28-29, 2010. Pp. 85-102.

Tsui C C, Tsai C C and Chen Z S (2013) Soil organic carbon stocks in relation to elevation gradients in volcanic ash soils of Taiwan. *Geoderma* **209:** 119-127.

Udayana C, Andreassen H P and Skarpe C (2019) Understory diversity and composition after planting of teak and mahogany in Yogyakarta, Indonesia. *Journal of Sustainable Forestry*, Doi: 10.1080/10549811.2019.1686029.

Ujjwala D, Rambabu M and Swamy NR (2017) Clonal propagation of forest tree *Gmelina arborea. Journal of Microbiology and Biotechnology Research* **3:** 16-18.

Updegraff K, Baughman M J and Taff S J (2004) Environmental benefits of cropland conversion to hybrids poplar: economic and policy considerations. *Biomass and Bioenergy* **27:** 411-428.

Uzoho B U, Oti N N and Ngwuta A (2007) Fertility status under land use types on soils of similar lithology. *Journal of American Science* **3:** 20-29.

Vågen T G and Winowiecki L A (2013) Mapping of soil organic carbon stocks for spatially explicit assessments of climate change mitigation potential. *Environment Research Letter* **8:** 1-9.

Van Noordwijk M, Cerri C, Woomer P L, Nugroho K and Bernoux M (1997) Soil carbon dynamics in the humid tropical forest zone. *Geoderma* **79:** 187-225.

Van Noordwijk M, Goverse T, Ballabio C, Banwart S, Bhattacharyya T, Goldhaber M, Nikolaidis N, Noellemeyer E and Zhao Y (2014) *Soil carbon transition curves: reversal of land degradation through management of soil organic matter for multiple benefits*. Soil Carbon Science, Management and Policy for Multiple Benefits.

Van Straaten O, Corre M D, Wolf K, Tchienkoua M, Cuellar E, Matthews R B and Veldkamp E (2015) Conversion of lowland tropical forests to tree cash crop plantations lose up to one half of stored soil organic carbon. *Proceedings of National Academy of Sciences* **112:** 9956-9960.

Van Wesemael B, Paustian K, Meersmans J, Goidts E, Barancikova G and Easter M (2010) Agricultural management explains historic changes in regional SOC stocks. *Proceedings of National Academy of Sciences* **107:** 14926-14930.

Vanden Bygaart A J and Angers D A (2006) Towards accurate measurements of soil organic carbon stock change in agroecosystems. *Canadian Journal of Soil Science* **86:** 465-471.

Vanden Bygaart A J, Gregorich E G and Angers D A (2003) Influence of agricultural management on soil organic carbon: a compendium and assessment of Canadian studies.*Canadian Journal of Soil Science* **83:** 363-380.

Vanden Bygaart A J, McConkey B G, Angers D A, Smith W, De Gooijer H, Bentham M and Martin T (2008) Soil carbon change factors for the Canadian agriculture national greenhouse gas inventory. *Canadian Journal of Soil Science* **88:** 671-680.

Vanlauwe B, Aihou K, Tossah BK, Diels J, Sanginga N, Merckx R (2005) *Senna siamea* trees recycle Ca from Ca-rich subsoil and increase the topsoil pH in agroforestry systems in the West African derived savanna zone. *Plant and Soil* **269:** 285-296.

Varnagirytė-Kabašinskienė I (2008) Complex study of foliage nutrient status in ash fertilized Scots pine stands in Lithuania. *Journal of Forest Science* **54:** 195-206.

Vashum K T and Jayakumar S (2012) Methods to estimate above-ground biomass and carbon stock in natural forests- a review. *Journal of Ecosystem & Ecography* **2:** 116.

Velasco E, Roth M, Tan S H, Quak M, Nabarro S D A and Norford L (2013_b) The role of vegetation in the CO_2 flux from a tropical urban neighbourhood. *Atmospheric Chemistry and Physics* **13:** 185-202.

Velesco E, Matthias R and Luisa T M (2013_a) Does urban vegetation enhance carbon sequestration? *Landscape and Urban Planning* **148:** 99-107.

Verma A, Tewari A and Shah S (2012) Carbon storage capacity of high altitude *Quercus semecarpifolia*, forests of Central Himalayan region. *Scandinavian Journal of Forestry Research* **27:** 609-618.

Verma B C, Datta S P, Rattan R K and Singh A K (2010) Monitoring changes in soil organic carbon pools, nitrogen, phosphorus and sulphur under different agricultural management practices in the tropics. *Environmental Monitoring and Assessment* **171:** 579-593.

Verma P, Bijalwan A, Shankhwar A K, Dobriyal M J R, Jacob V and Rathaude SK (2017) Scaling up an Indigenous Tree Based Agroforestry system India, *International Journal of Science and Qualitative Analysis* **3:** 73-77.

Vila-Ruiz C P, Meléndez-Ackerman E, Santiago-Bartolomei R, Garcia-Montiel D, Lastra L, Figuerola C E and Fumero-Caban J (2014) Plant species richness and abundance in residential yards across a tropical watershed: implications for urban sustainability. *Ecology and Society*, Doi: 10.5751/ES-06164-190322.

Viscarra Rossel R A, Webster R, Bui E N and Baldock J A (2014) Baseline map of organic car-bon in Australian soil to support national carbon accounting and monitoring under climate change. *Global Change Biology* **20:** 2953-2970.

Vrscaj B, Poggio L and Marsan F A (2008) A method for soil environmental quality evaluation for management and planning in urban areas. *Landscape and Urban Planning* **88:** 81-94.

Walker S M, Pearson T R H, Munishi P and Petrova S (2008) Carbon market opportunities for the forestry sector of Africa. *Paper presented at the FAO African Forestry and Wildlife Commission 16th Session*. Kharthoum, Sudan.

Walther R G, Eric P, Convey P, Menzel A, Parmesan C, Beebee T J C, Fromentin J M, Guldberg O H and Bairlein F (2002) Ecological responses to recent climate change. *Journal of Urban Ecosystem* **416:** 88-95.

Wang B, Liu B G, Xue S and Zhu B (2011) Changes in soil physico-chemical and micro-biological properties during natural succession on abandoned farmland in the Loess Plateau. *Environment and Earth Science* **62:** 915-925.

Wang C J, Pan G X and Tian Y G (2009) Characteristics of cropland topsoil organic carbon dynamics under different conservation tillage treatments based on long-

term agro-ecosystem experiments across mainland China. *Journal of Agro-Environment Science* **28:** 2464-2475.

Wang C J, Pan G X, Tian Y G, Li L Q, Zhang X H and Han X J (2010) Changes in cropland topsoil organic carbon with different fertilizations under long-term agro-ecosystem experiments across mainland China. *Science China Life Science* **53:** 858-867.

Wang F, Wang Z, Yang Z and Ji X (2008) Vegetation succession process induced by reforestation in erosion areas. *Frontiers of Forestry in China* **3:** 279-285.

Wang G, Huang Y, Zhang W, Yu Y and Sun W (2015) Quantifying carbon input for targeted soil organic carbon sequestration in China's croplands. *Plant and Soil* **394:** 57-71.

Wang S, Huang M, Shao X, Mickler R A, Li K and Ji J (2004) Vertical distribution of soil organic carbon in China. *Environment and Managemen t***33:** S200-S209.

Wani N R, Qaisar K N and Khan P A (2014) Biomass, carbon stock and carbon dioxide mitigation potential of *Cedrus deodara* (deodar) under temperate conditions of Kashmir. *Canadian Journal of Pure and Applied Sciences* **8:** 677-864.

Wani N, Velmurugan A and Dadhwal V K (2010) Assessment of agricultural crop and soil carbonpools in Madhya Pradesh, India. *Tropical Ecology* **51:** 11-19.

Wardle D A (2002) *Communities and Ecosystems: Linking the Above ground and Below ground Components*. Monographs in Population and Biology 34. Princet on University Press, Princet on, NJ.

Waring B G and Powers J S (2017) Overlooking what is underground: Root: shoot ratios and coarse root allometric equations for tropical forests. *Forest Ecology and Management* **385:**10-15.

Watt M S, Coker G, Clinton P W, Davis M R, Parfitt R, Simcock R, Garrett L, Payn T, Richardson Band Dunningham A (2005) Defining sustainability of plantation forests through identification of site quality indicators influencing productivity-A national view for New Zealand. *Forest Ecology and Management* **216:** 51-63.

Webb E L and Shah R N (2003) Structure and diversity of natural and managed sal (*Shorea robusta* Gaertn f.) forest in the Terai of Nepal. *Forest Ecology and Management* **176:** 337-353.

Wei W S, Tai S F and Chung R S (2015_b) Effects of three different fertilization managements on soil chemical properties and the accumulation and transformation of soil carbon and nitrogen under two different cropping systems

for twenty years. *Taiwanese Journal of Agriculture Chemistry Food Science* **53:** 43-54.

Wei W S, Wang C H, Chen C L and Chung R S (2015_a) Accumulation and transformation of soil carbon and nitrogen under different fertilization managements and upland-low-land rotation for 13 years. *Taiwanese Journal of Agriculture Chemistry Food Science* **53:** 9-21.

Westoby M, Falster D S, Moles A T, Vesk P A and Wright I J (2002) Plant ecology strategies: some leading dimensions of variation between species. *Annual Review of Ecology and Systematic* **33:** 125-159.

Wheeler I (2014) *The auditability of soil carbon at the farm scale*. Ph. D. Thesis. The University of Sydney, Sydney, Australia. Unpubl.

Whitmore A P, Kirk G J D and Rawlins B G (2015) Technologies for increasing carbon storage in soil to mitigate climate change. *Soil Use and Management* **31:** 62-71.

Whitmore T C (1991) Tropical rain forest dynamics and its implications for management. In: *Rain Forest Regeneration and Management*, Man and Biosphere Series 6, UNESCO, Parthenon Publishing Group, Paris, New Jersey. Pp. 67-90.

Whittaker R H (1972) Evolution and measurement of species diversity.*Taxon* **21:** 213-251.

Winowiecki L, Vågen T G and Huising J (2016_a) Effects of land cover on ecosystem services in Tanzania: a spatial assessment of soil organic carbon. *Geoderma* **263:** 274-283.

Winowiecki L, Vågen T-G, Massawe B, Jelinski N A, Lyamchai C, Sayula G and Msoka E (2016_b) Landscape-scale variability of soil health indicators: effects of cultivation on soil organic carbon in the Usambara Mountains of Tanzania. *Nutrient Cycle Agroecosystems* **105:** 263-274.

Woomer P L (1999) Impact of cultivation of carbon fluxes in woody savannas of Southern Africa. *Water, Air and Soil Pollution* **70:** 403-412.

Woomer P L, Martin A, Albrecht A, Reseck D V S and Scharpenseel H W (1994) The importance and management of soil organic matter in the tropics. In: *The biological management of tropical soil fertility*, eds. Woomer P L and Swift M J.Wiley Chichester.

Wright I J, Reich P B, Westoby M, Ackerly D D, Baruch Z, Bongers F, Cavander-Bares J, Chapin F S, Cornelissen J H C, Diemer M, Flexas J, Garnier E, Groom P K, Gulias J, Hikosaka K, Lamont B B, Lee W, Lusk C, Midgley J J, Navas M L,

Niinemets U, Oleksyn J, Osada N, Poorter H, Poot P, Prior L, Pyankov V I, Roumet C, Thomas S C, Tjoelker M G, Veneklass E and Villar R (2004) The world-wide leaf economics spectrum. *Nature* **428:** 821-827.

Xie Z, Zhu J, Liu G, Cadisch G, Hasegawa T, Chen C, Sun H, Tang H and Zeng Q (2007) Soil organic carbon stocks in China and changes from 1980s to 2000s. *Global Change and Biology* **13:** 1989-2007.

Yang X, Blagodatsky S, Liu F, Beckschaefer P, Xu J and Cadisch G (2017) Rubber tree allometry, biomass partitioning and carbon stocks in mountainous landscapes of sub-tropical China. *Forest Ecology and Management* **404:** 84-99.

Yavaşli DD (2012) Recent approaches in aboveground biomass estimation methods. *Aegean Geographical Journal* **21:** 39-49.

Yavorska O G (2009) The North American species of the non-native flora of Kyiv urban area (Ukraine). *Biodiversity Research and Conservation* **13:** 25-30.

Yu D, Shi X, Wang H, Sun W, Warner E D and Liu Q (2007) National scale analysis of soil organic carbon storage in China based on Chinese soil taxonomy. *Pedosphere* **17:** 11-18.

Yuen J Q, Ziegler A D, Webb E L and Ryan C M (2013) Uncertainty in below-ground carbon biomass for major land covers in Southeast Asia. *Forest Ecology and Management* **310:** 915-926.

Zalamea M, Gonzàlez G and Lodge D J (2016) Physical, chemical and biological properties of soil under decaying wood in a tropical wet forest in Puerto Rico. *Forests* **7**, Doi: 10.3390/f7080168.

Zhang X, Zhang X, Han H, Shi Z and Yang X (2019) Biomass accumulation and carbon sequestration in an age-sequence of Mongolian Pine plantations in Horqin Sandy Land, China. *Forests* **10:** 197, Doi: 10.3390/f10020197.

Zhang Y, Duan B, Xian J, Korpelainen H and Li C (2011) Links between plant diversity, carbon stocks and environmental factors along a successional gradient in a subalpine coniferous forest in Southwest China. *Forest Ecology and Management* **262:** 361-369.

Zhao S Q, Liu S G, Li Z P and Sohl T L (2010_b) Federal land management, carbon sequestration, and climate change in the southeastern US: a case study with fort benning. *Environment Science and Technology* **44:** 992-997.

Zhao S Q, Liu S, Li Z and Sohl T L (2009) Ignoring detailed fast-changing dynamics of land use overestimates regional terrestrial carbon sequestration. *Biogeosciences* **6:** 1647-1654.

Zhao S Q, Liu S, Li Z and Sohl T L (2010_a) A spatial resolution threshold of land cover in estimating terrestrial carbon sequestration in four counties in Georgia and Alabama, USA. *Biogeosciences***7:** 71-80.

Zhao S, Liu S, Sohl T, Young C and Werner J (2013) Land use and carbon dynamics in the southeastern United States from 1992 to 2050. *Environmental Research Letters* **8:** 044022, Doi: 10.1088/1748-9326/8/4/044022.

Zhou G, Liu S, Li Z, Zhang D, Tang X, Zhou C, Yan J and Mo J (2006) Old-growth forests can accumulate carbon in soils. *Science* **314:** 1417.

Zhu B, Li Z, Li P, Liu G and Xue S (2010) Soil erodibility, microbial biomass, and physical-chemical property changes during long-term natural vegetation restoration: a case study in the Loess Plateau, China. *Ecological Research* **25:** 531-541.

Zhu L, Li J, Tao B and Hu N (2015) Effect of different fertilization modes on soil organic car-bon sequestration in paddy fields in South China: a meta-analysis. *Ecological Indicators* **53:** 144-153.

Zhu Z L, Bouchard M, Butman D, Hawbaker T, Li Z, Liu J, Liu S, McDonald C, Reker R, Sayler K, Sleeter B, Sohl T, Stackpoole S, Wiene A and Zhu Z (2011) Baseline and projected future carbon storage and greenhouse-gas fluxes in the Great Plains region of the United States. In: *US Geological Survey Professional Paper 1787*, ed. Zhu Z L. USGS, Reston, VA. (Available at http://pubs.usgs.gov/pp/1787/)

Ziegler A D, Phelps J, Yuen J Q, Webb E L, Lawrence D, Fox J M, Bruun T B, Leisz S J, Ryan C M, Dressler W, Mertz O, Pascual U, Padoch C and Koh L P (2012) Carbon outcomes of major land-cover transitions in SE Asia: great uncertainties and REDD+ policy implications. *Global Change Biology* **18:** 3087-3099.

Zuber S M and Villamil M B (2016) Meta-analysis approach to assess effect of tillage on microbial biomass and enzyme activities. *Soil Biology and Biochemistry* **97:** 176-187.